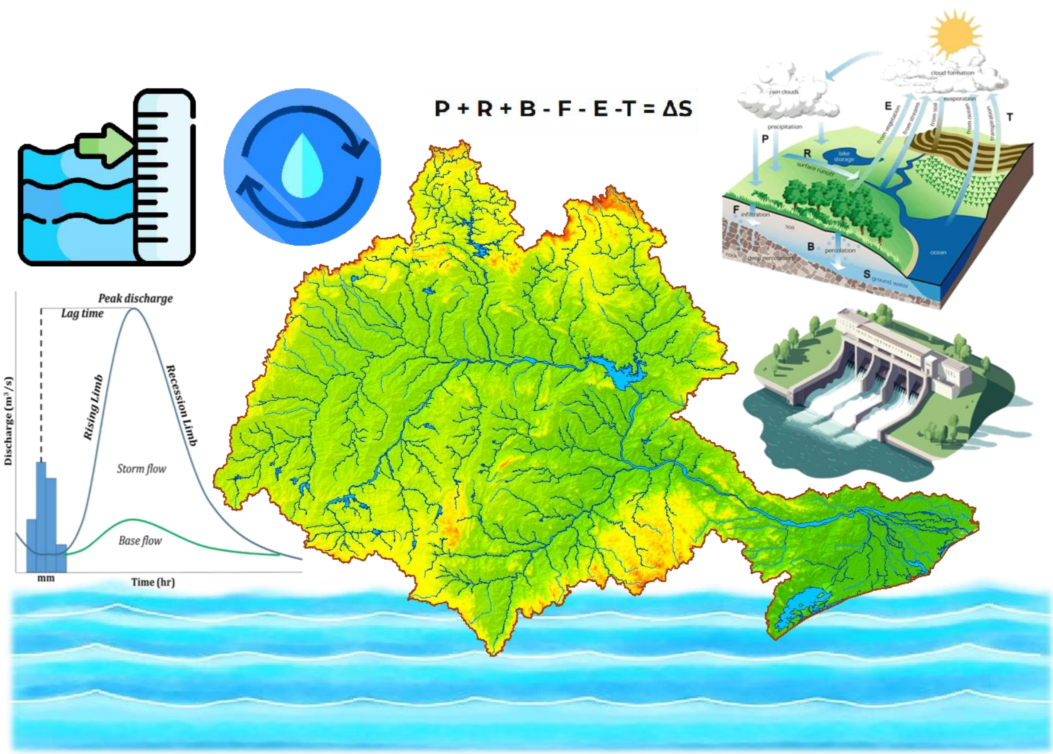
National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Hydrological Status of

Mahanadi River Basin



December 2024

cMahanadi

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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 and Studies (cMahanadi)

The Center for Mahanadi River Basin Management and 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

Centres 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

CAMP	Condition Assessment and Management Plan
CGWB	Central Ground Water Board
cMahanadi	Centre for Mahanadi River Basin Management and Studies
CWC	Central Water Commission
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization of the United Nations
GD	Gauge Discharge
GDSQ	Gauge Discharge Sediment Water Quality
GIS	Geographic Information System
HWSD	Harmonized World Soil Database
IIASA	International Institute for Applied Systems Analysis
IIT	Indian Institute of Technology
IMD	Indian Meteorological Department
ISRIC	International Soil Reference and Information Centre
JAXA	Japan Aerospace Exploration Agency
LULC	Land Use Land Cover
MCM	Million Cubic Meter
MRB	Mahanadi River Basin
NASA	National Aeronautics and Space Administration
NGA	National Geospatial-Intelligence Agency
NIT	National Institute of Technology
RF	Rainfall
SRTM	Shuttle Radar Topography Mission
WL	Water Level
WMO	World Meteorological Organization
WRD	Water Resource Department
WRIS	Water Resource Information System

1. Preamble

Hydrological data refers to the collection and analysis of information related to the movement, distribution, and quality of water across the Earth's surface and subsurface. This data is essential for understanding how water flows through various systems, including rivers, lakes, reservoirs, aquifers, and the atmosphere. It serves as the foundation for hydrological models, which are used for managing water resources, predicting floods, droughts, and understanding climate change impacts. This includes data on precipitation, stream-flow, groundwater levels, evaporation, snowmelt, soil moisture, and other relevant water-related variables (Ponce, 2013).

1.1. Significance of Hydrological Data

a. **Water Resources Management**: Hydrological data provides the quantitative information needed to manage water resources effectively. This includes ensuring the availability of water for domestic, industrial, and agricultural uses, and addressing issues like droughts and floods (Vörösmarty et al., 2000).
b. **Flood Prediction and Management**: Accurate hydrological data is fundamental in flood prediction and floodplain management. By analysing rainfall, stream-flow, and soil moisture, scientists and engineers can predict potential flooding events, allowing authorities to prepare and mitigate risks (Kundzewicz & Takeuchi, 2005).
c. **Drought Monitoring**: Droughts are a significant concern in many parts of the world. Hydrological data helps monitor soil moisture, precipitation deficits, and stream-flow reductions, providing early warnings for drought conditions and helping to manage water allocations during dry periods (Mishra & Singh, 2010).
d. **Climate Change Impact Assessment**: As the climate changes, hydrological patterns, such as precipitation, evaporation, and streamflow, is also affected. Hydrological data enables researchers to assess the impacts of climate change on water resources, helping policymakers design adaptive strategies for water management (Kundzewicz et al., 2007).
e. **Environmental and Ecosystem Management**: Hydrological data is essential for assessing the health of aquatic ecosystems. Stream-flow data, for example, helps scientists understand the impacts of water scarcity, pollution, or changes in land use on freshwater ecosystems, which is crucial for biodiversity conservation and ecosystem restoration (Poff et al., 1997).

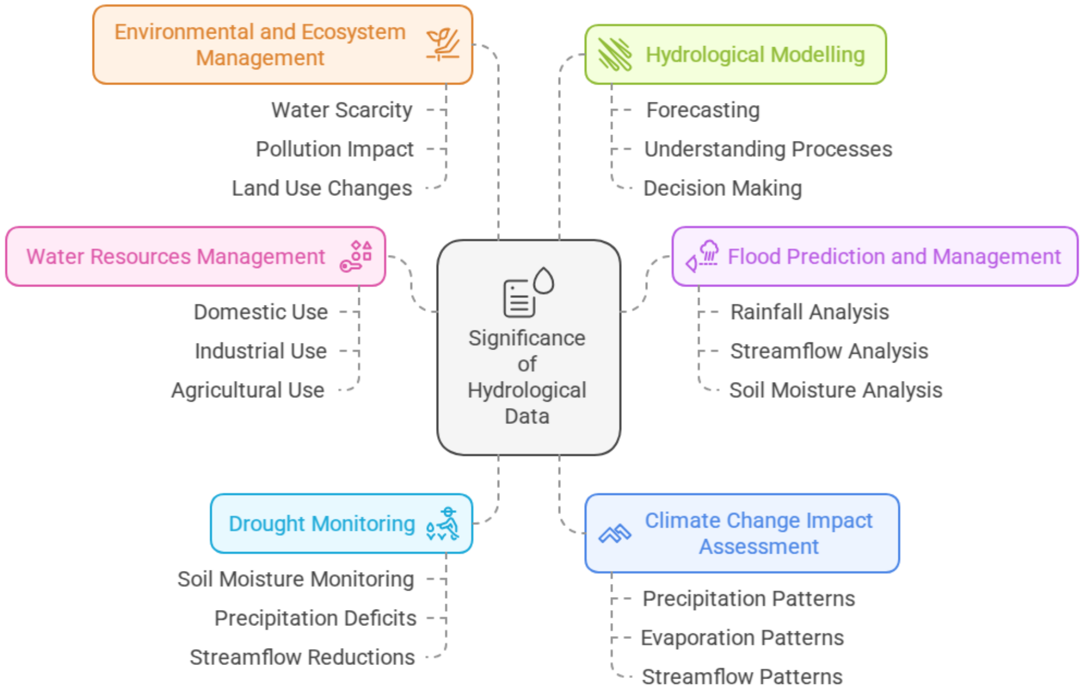

Figure 1. Significance of Hydrological Data

f. **Hydrological Modelling**: Hydrological models are built on the foundation of hydrological data, which helps simulate the movement and distribution of water in the environment. These models are essential for forecasting, understanding hydrological processes, and making decisions about flood control, water storage, and resource allocation (Beven, 2012). Hydrological data is critical in hydrological modelling for the following reasons:

i. **Calibration and Validation**: Accurate data is essential for calibrating hydrological models, ensuring that the model represents real-world conditions. Validating the model with observed data helps in ensuring its reliability for predicting future scenarios (Abbott et al., 1986).

ii. **Prediction of Water Resources**: Hydrological data helps predict future water availability, peak flow, droughts, floods, and water quality, supporting water resource management and planning (Singh, 1995).

iii. **Impact Assessment**: Hydrological data enables the assessment of the impact of land-use changes, climate change, and human activities (e.g., urbanization, deforestation) on water resources (Milly et al., 2008).

iv. **Design and Planning**: Engineers and planners use hydrological data to design infrastructure such as dams, reservoirs, flood control systems, and irrigation networks (Chow et al., 1988).

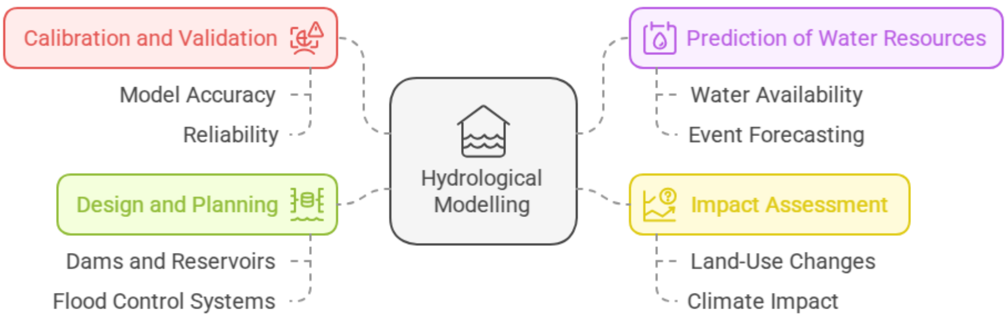

Figure 2. Role of Hydrological Data in Modelling

1.2. Technologies for Collecting Hydrological Data

1. **Ground-Based Observations**: Traditional methods for collecting hydrological data include monitoring stations placed at key locations to measure stream-flow, rainfall, groundwater levels, and other parameters. These data collection stations often form the backbone of hydrological data networks in many regions (World Meteorological Organization, 2018).
2. **Remote Sensing**: Satellite and aerial sensors are increasingly used to collect hydrological data over large and difficult-to-access areas. Remote sensing technology can provide data on precipitation, soil moisture, and land surface temperature, and is a valuable tool for monitoring hydrological systems globally (Levizzani et al., 2018).
3. **Hydrological Gauging Stations**: These stations are typically located along rivers and lakes to monitor water flow, water quality, and other parameters. They provide real-time data that is vital for managing flood events and understanding long-term hydrological trends (Herschy, 1995).

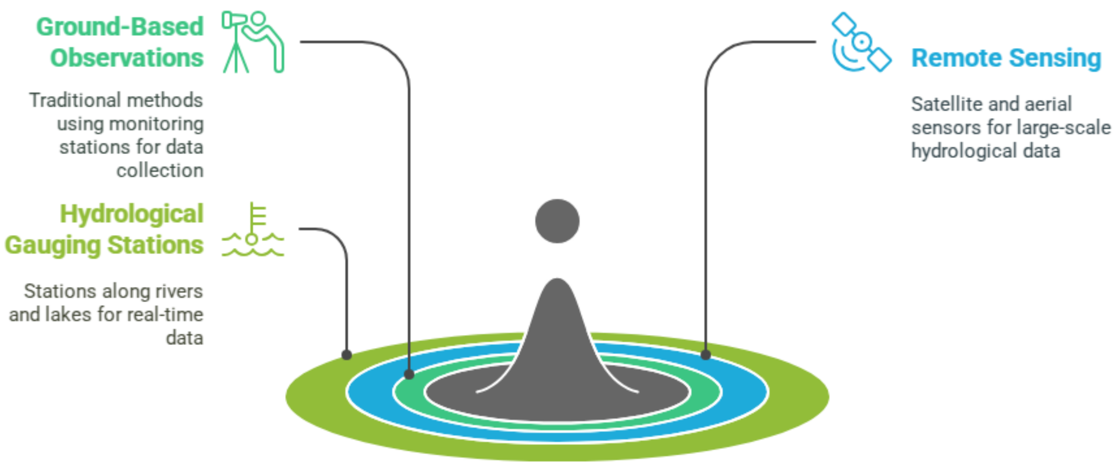

Figure 3. Hydrological Data Collection Methods

1.3. Scope of the Work

In the context of a **Condition Assessment and Management Plan (CAMP) for a river basin**, hydrological data plays a key role in understanding the current state and future management needs of the river basin. Specifically:

a. **Condition Assessment**: Hydrological data allows for an accurate assessment of the current condition of the river basin, including water quantity and quality, stream-flow patterns, and the health of water ecosystems. It helps identify areas of concern, such as water scarcity, pollution, or erosion (Vörösmarty et al., 2010).

b. **Sustainable Management**: By incorporating hydrological data into management plans, authorities can ensure that the water resources of the river basin are used efficiently and sustainably. It helps in making informed decisions about water allocation, flood control, and conservation efforts (Ribbe et al., 2010).

c. **Flood and Drought Management**: Hydrological data helps forecast extreme events such as floods and droughts, which are critical for preparing management plans to mitigate their effects on communities and ecosystems (IPCC, 2012).

d. **Ecosystem and Environmental Protection**: Data on stream-flow, groundwater levels, and water quality is crucial for understanding the health of aquatic ecosystems, helping guide environmental protection and restoration efforts within the river basin (Tockner et al., 2010).

Figure 4. Role of Hydrological Data in River Basin Management

1.4. Data Sources

Table 1: Type of Hydrological Data and its Sources

S. No.	Type of Data	Source
1.	Digital Elevation Model (DEM)	Shuttle Radar Topography Mission (SRTM), Japan Aerospace Exploration Agency (JAXA)
2.	Soil Data	Harmonized World Soil Database (HWSD) v2.0, a comprehensive global soil dataset developed by FAO, IIASA, ISRIC, and other partners
3.	Land Use Land Cover (LULC) Data	Sentinel-2 10m Land Use/Land Cover 2023dataset, provided by ESRI
4.	Hydrological Monitoring Data (Discharge, Water Levels, and Inter-Basin Transfers)	WRD Chhattisgarh, India WRIS, CWC India
5.	Hydrological Cycle Components	IMD, CWC India
6.	Groundwater	WRD Chhattisgarh, CGWB, India WRIS
7.	Sediment Load	CWC India

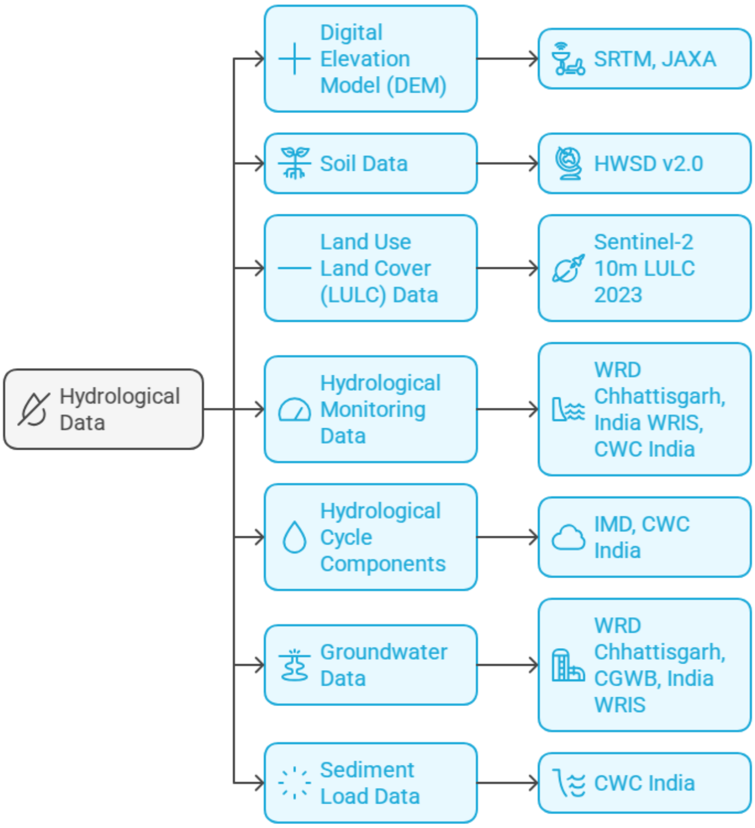

Figure 5. Sources of Hydrological Data

2. Study Area

The Mahanadi River, one of the major river systems of peninsular India, originates from the Sihawa Hills in the Dhamtari district of Chhattisgarh at approximately 442 meters above sea level. It traverses a significant portion of central and eastern India before emptying into the Bay of Bengal. The river has a total length of about 851 kilometers and drains an expansive basin of over 141,600 square kilometers, encompassing parts of Chhattisgarh, Odisha, Jharkhand, and Maharashtra (Figure 6 & 7).

In its initial course, the river flows through Chhattisgarh, where it is joined by prominent tributaries such as the Seonath, Hasdeo, Mand, and Jonk. The Seonath River, the longest tributary, originates from the Maikal Hills and significantly contributes to the flow of the Mahanadi. The Hasdeo River, originating from the dense forests of the Chhattisgarh hills, also plays a crucial role in the hydrological dynamics of the basin. As the river progresses into Odisha, it receives additional tributaries, such as the IB, Ong, and Tel, further augmenting its volume. These tributaries, arising from the Eastern Ghats and surrounding highlands, contribute to the basin's geomorphic diversity and hydrological complexity.

Table 2: Details of Tributary/ Sub-basin of MRB

S. No.	Name of the Tributary/Sub- basin	Bank	Length (km)
1	Mahanadi		851
2	Pairi	Right	113
3	Seonath	Left	383
4	Jonk	Right	196
5	Hasdeo	Left	333
6	Mand	Left	242
7	Ib	Left	251
8	Ong	Right	204
9	Tel	Right	296

The basin encompasses various landscapes, ranging from rugged plateaus and forested regions in its upper reaches to expansive floodplains and deltas in its lower course. As the Mahanadi approaches the coastal plains of Odisha, it forms a sprawling delta before merging with the Bay of Bengal near Paradip. Fertile soils, intricate distributary networks, and significant socio-economic activities, including agriculture and aquaculture characterize this deltaic region.

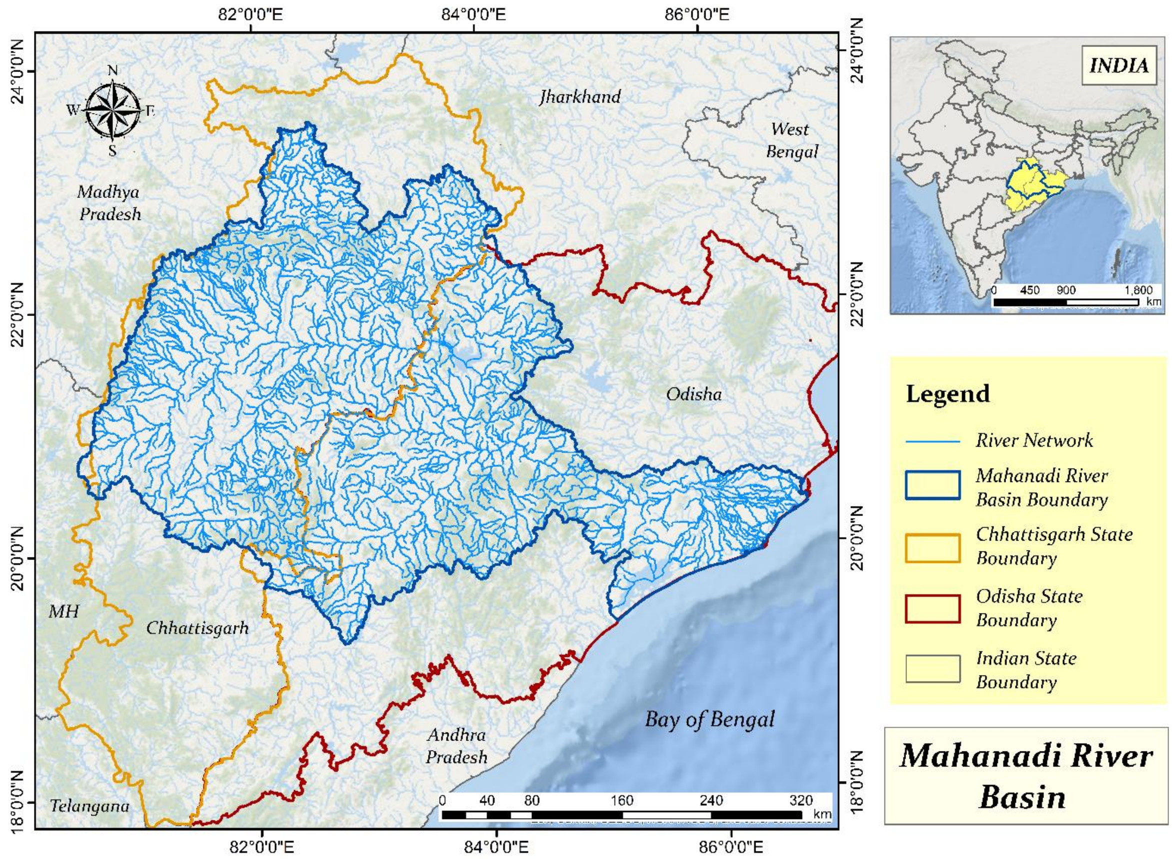

Figure 6. Location Map of Mahanadi River Basin

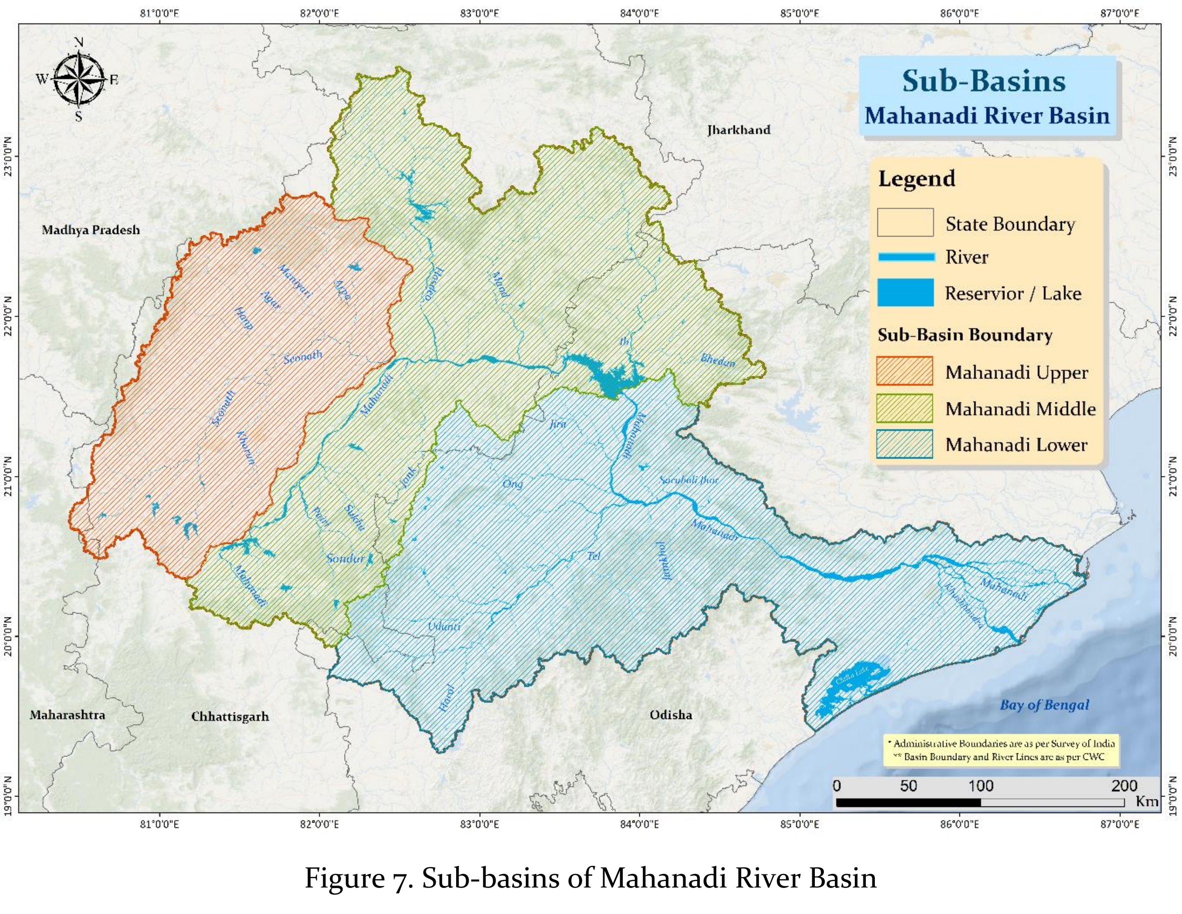

Figure 7. Sub-basins of Mahanadi River Basin

Table 3: Water storage/ diversion structures constructed/ under construction in the basin

S. No.	**Name of the Project**	**River**	**Status**	**Original Capacity in Million Cubic Meter (MCM)**	
				Gross	Live
1.	Hirakud Dam	Mahanadi	Existing	8141.0	5892.0
2.	Bango Dam	Hasdeo	Existing	3417.0	3046.0
3.	Ravishankar Sagar Dam	Mahanadi	Existing	909.0	768.0
4.	Murumsilli	Sillary	Existing	165.0	162.0
5.	Dudhawa Dam	Mahanadi	Existing	288.0	284.0
6.	Tandula	Tandula	Existing	322.0	312.0
7.	Kharang	Kharang	Existing	-	192.32
8.	Kodar Reservoir	Kodar Nala	Existing	160.23	148.91
9.	Mayana Tank	Naini Nala	Existing	211.24	157.93
10.	Kelo Project	Kelo	Under const.	76.0	46.0
11.	Maniyari Project	Maniyari	Existing	151.0	148.0
12.	Kosarteda Project	Kosarteda	Existing	72.86	63.7
13.	Sikasar Dam	Pairi	Existing	217.0	199.0
14.	Sondur Dam	Sondur	Existing	198.0	179.0
15.	Lower Indra	Indra	Under const.	321.63	314.25
16.	Lower Suktel	Suktel	Under const.	320.28	263.43
17.	Paralkot Dam	Dewadha	Existing	66.3	63.6

(*Source: Water Year Book, Volume-I, June 2017- May 2018, CWC, Mahanadi Basin*)

3. Hydrological Data

3.1. Types

1. **Precipitation**: Precipitation data includes rainfall, snow, hail, and other forms of water that fall from the atmosphere. This data is fundamental because it is the primary source of freshwater and influences river discharge, groundwater recharge, and overall water availability in a region (Semenov et al., 2010).
2. **Stream-flow**: Stream-flow or river discharge data measures the flow of water in rivers, streams, and other surface water bodies. Stream-flow is a critical variable in hydrology as it is used to assess the amount of water available for use, to predict floods, and to study the movement of water through landscapes (Herschy, 1995).
3. **Groundwater Levels**: Groundwater data provides information about the depth of water in wells and aquifers. This data is important for understanding groundwater recharge rates, the sustainability of groundwater supplies, and assessing the impacts of human activities like over-extraction (Foster & Hirata, 2014).
4. **Evaporation and Transpiration**: Evaporation data measures the loss of water from the Earth's surface to the atmosphere, while transpiration refers to the loss of water by plants. Combined, these processes are known as evapotranspiration and are crucial for understanding the water balance in a region, especially in agriculture and ecosystem studies (McMahon et al., 2007).
5. **Soil Moisture**: Soil moisture data refers to the amount of water stored in the soil. This is essential for understanding hydrological processes like runoff, infiltration, and groundwater recharge, as well as its importance for agriculture and ecosystem health (Robock et al., 2000).
6. **Water Quality**: Hydrological data also includes the chemical and biological characteristics of water, such as the concentration of pollutants, sediment load, and temperature. Water quality data is crucial for managing water resources, especially for drinking water, agriculture, and maintaining ecosystem health (EPA, 2018).

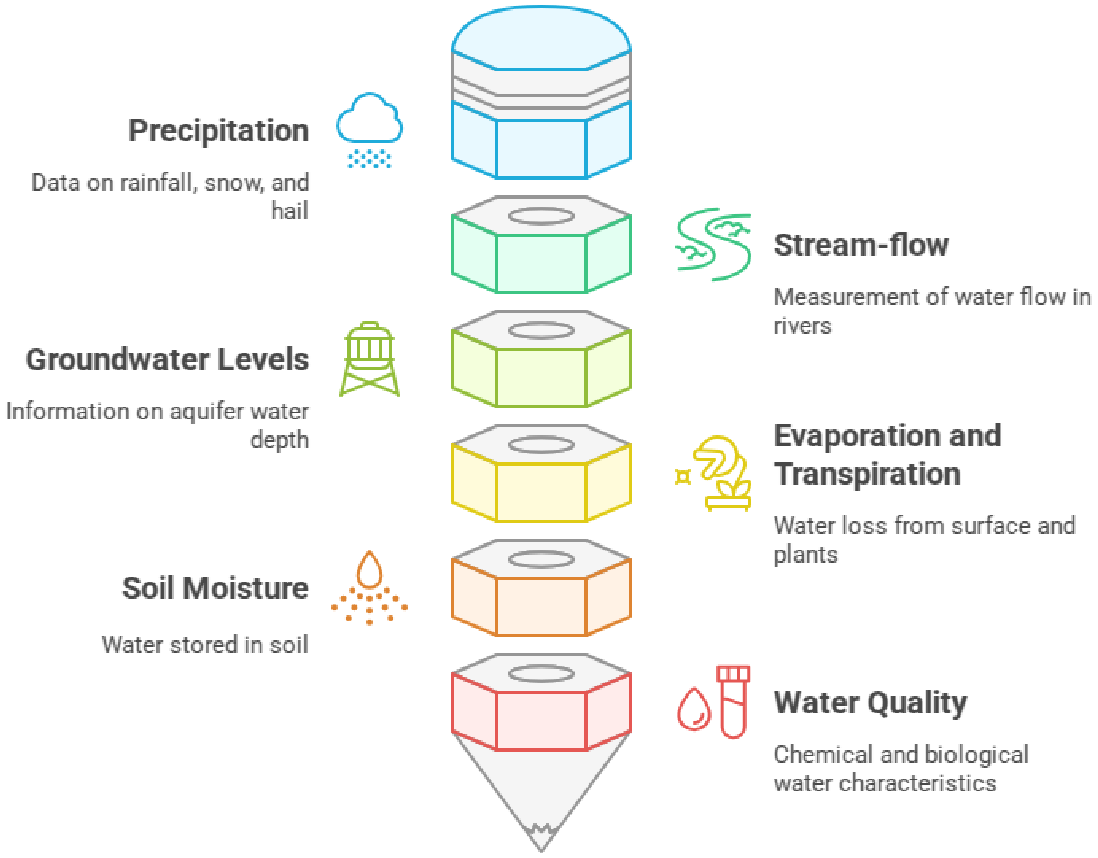

Figure 8. Components of Hydrological Data

3.2. Digital Elevation Model (DEM)

A **Digital Elevation Model (DEM)** is a 3D representation of terrain elevation that plays a crucial role in hydrology by helping analyse water flow and distribution. It provides essential data for understanding how water moves across landscapes, making it vital for watershed management, flood prediction, and water resource planning. DEMs help delineate watersheds, which are critical for assessing flood risks and managing water resources effectively (Zhu et al., 2016; Moore et al., 2015).

In flood modelling, DEMs simulate how water spreads across a landscape during flood events. By integrating DEMs with weather and precipitation data, hydrologists can predict flood extents and identify vulnerable areas, aiding in floodplain mapping and risk assessment. This helps prepare for and mitigate the impacts of floods (Jenson & Domingue, 1988; Wilson & Gallant, 2000).

DEMs are also essential for studying runoff and erosion. They allow hydrologists to model how water flows over different terrains, influencing surface runoff and erosion patterns. This helps predict areas prone to erosion and runoff, crucial for soil and water quality management (Fell et al., 2008; Beven & Kirkby, 1979).

In hydrological modelling, DEMs support the simulation of water movement, infiltration, and groundwater recharge. These models are key to effective watershed management, irrigation planning, and flood control (Feng et al., 2021; Gallant & Wilson, 2000). DEMs also play a role in assessing climate change impacts by forecasting shifts in water availability, flood risks, and drought patterns, all based on terrain characteristics and future climate projections (González et al., 2019; Lamb et al., 2022).

DEMs integration with other environmental data enhances our understanding of water dynamics, enabling better decision-making in water management and climate change adaptation (Niemeyer et al., 2020; Singh et al., 2013).

Figure 9. shows the DEM of Mahanadi basin downloaded from Shuttle Radar Topography Mission (SRTM) of 30-meter resolution. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The SRTM obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth.

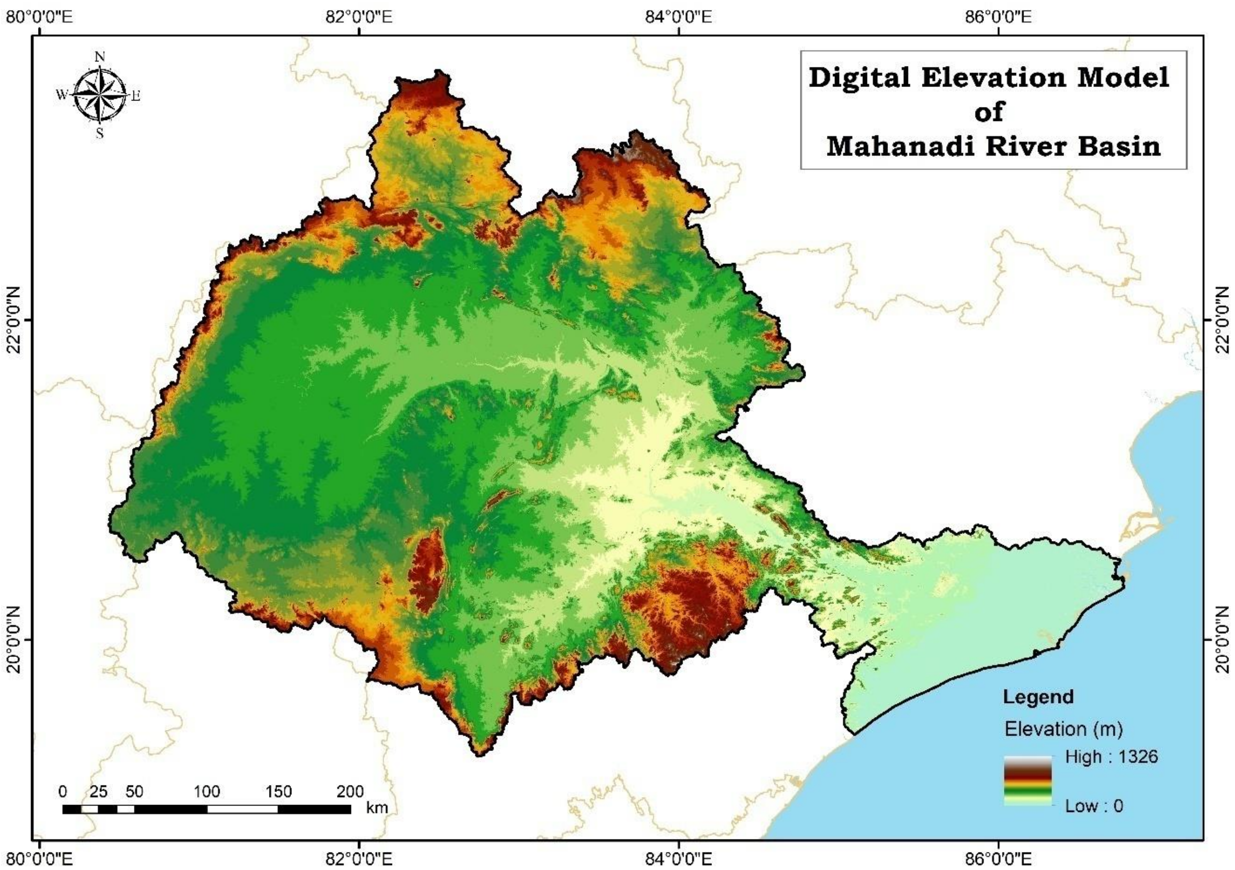

Figure 9. Digital Elevation Model Map of Mahanadi River Basin

3.3. Soil Data

Soil texture is a critical property influencing hydrological processes such as infiltration, water retention, and runoff. This report analyses the soil texture of the Mahanadi River Basin using USDA soil classification data derived from the Harmonized World Soil Database (HWSD) v2.0, a comprehensive global soil dataset developed by FAO, IIASA, ISRIC, and other partners. The objective of this analysis is to provide an overview of the spatial distribution of soil texture across the Mahanadi River Basin to support hydrological modelling, agricultural planning, and watershed management.

3.3.1. Soil Texture Classification: USDA soil texture classification was used, which categorizes soils into 12 classes based on the proportion of sand, silt, and clay.

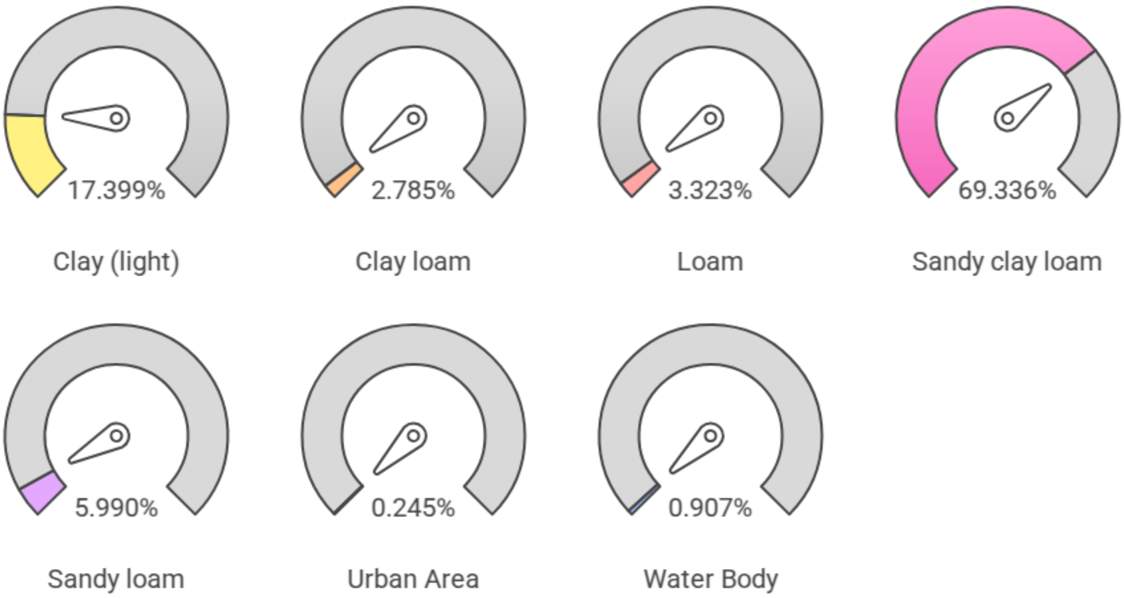

Figure 10. Predominant USDA Soil Texture classes in Mahanadi River Basin

3.3.2. Hydrological Implications

Infiltration and Runoff: Sandy soils in the upper basin have higher infiltration rates, while clayey soils in the lower basin contribute to surface runoff.

Water Retention: Clayey soils in the deltaic regions exhibit high water-holding capacity, beneficial for agriculture but prone to water-logging.

Erosion Susceptibility: Loamy soils in the mid-basin are moderately prone to erosion, necessitating soil conservation measures.

Spatial Analysis

GIS-based maps highlight the spatial heterogeneity in soil texture. These maps can aid in:

- Identifying zones suitable for specific crops.
- Designing site-specific water management strategies.
- Predicting hydrological responses to rainfall events.

The soil map (Figure 11.) demonstrates the significant variability in soil texture within the Mahanadi River Basin. By leveraging USDA classification and HWSD v2.0 data, the findings provide valuable insights for hydrological modelling, agricultural planning, and sustainable watershed management. Future studies may incorporate dynamic factors such as land use changes and climate variability to refine these insights further.

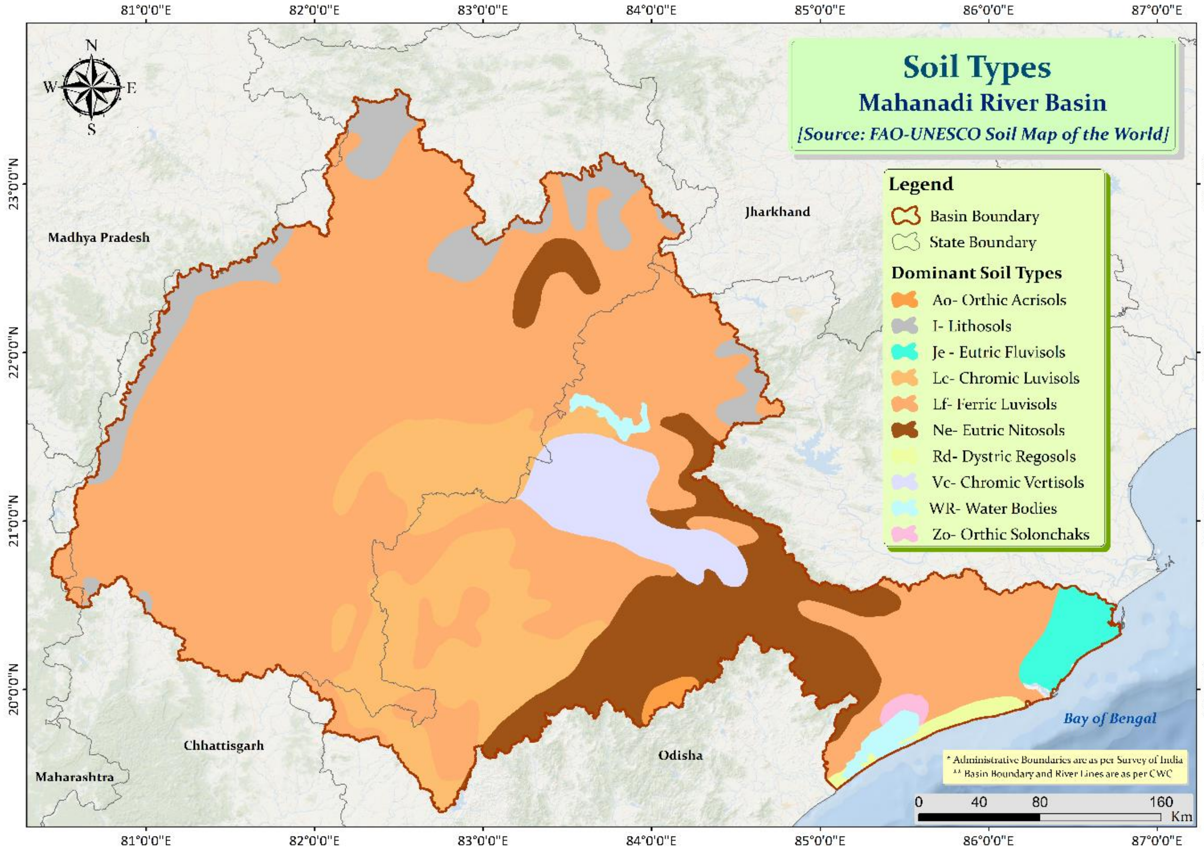

Figure 11. Soil Map of Mahanadi River Basin

3.4. Land Use Land Cover (LULC) Data

Land Use and Land Cover (LULC) data play a crucial role in understanding the hydrological dynamics of river basins. The LULC characteristics influence key hydrological processes such as surface runoff, infiltration, evapotranspiration, and groundwater recharge. The LULC data for the Mahanadi River Basin is taken from the ESRI's Sentinel-2 10m Land Use/Land Cover dataset for the year 2023 showing present conditions The dataset categorizes the MRB region into seven distinct classes, providing high-resolution insights critical for hydrological studies and water resource management (Source: *https://livingatlas.arcgis.com/landcover/*).

The **Sentinel-2 10m Land Use/Land Cover 2023** dataset, provided by **ESRI**, offers a globally consistent LULC classification system derived from Sentinel-2 imagery. The dataset is based on the following key attributes:

- **Spatial Resolution**: 10 meters
- **Temporal Coverage**: 2023
- **Classification Scheme**: Includes major classes such as agriculture, forests, grasslands, water bodies, urban areas, and barren land.

The LULC classification reveals the following distribution of land cover types within the Mahanadi River Basin in 2023:

Table 4: Land Use/ Land Cover Classes for Mahanadi River Basin

S. No.	LULC Class	Area (sq. km)	Percentage (%)
1.	Water	4384.41	3.02
2.	Trees	41830.83	28.77
3.	Flooded vegetation	285.56	0.20
4.	Crops	59411.23	40.86
5.	Built Area	7342.11	5.05
6.	Bare ground	334.30	0.23
7.	Rangeland	31826.17	21.89

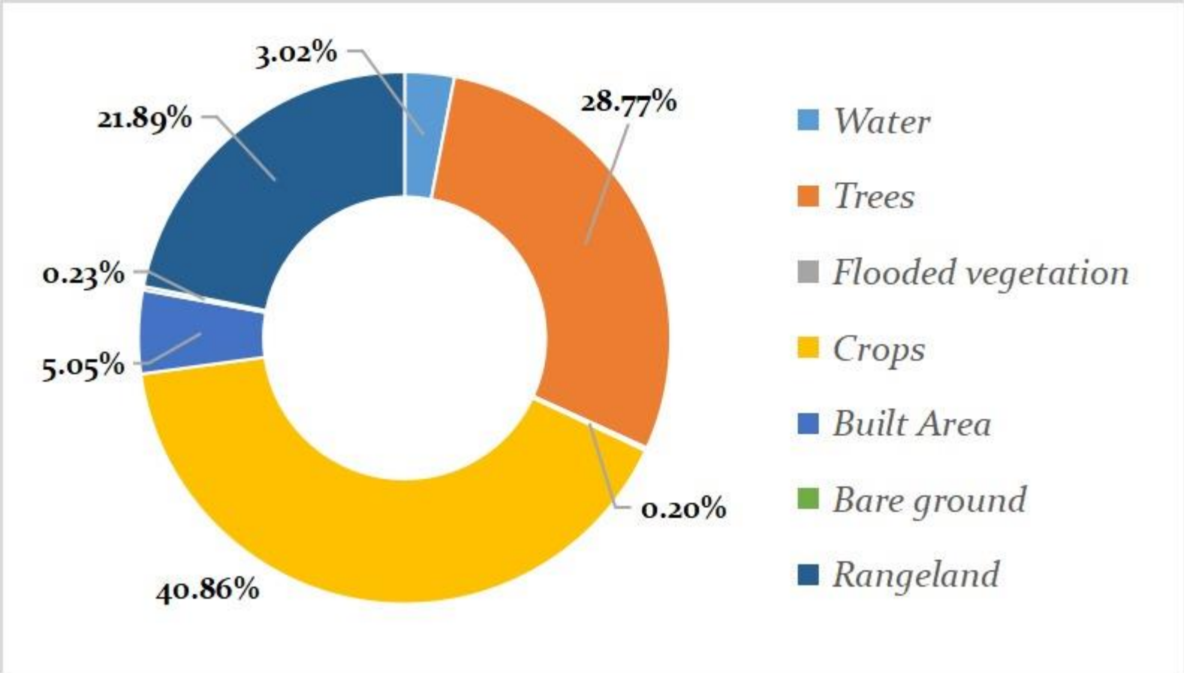

Figure 12. Percent coverage of land use land cover classes for Mahanadi River Basin

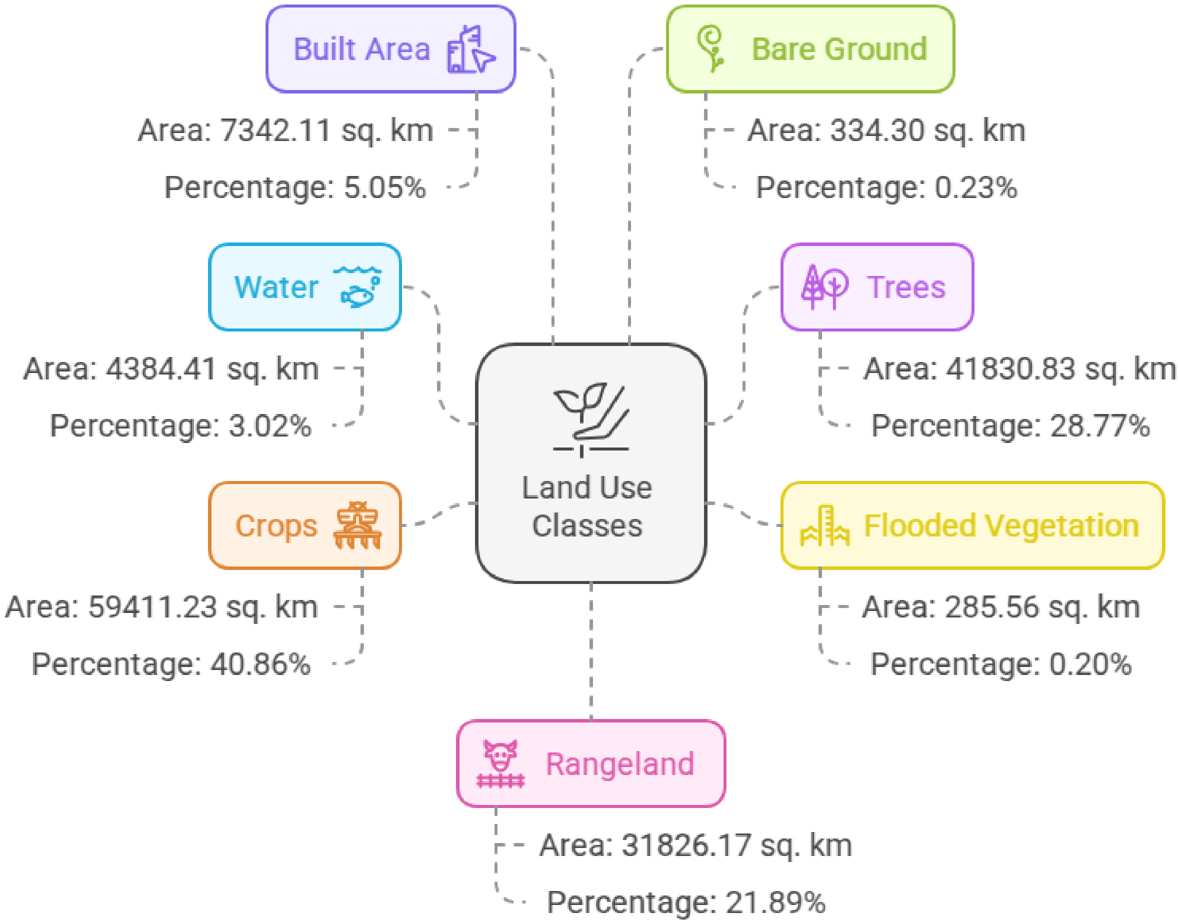

Figure 13. Land use land cover distribution in Mahanadi River Basin

Key Observations:

- **Agricultural Dominance**: Agriculture is the most dominant land use in the basin, with significant coverage in the middle and lower reaches.
- **Forest Cover**: Forests occupy a substantial portion, mainly concentrated in the upper basin regions of Chhattisgarh and Odisha.
- **Urban Expansion**: Rapid urbanization, particularly around Bhubaneswar and Raipur, contributes to increased impervious surfaces, affecting runoff patterns.

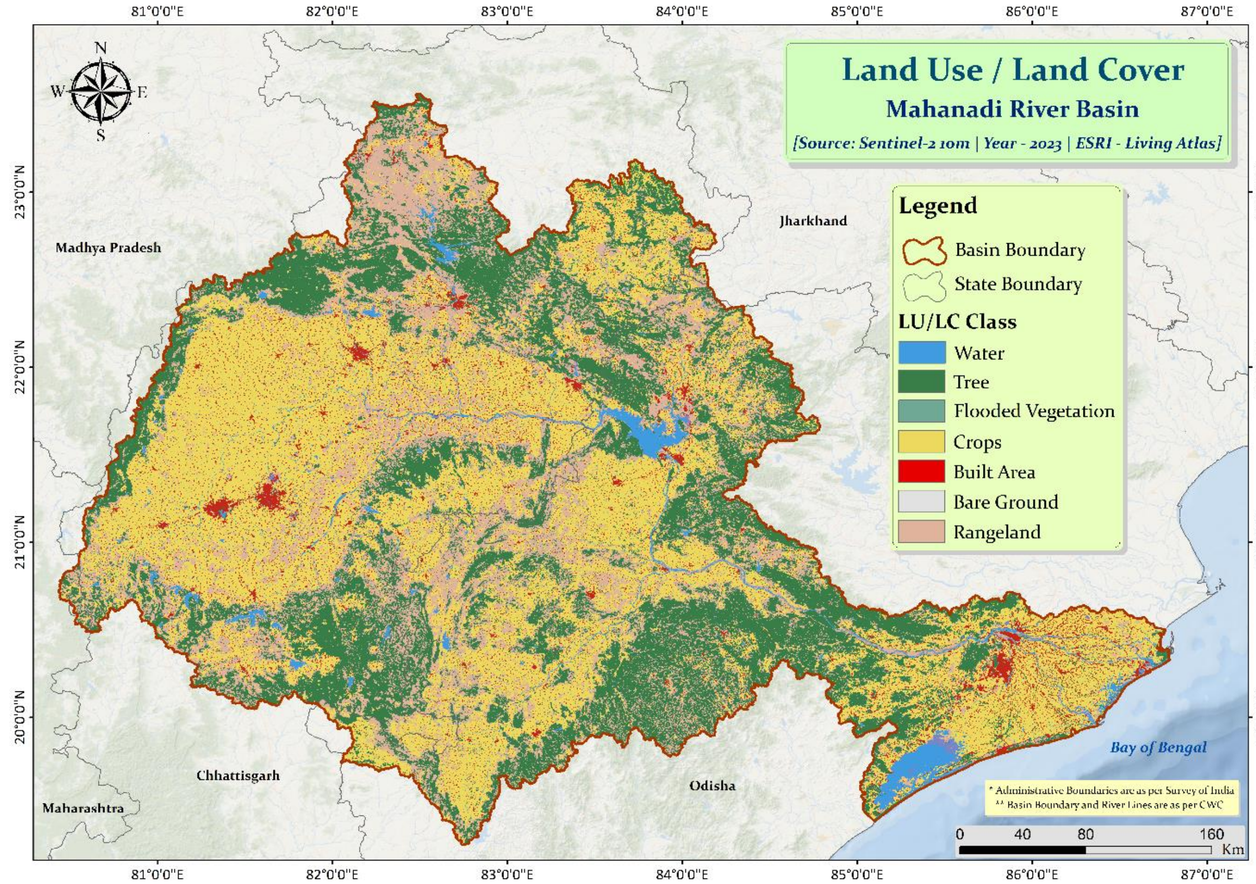

Figure 14. Land Use Land Cover (LULC) Map of Mahanadi River Basin

3.5. Hydrological Monitoring Data

Hydrological monitoring data plays a vital role in understanding and managing water systems. Key components of hydrological monitoring include **discharge**, **water levels**, and **inter-basin transfers**, which provide critical insights into river flow, water availability, and water movement between basins.

Discharge refers to the volume of water flowing through a river or stream over a specified period, typically measured in cubic meters per second (m^3/s). It is a key parameter for flood forecasting, water resource management, and environmental monitoring. Monitoring discharge helps assess the availability of water for consumption, irrigation, and hydroelectric power generation (Peters et al., 2017).

Water levels are measured to track the height of water in rivers, lakes, or reservoirs. These measurements are essential for flood prediction, as rising water levels indicate potential flooding, especially in flood-prone areas. Water level data is also crucial for managing reservoirs and ensuring adequate water supply during dry periods (Bureau of Reclamation, 2016).

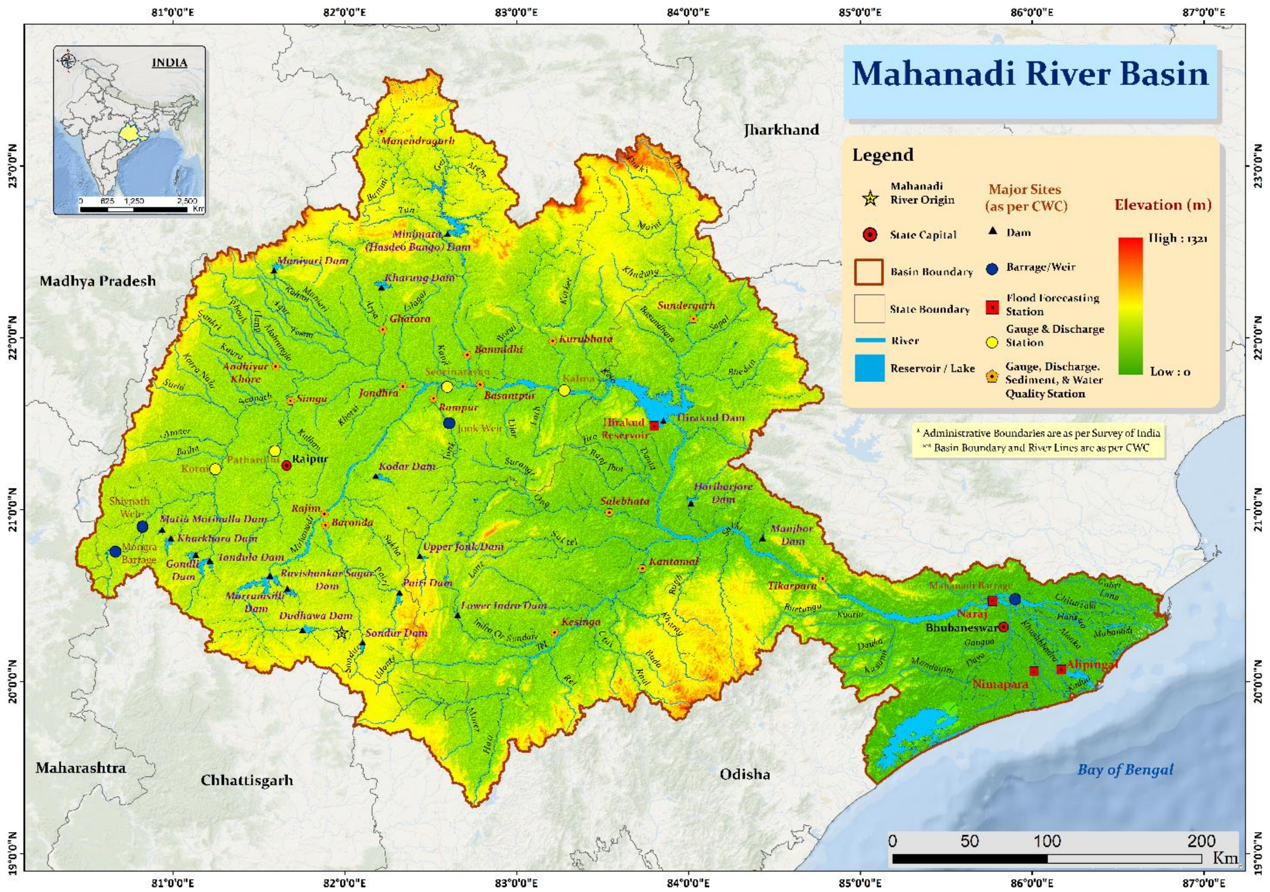

Figure 15. Major Sites including GDSQ stations of Mahanadi River Basin as per CWC

Table 5: Details of CWC Sites in Mahanadi Basin

S. No.	Station Name	River/Tributary	Code No	Type	Latitude	Longitude
1	Andhiyarkore	Hamp	EMP60E5	GDSQ	21°50’02”	81°36’21”
2	Bamnidih	Hasdeo	EMM00B3	GDSQ	21°53’55”	82°43’02”
3	Bangodam	Hasdeo	001A	G	22°35’35”	82°34’31”
4	Baronda	Pairi	EMR00A4	GDSQ	20°54’45”	81°53’10”
5	Basantpur	Mahanadi	EM000R2	GDSQ	21°43’36”	82°47’17”
6	Baikunthpur	Hasdeo	004A	RF	23°15’02”	82°35’00”
7	Burla	-	001B	RF	21°30’30”	83°53’30”
8	Deogaon	Mahanadi	0012B	G	21°18’30”	83°54’00”
9	Dharamjaigarh	Mond	002B	G	22°28’20”	83°12’52”
10	Ghatora	Arpa	EMP40F2	GDSQ	22°03’24”	82°13’15”
11	Gopalpur	Basundhara	0011B	RF	22°03’40”	83°43’50”
12	Jamadarpali	Mahanadi	008B	G	21°34’14”	83°59’20”
13	Jondhra	Seonath	EMP00A4	GDSQ	21°43’ 30”	82°20’50”
14	Kantamal	Tel	EMF00C3	GDSQ	20°39’00”	83°43’55”
15	Keloat Raigarh	Mahanadi	009B	GD(S)	21°53’19”	83°24’10”
16	Kesinga	Tel	EMF00K6	GDSQ	20°11’51”	83°13’30”
17	Khairmal	Mahanadi	007B	G	20°49’18”	84°00’00”
18	Korba	Hasdeo	002A	G	22°21’30”	82°41’30”
19	Kotni	Seonath	EMP00P8	GDSQ	21°14’10”	81°14’50”
20	Kurubhata	Mand	EMK00E2	GDSQ	21°59’15”	83°12’15”
21	Mahulpali	Bheden	0010B	G	22°52’30”	84°25’00”
22	Manendragarh	Hasdeo	EM00T7	GDSQ	23°12’10”	82°13’05”
23	Parmanpur	Bheden	004B	GD(S)	21°46’50”	84°04’54”
24	Patharidihi	Kharun	EMP70F3	GDQ	21°20’28”	81°35’38”
25	Pendra Road	Arpa	003A	RF	22°45’30”	81°54’30”
26	Phulbani	Mahanadi	006B	RF	20°28’00”	84°15’00”
27	Raipur	-	-	RF	21°15’36”	81°36’18”
28	Rajim	Mahanadi	EM000U7	GDSQ	20°58’25”	81°52’48”
29	Rampur	Jonk	EMN00B3	GDSQ	21°39’06”	82°31’10”
30	Salebhata	Ong	EMG00E5	GDSQ	20°59’00”	83°32’22”
31	Sankara	Jonk	163	G	21°17’19”	82°31’00”
32	Seorinarayan	Mahanadi	EM000R6	GDSQ	21°43’00”	82°35’48”

33	Simga	Seonath	EMP00J1	GDSQ	21^{0}37’54”	81^{0}41’16”
34	Sundargarh	Ib	EMI00H3	GDSQ	22^{0}06’55”	84^{0}00’40”
35	Surajgarh	Mahanadi	005B	G	21^{0}41’35”	83^{0}22’17”
36	Thethetanger	Ib	003B	G	22^{0}40’05”	83^{0}54’36”
37	Alipingal	Devi	-	G	20^{0}10’00”	86^{0}10’00”
38	Arampur	Sindolijore	-	G	20^{0}48’06”	84^{0}36’04”
39	Kanas	Daya	-	G(S)	20^{0}00’08”	85^{0}38’47”
40	Khandapara	Kusumi	-	G	20^{0}15’22”	85^{0}11’16”
41	Marshaghai	Luna	-	G	20^{0}20’24”	86^{0}28’51”
42	Naraj	Mahanadi	-	G	20^{0}28’30”	85^{0}46’30”
43	Nimapara	Kushabhadara	-	G	20^{0}04’10”	86^{0}00’00”
44	Padmavati	Mahanadi	-	G	20^{0}20’36”	85^{0}17’51”
45	Pubansa	Luna	-	G(S)	20^{0}26’39”	86^{0}14’51”
46	Tikarpara	Mahanadi	-	GDSQ	22^{0}38’00”	84^{0}37’08”
47.	Gunderdehi	Tandula	164	GD	20^{0}57’11”	81^{0}16’45”
48.	BalaKathi Rd. Bridge	Bhargavi	-	G(S)	20°12'09"	85°51'54"
49.	Balanga	Bhargavi	-	G(S)	20°02'20"	85°52'45"
50.	Bhingarpur	Kushbhadra	-	G(S)	20°15'48"	85°55'59"
51.	DayaRd. Bridge	Daya	-	G(S)	20°12'36"	85°51'07"
52.	Kishan Nagar	Mahanadi	-	G(S)	20°25'34"	86°05'19"
53.	Tarpur	Mahanadi	-	G(S)	20°19'02"	86°22'31"
54.	Kathajodi Bridge	Kathajodi (Devi)	-	G(S)	20°26'13"	85°53'17"
55	Boudh	Mahanadi	-	GD	20°51'56"	84°18'48"
56	Katghora	Ahiran	-	G(S)	22°29'31"	82°32'19"
57	Padampur	Ong	-	GD(S)	21°00'57"	83°06'11"
58	Maniyari	Maniyari	-	G(S)		
59	Sarangpal	Mahanadi	-	G(S)	21°43'00"	82°20'34"
60	Kalma	Mahanadi	-	GD	21°41'40"	83°16'44"
61	Malgaon	Mahanadi (Pairi)	-	G	20°39'25"	32°02'20"

Inter-basin transfers involve the movement of water between different river basins, either for irrigation, hydroelectric generation, or water supply. This type of data is significant for managing large-scale water systems, particularly in regions where water availability is unevenly distributed. Monitoring inter-basin transfers ensures that water resources are used efficiently and helps in the management of water scarcity (Vörösmarty et al., 2010).

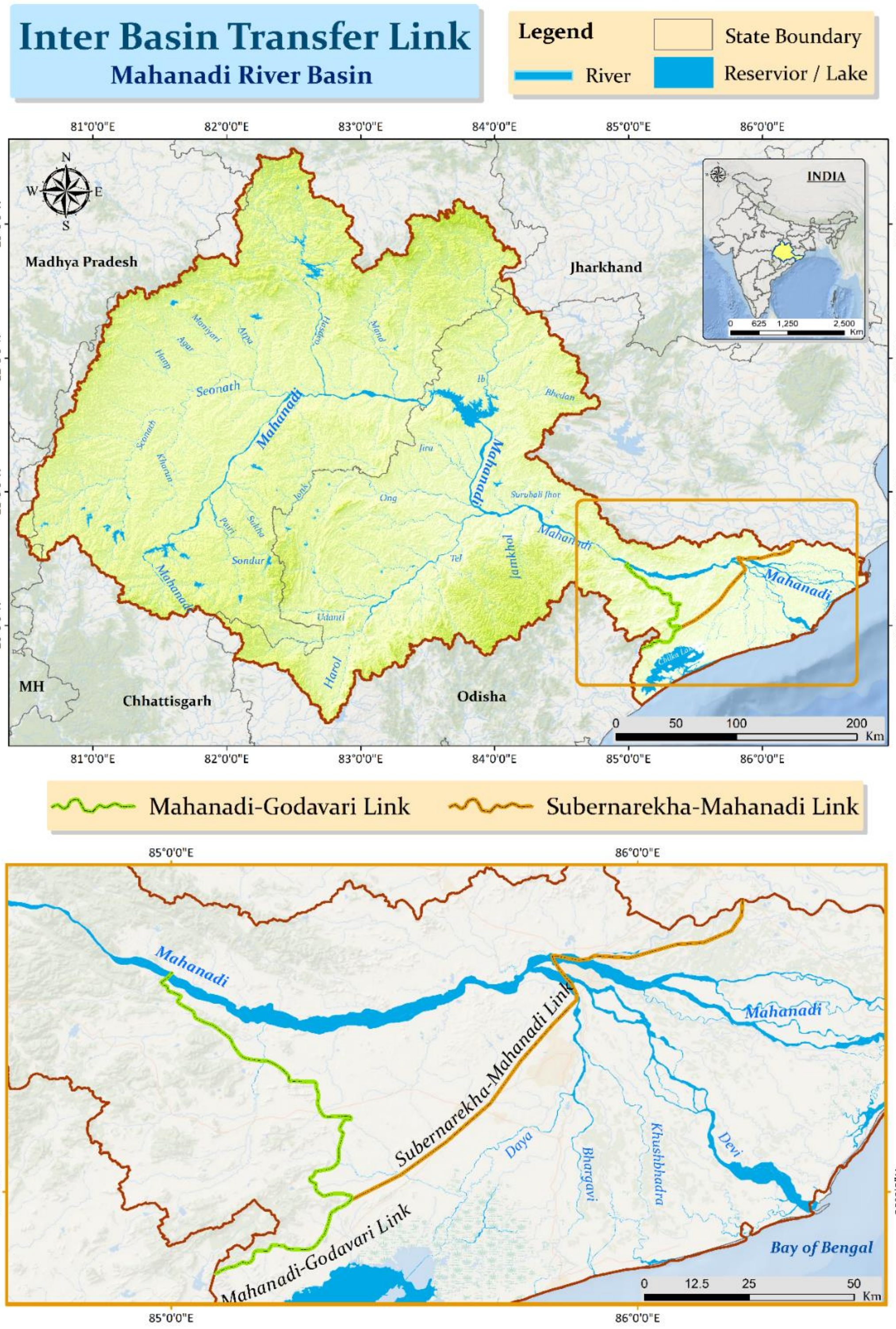

Figure 16. Inter-basin Transfer Links of Mahanadi River Basin

3.6. Hydrological Cycle Components

The **hydrological cycle** describes the continuous movement of water within the Earth-atmosphere system. It is essential for maintaining water availability and ecosystem balance. Key components of the hydrological cycle include **precipitation**, **evaporation**, **transpiration**, **infiltration**, **runoff**, and **storage**.

Precipitation is the process by which water vapour in the atmosphere condenses and falls to the Earth's surface as rain, snow, sleet, or hail. It is the primary source of water for rivers, lakes, and groundwater (Chahine, 1992).

Evaporation is the process by which water changes from liquid to vapour, primarily from oceans, lakes, and rivers. **Transpiration** is the release of water vapour from plants, often combined with evaporation in a process called **evapo-transpiration**. These processes are crucial for returning moisture to the atmosphere (Priestley & Taylor, 1972).

Infiltration refers to the movement of water from the surface into the soil, contributing to groundwater recharge. The rate of infiltration depends on soil properties and land cover (Chow et al., 1988).

Runoff is the flow of water over the land surface into rivers, lakes, and oceans. It is influenced by precipitation intensity, land use, and topography (Wang et al., 2001).

Storage involves water being stored in various reservoirs, such as groundwater aquifers, rivers, and lakes, where it can be accessed for various uses (Melton, 1957).

Table 6. Data availability of Hydrological Cycle Components

S.No	Type of Data	Resolution	Data Available	Sources
1	Precipitation	0.25^{o}x0.25^{o}	1901 – 2023	IMD
2	Temperature	1^{o}x1^{o}	1951 - 2023	IMD
3	Ground Water Level	-	05 Jan 1994 - 24 May 2024	India-WRIS

The table enumerates various types of data along with their resolution and the periods for which they are available.

3.7. Precipitation

The average annual variations in the basin based on daily rainfall data (0.25° X 0.25°) for the period 1971-2024, collected from IMD, is shown in Figure 17. The data reveals significant spatial differences in precipitation across the basin. Most of the Upper Mahanadi Basin receives an average annual rainfall of 1000-1200 mm. In contrast, the Middle and Lower Mahanadi sub-basins receive higher rainfall, averaging between 1200-1600 mm annually. A substantial portions of the basin's annual rainfall, about 80-90%, occurs during the southwest monsoon season, which spans from June to September, comparatively less rainfall from the southwest monsoon, approximately 60-70% of their average annual total. Instead, these deltaic regions benefit from the northeast monsoon, which occurs from October to December, contributing 10-22% of their annual rainfall. This distribution pattern underscores the critical role of both monsoon systems in influencing the hydrological dynamics of the Mahanadi Basin, necessitating tailored water management and agricultural planning strategies to accommodate these variations and optimize resource utilization throughout the year.

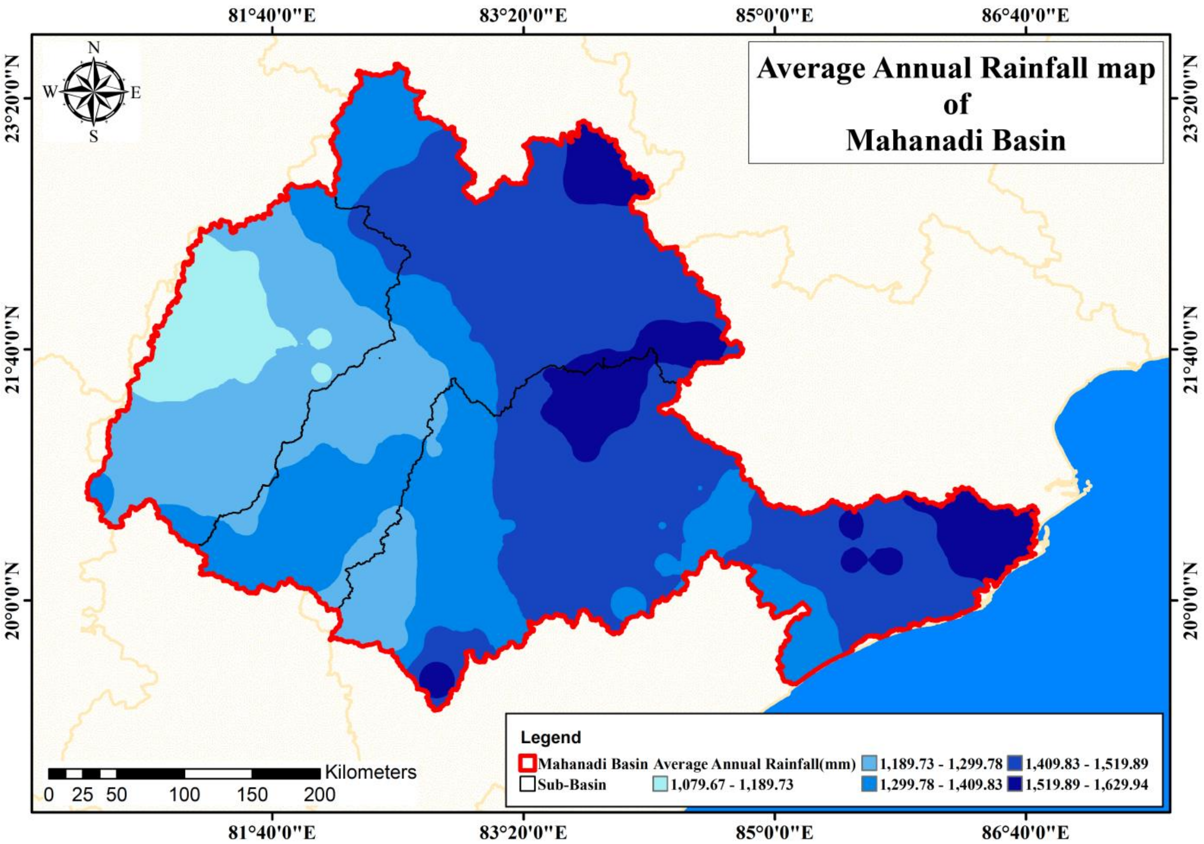

Figure 17. Annual Average Rainfall Map of Mahanadi River Basin

3.8. Groundwater

Groundwater refers to water that is stored beneath the Earth's surface in soil pores and rock formations, forming aquifers. It is a critical part of the hydrological cycle, supplying water for drinking, irrigation, and industrial use, particularly in areas where surface water is scarce. Groundwater is replenished through **recharge**, which occurs when rainwater or surface water percolates down through the soil and rock layers to the aquifers (Scanlon et al., 2006).

The movement of groundwater is influenced by **hydraulic conductivity** and **permeability**, which determine how easily water can flow through porous materials. Groundwater flows from areas of high pressure to low pressure, often discharging into rivers, lakes, or coastal regions, a process known as **baseflow** (Todd & Mays, 2005).

Groundwater is also susceptible to **over-extraction**, especially in regions where the rate of withdrawal exceeds the natural recharge rate, leading to depletion and potential issues like land subsidence and saline intrusion in coastal areas (Vörösmarty et al., 2010).

3.9. Sediment Load

Sediment load refers to the amount of solid material, such as sand, silt, and clay, that is carried by water in rivers, streams, and other surface water bodies. This material is transported by water flow and can be either **suspended load** (particles held in the water column) or **bed load** (larger particles that move along the riverbed). Sediment load is an important parameter in hydrology and geomorphology as it influences river channel morphology, water quality, and aquatic habitats (Walling, 2006).

Sediment transport is primarily driven by the **flow velocity** of water, with higher flows capable of carrying larger particles. Factors such as land use, vegetation cover, and rainfall intensity also affect sediment yield and transport. Excessive sediment load can result from human activities like deforestation and urbanization, leading to increased erosion and water pollution (Parker, 1991).

The management of sediment load is crucial for flood control, reservoir storage, and maintaining water quality, as high sediment concentrations can reduce water clarity, increase water treatment costs, and impact aquatic life (Ramos-Scharrón & MacDonald, 2007).

Table 7. Data availability GDSQ as per CWC

S. No.	Name of Site	Tributary/ Sub-tributary	Type	Data Available	
				From	To
1.	Alipingal	Devi	GD		
			Gauge	01-08-1979	31-12-2012
			Discharge	01-08-1979	31-12-2012
2.	Kanas	Daya	GD		
			Gauge	01-08-1979	31-12-2012
			Discharge	01-08-1979	31-12-2012
3.	Kantamal	Tel	GDSQ		
			Gauge	01-08-1971	31-12-2012
			Discharge	01-08-1971	31-05-2012
			Sediment	01-01-2010	30-06-2020
			Water quality	01-01-2010	02-03-2020
4.	Kesinga	Tel	GDSQ		
			Gauge	01-11-1977	31-05-2012
			Discharge	01-11-1977	31-05-2012
			Sediment	01-01-2010	30-09-2020
			Water quality	01-01-2010	02-03-2020
5.	Khairmal	Mahanadi	GD		
			Gauge	01-07-1984	31-05-2012
			Discharge	01-07-1984	31-05-2012
6.	Marshaghai	Luna	GD		
			Gauge	30-07-2003	20-10-2012
			Discharge	30-07-2003	20-10-2012
7.	Nimapara	Kushabhadra	GD		
			Gauge	01-07-1976	31-12-2012
			Discharge	01-07-1976	31-12-2012
8.	Pandigaon	Hati(Tel)	GD		
			Gauge	01-06-1989	30-04-2001
			Discharge	01-06-1989	30-04-2001
9.	Pubansa	Luna	GDSQ		
			Gauge	16-07-2003	30-09-2012
			Discharge	16-07-2003	30-09-2012
10.	Rampur	Jonk	GDSQ		
			Gauge	01-01-1971	30-09-2011
			Discharge	01-01-1971	30-09-2011
			Sediment	01-01-2010	30-06-2020
			Water quality	01-01-2010	01-05-2019
11.	Salebhata	Ong	GDSQ		
			Gauge	01-12-1971	31-05-2012
			Discharge	01-12-1971	31-05-2012
			Sediment	01-01-2010	31-06-2020

			Water quality	01-01-2010	02-03-2020
12.	Sundargarh	Ib	GDSQ		
			Gauge	01-08-1977	31-05-2012
			Discharge	01-08-1977	31-05-2012
			Sediment	01-01-2010	31-05-2020
			Water quality	01-01-2010	02-03-2020
13.	Tikarpara	Mahanadi	GDSQ		
			Gauge	19-02-1971	31-12-2012
			Discharge	19-02-1971	31-12-2012
			Sediment	01-01-2010	30-05-2020
			Water quality	01-01-2010	02-03-2020
14.	Andhiyarkore	Hamp	GDSQ		
			Gauge	01-09-1977	30-09-2011
			Discharge	01-09-1977	30-09-2011
			Sediment	01-01-2010	30-05-2020
			Water quality	01-01-2010	01-05-2019
15.	Bamnidhi	Hasdeo	GDSQ		
			Gauge	29-01-1971	31-05-2011
			Discharge	29-01-1971	31-05-2011
			Sediment	01-01-2010	30-07-2020
			Water quality	01-01-2010	02-03-2020
16.	Baronda	Pairi	GDSQ		
			Gauge	01-07-1977	30-09-2011
			Discharge	01-07-1977	30-09-2011
			Sediment	01-01-2010	31-06-2020
			Water quality	01-01-2010	01-05-2020
17.	Basantpur	Mahanadi	GDSQ		
			Gauge	01-05-1971	30-06-2011
			Discharge	01-05-1971	30-06-2011
			Sediment	01-01-2010	31-05-2020
			Water quality	01-01-2010	02-03-2020
18.	Deogaon	Mahanadi	GDSQ		
			Gauge	01-07-2004	31-05-2012
			Discharge	01-07-2004	31-05-2012
19.	Ghatora	Arpa	GDSQ		
			Gauge	01-06-1978	31-05-2011
			Discharge	01-06-1978	31-05-2011
			Sediment	01-01-2010	31-07-2020
			Water quality	01-01-2010	02-03-2020
20.	Jondhra	Seonath	GDSQ		
			Gauge	24-01-1979	31-05-2011
			Discharge	24-01-1979	31-05-2011
			Sediment	01-01-2010	30-05-2020

			Water quality	01-01-2010	02-03-2020
21.	Raigarh	Kelo	GDSQ		
			Gauge	01-05-1988	31-05-2012
			Discharge	01-05-1988	31-05-2012
22.	Korba	Haseo	GD		
			Gauge	01-06-1985	31-05-2011
			Discharge	01-06-1985	31-05-2011
23.	Kotni	Seonath	GDSQ		
			Gauge	01-09-1977	30-09-2011
			Discharge	01-09-1977	30-09-2011
			Sediment	01-01-2010	31-06-2020
			Water quality	01-05-2016	01-05-2019
24.	Kurubhata	Mand	GDSQ		
			Gauge	01-10-1977	31-05-2012
			Discharge	01-10-1977	31-05-2012
			Sediment	01-01-2010	31-05-2020
			Water quality	01-01-2010	02-03-2020
25.	Mahulpali	Bheden	GD		
			Gauge	01-07-2005	31-03-2012
			Discharge	01-07-2005	31-03-2012
26.	Manendragarh	Hasdeo	GDSQ		
			Gauge	21-06-1987	10-04-2011
			Discharge	21-06-1987	10-04-2011
			Sediment	01-01-2010	30-05-2020
			Water quality	01-01-2010	02-03-2020
27.	Parmanpur	Bheden	GD		
			Gauge	01-10-1988	31-05-2012
			Discharge	01-10-1988	31-05-2012
28.	Pathardhi	Kharun	GDSQ		
			Gauge	01-06-1987	31-08-2011
			Discharge	01-06-1987	31-08-2011
			Sediment	01-01-2010	30-06-2020
			Water quality	01-01-2010	01-05-2019
29.	Rajim	Mahanadi	GDSQ		
			Gauge	01-02-1971	30-09-2011
			Discharge	01-02-1971	30-09-2011
			Sediment	01-01-2010	31-06-2020
			Water quality	01-01-2010	01-05-2019
30.	Sankara	Jonk	GD		
			Gauge	01-06-1987	31-08-2011
			Discharge	01-06-1987	31-08-2011
31.	Seorinarayan	Mahanadi	GDSQ		
			Gauge	01-06-1985	31-05-2011

			Discharge	01-06-1985	31-05-2011
			Sediment	01-01-2010	31-05-2020
			Water quality	01-05-2016	02-03-2020
32.	Simga	Seonath	GDSQ		
			Gauge	01-07-1971	30-09-2011
			Discharge	01-07-1971	30-09-2011
			Sediment	01-01-2010	30-06-2020
			Water quality	01-01-2010	01-05-2019

4. Conclusions and Recommendations

Hydrological data plays an essential role in the study and management of water resources. It enables informed decision-making in areas such as flood management, drought response, climate change adaptation, and environmental protection. By continuously improving data collection methods and using advanced technologies like remote sensing, we can enhance our understanding of water systems and improve the management of vital water resources globally. In summary, hydrological data is fundamental to effectively managing and assessing the condition of river basins, ensuring sustainable water use, and safeguarding against the impacts of climate variability and human activities.

4.1. Summary of Findings

- The study of **soil data** demonstrates the significant variability in soil texture within the Mahanadi River Basin. By leveraging USDA classification and HWSD v2.0 data, the findings provide valuable insights for hydrological modelling, agricultural planning, and sustainable watershed management.
- **Land use/ land cover** analysis suggests that **a**griculture is the most dominant land use in the basin, with significant coverage of 40.86% in the middle and lower reaches. Forests occupy a substantial portion of 28.77%, mainly concentrated in the upper basin regions of Chhattisgarh and Odisha. Rapid urbanization, particularly around Bhubaneswar and Raipur, contributes to increased impervious surfaces, affecting runoff patterns.
- **Data Gap and Uncertainty:** It can significantly affect the accuracy and reliability of water resource management, environmental assessments, and decision-making processes.

Table 8. Data Gaps and Uncertainty

S. No.	Data	Data Received or Available Online	Data Gaps/ Uncertainty Identified
1	Digital Elevation Model (DEM)	Available and mapped for 30 m and 12.5 m resolution	Finer Resolution data of the MRB.
2	Land Use Land Cover (LULC) Data	Available and mapped for 10 m resolution	Finer Resolution data of the MRB.
3	Soil Data	Mapped based on USDA soil texture classification, which categorizes soils into 12 classes based on the proportion of sand, silt, and clay.	**Concern:** Which source to rely on as Soil data is available from different sources.
4	Hydrological Monitoring Data	GD (01-08-1971 to 31-12-2012), SQ (01-01-2010- 30-05-2020)	GD(2012-2024), SQ (2020-2024).
5	Hydrological Cycle Components	Precipitation (1901 – 2023), Temperature (1951 – 2023)	Recent year data not available from 2023-2024.
6	Groundwater Level	05 Jan 1994 - 24 May 2024 (India- WRIS)	Past records before 1994 not available.
7	Sediment Load	01 Jan 2010- 30 May 2020	Recent year data not available from 2020-2024.

- **Significance of Report**: Hydrological data is crucial for assessing the health and sustainability of the Mahanadi River Basin. This data supports effective management planning, guiding decisions on water allocation, irrigation, flood control, and environmental protection, while promoting sustainable resource use and long-term ecological balance.
- **Stakeholder Engagement**:
  - ✓ **Government Agencies:** Their role is to regulate water usage, establish legal frameworks, and ensure sustainable practices are followed.
  - ✓ **Local Communities:** They provide valuable insights into local water challenges, and their engagement is crucial in designing sustainable solutions that benefit them directly.

- ✓ **Farmers and Irrigation Associations:** Engaging them in discussions about water availability, flood risks, and droughts helps optimize water allocation and prevent over-exploitation.
- ✓ **Environmental Groups:** NGOs and environmental organizations focus on preserving biodiversity and protecting ecosystems in and around the river. Their input is vital for ensuring that management plans promote ecological balance and environmental conservation.
- ✓ **Academia and Research Institutions:** Universities and research bodies contribute technical expertise in hydrological modelling, data analysis, and climate change impact studies. Their involvement enhances the scientific foundation of management plans.

4.2. Recommendations for Further Work

Data gaps hinder effective decision-making on water allocation, flood control, and drought management, potentially leading to resource mismanagement and ecological damage. To ensure sustainable water use and ecosystem protection, it is crucial to fill these data gaps by improving monitoring systems and data collection, enabling informed and effective management strategies.

- ➢ Hydrological Implications of **land use/ land cover** data**:**
  - The extensive agricultural land use highlights the need for efficient irrigation practices to minimize water losses.
  - Forest cover in the upper basin acts as a critical zone for groundwater recharge and erosion control.
  - Urbanization trends suggest a growing need for storm-water management to prevent flooding in downstream areas.
- ➢ Using **soil** data following works can be done ahead:
  - Develop targeted soil and water conservation strategies in erosion-prone areas.
  - Promote crop selection based on soil texture and water availability.
  - Implement integrated watershed management plans considering soil texture variability.

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- Japan Aerospace Exploration Agency (JAXA)
- Harmonized World Soil Database (HWSD)
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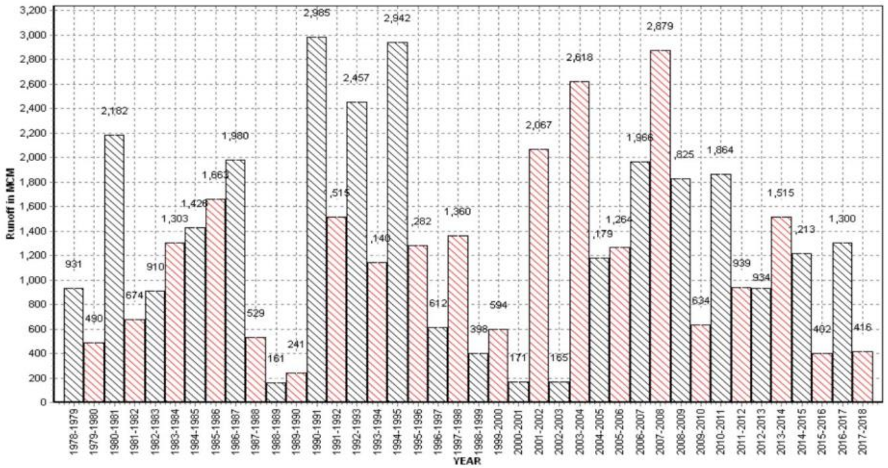
- India Water Resource Information System (WRIS)

References

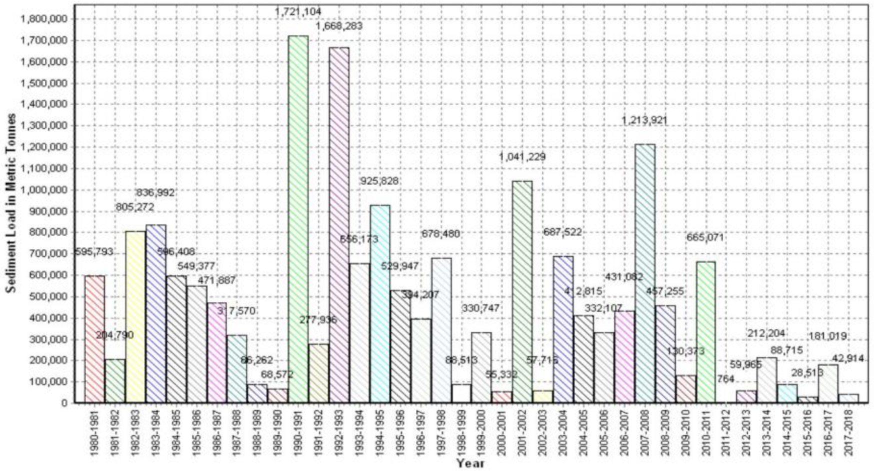
1. Abbott, M. B., Refsgaard, J. C., & Rosbjerg, D. (1986). *Hydrological Modelling in the Uplands: Conceptual Models for Streamflow Prediction*. Springer.
2. Barnett, T. P., Adam, J. C., & Lettenmaier, D. P. (2005). *Potential impacts of a warming climate on water availability in snow-dominated regions*. Nature, 438(7066), 303-309.
3. Beven, K. (2012). *Rainfall-Runoff Modelling: The Primer*. John Wiley & Sons.
4. Beven, K. J., & Kirkby, M. J. (1979). A physically based, variable contributing area model of basin hydrology. *Hydrological Sciences Bulletin*, 24(1), 43–69.
5. Bureau of Reclamation. (2016). *Water Measurement Manual*. U.S. Department of the Interior.
6. Chahine, M. T. (1992). The hydrological cycle and climate change. *Nature*, 359(6394), 190-193.
7. Chow, V. T., Maidment, D. R., & Mays, L. W. (1988). *Applied Hydrology*. McGraw-Hill.
8. EPA (2018). *National Water Quality Inventory: Report to Congress*. United States Environmental Protection Agency.
9. Fell, R., MacGregor, P., & Stapledon, D. (2008). Geotechnical Engineering of Dams. *CRC Press*.
10. Feng, Z., Liu, L., & Zhang, X. (2021). Hydrological simulation using DEM-based terrain models: Impact on water movement and groundwater recharge. *Water Resources Research*, 57(2), e2020WR028879.
11. Foster, S., & Hirata, R. (2014). *Groundwater and Climate Change: Impacts and Adaptation Strategies*. CRC Press.
12. Gallant, J. C., & Wilson, J. P. (2000). Primary topographic attributes. *In: Terrain Analysis: Principles and Applications* (pp. 51-85). Wiley.
13. González, M., Sarma, K., & Ballesteros, M. (2019). Impact of climate change on hydrological systems in mountain regions using DEM-based models. *Environmental Modeling & Assessment*, 24(3), 427-440.
14. Herschy, R. W. (1995). *Streamflow Measurement*. Wiley.
15. IPCC (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge University Press.
16. Jenson, S. K., & Domingue, J. O. (1988). Extracting topographic structure from digital elevation models. *Photogrammetric Engineering & Remote Sensing*, 54(11), 1593–1600.
17. Kundzewicz, Z. W., & Takeuchi, K. (2005). *Flood risk and climate change: Global and regional perspectives*. Hydrological Sciences Journal, 50(3), 347-355.
18. Kundzewicz, Z. W., et al. (2007). *Changes in flood hazard and risk due to climate change*. Journal of Hydrology, 323(1), 1-4.
19. Lamb, R., Zhang, X., & Ho, Y. (2022). Assessing the impact of climate change on flood risks using DEM-based flood models. *Climate Risk Management*, 34, 100348.
20. Levizzani, V., et al. (2018). *Remote sensing of precipitation and its role in hydrological modelling*. Springer.
21. McMahon, T. A., et al. (2007). *Streamflow and water quality monitoring*. In "Applied Hydrology," (Chow et al., Eds.), McGraw-Hill.
22. Melton, M. A. (1957). An analysis of the relations among elements of climate, surface properties, and runoff. *U.S. Geological Survey Professional Paper*, 282-C.
23. Milly, P. C. D., Dunne, K. A., & Vecchia, A. V. (2008). *Global pattern of trends in streamflow and water availability in a changing climate*. Nature, 438(7066), 347-350.
24. Mishra, A. K., & Singh, V. P. (2010). *Droughts: A Global Assessment*. Springer.
25. Moore, I. D., Grayson, R. B., & Ladson, A. R. (2015). Digital elevation models in hydrology: Applications and limitations. *Hydrological Processes*, 29(12), 3001-3010.

26. Niemeyer, I., Ritter, R. A., & Nascimento, M. A. (2020). DEM-based hydrological models and water availability predictions under climate change scenarios. *Journal of Hydrology*, 586, 124861.
27. Parker, G. (1991). Selective sorting and abrasion of river gravel. *Science*, 246(4936), 1336-1341.
28. Peters, M., Bhowmik, R., & Johnson, J. (2017). The role of discharge data in hydrological modeling and water resource management. *Journal of Hydrology*, 550, 397-407.
29. Poff, N. L. R., et al. (1997). *The natural flow regime: A paradigm for river conservation and restoration*. BioScience, 47(11), 769-784.
30. Ponce, V. M. (2013). *Hydrology: Principles, Analysis, and Design*. Prentice Hall.
31. Priestley, C. H. B., & Taylor, R. J. (1972). On the assessment of surface heat flux and evaporation using large-scale parameters. *Monthly Weather Review*, 100(2), 81-92.
32. Ramos-Scharrón, C. E., & MacDonald, L. H. (2007). Runoff and sediment production in a tropical dry forest watershed in Puerto Rico. *Journal of Hydrology*, 334(1), 57-69.
33. Ribbe, L., Gräfe, C., & Born, S. (2010). *Hydrological Modeling and Integrated Water Resources Management*. Springer.
34. Robock, A., et al. (2000). *The global soil moisture data set*. Journal of Geophysical Research, 105(D1), 20739-20749.
35. Scanlon, B. R., Jolly, I., & Sophocleous, M. (2006). Global impacts of land use changes on groundwater resources. *Journal of Hydrology*, 323(1), 257-275.
36. Semenov, M. A., et al. (2010). *Impacts of climate change on agricultural productivity in the United States*. PNAS, 107(17), 8306-8311.
37. Singh, V. P. (1995). *Computer Models of Watershed Hydrology*. Water Resources Publications.
38. Tockner, K., Malard, F., & Ward, J. V. (2010). *An Ecosystem Perspective of Intermittent Rivers and Streams*. Elsevier.
39. Todd, D. K., & Mays, L. W. (2005). *Groundwater Hydrology* (3rd ed.). Wiley.
40. Vörösmarty, C. J., et al. (2000). *Global water resources: Vulnerability from climate change and population growth*. Science, 289(5477), 284-288.
41. Vörösmarty, C. J., McIntyre, P. B., & Gessner, M. O. (2010). *Global threats to human water security and river biodiversity*. Nature, 467(7315), 555-561.
42. Walling, D. E. (2006). Human impact on land-ocean sediment transfer by the river system. *Philosophical Transactions of the Royal Society A*, 364(1845), 2185-2201.
43. Wang, L., Li, X., & Zhang, L. (2001). Runoff prediction using GIS-based hydrological modeling techniques. *Water Resources Management*, 15(3), 159-174.
44. Wilson, J. P., & Gallant, J. C. (2000). Terrain Analysis: Principles and Applications. *Wiley*.
45. World Meteorological Organization (2018). *WMO Integrated Global Observing System (WIGOS)*. WMO, Geneva.
46. Zhu, Y., Cao, W., & Xu, W. (2016). Digital Elevation Models for watershed hydrological analysis: Methodologies and applications. *Environmental Earth Sciences*, 75(14), 1056.

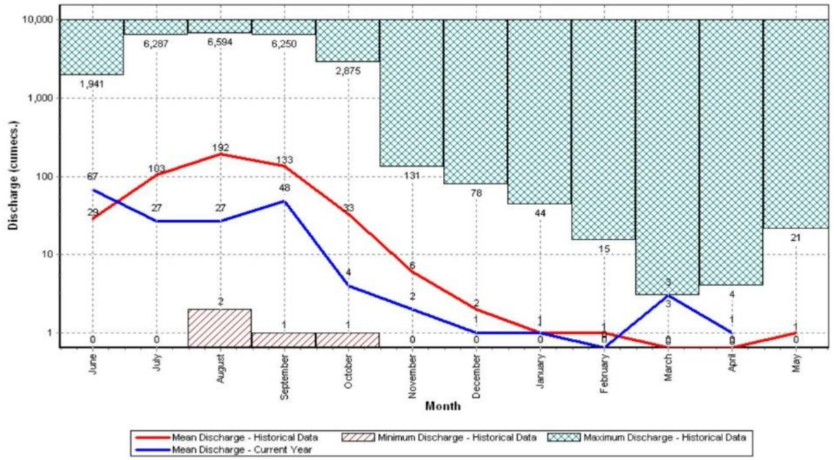


Annual Runoff Values between 1978-2018

Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

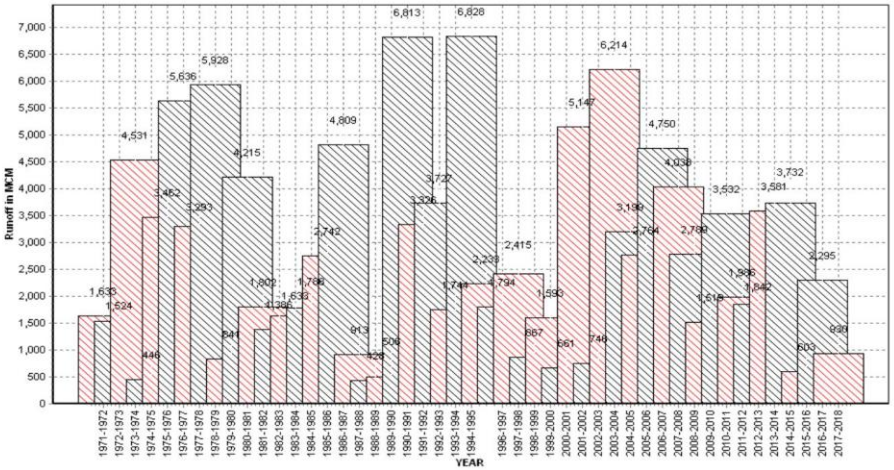


Annual Sediment Load: 1980-2018

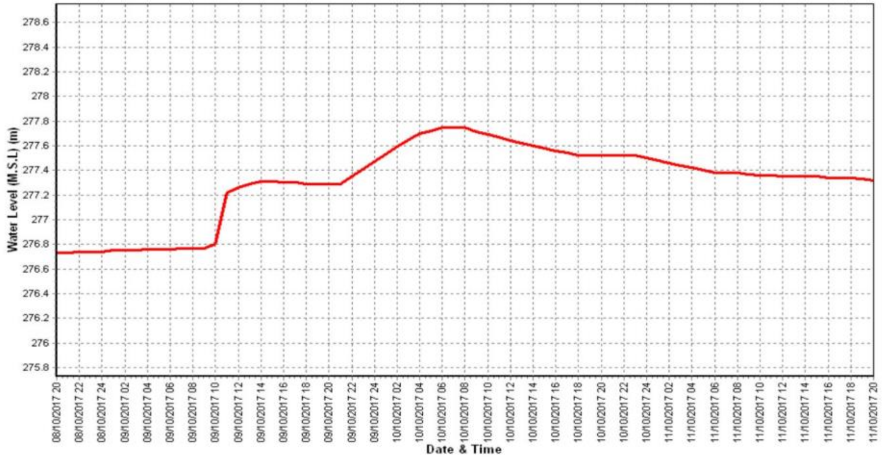


Histogram Hydrograph for the Water Year 2017-18

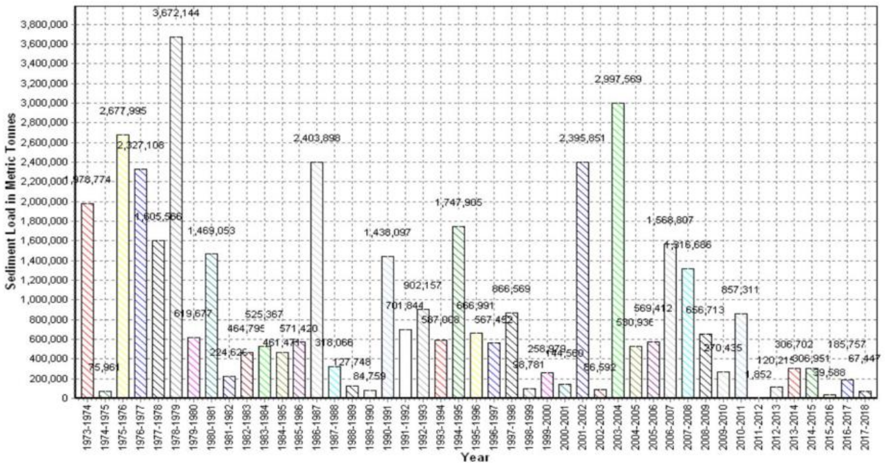
Appendix-II (Hydrological Observations as per CWC, Site: Rajim, Upper Mahanadi Sub Basin)



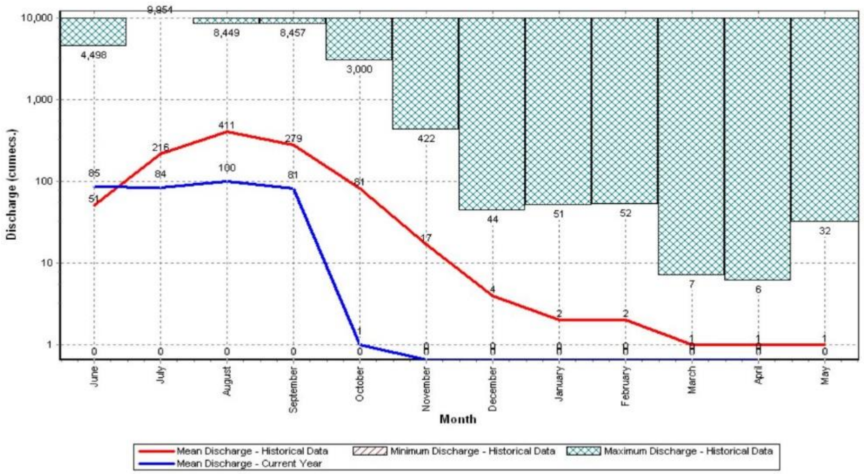
Annual Runoff Values between 1971-2018



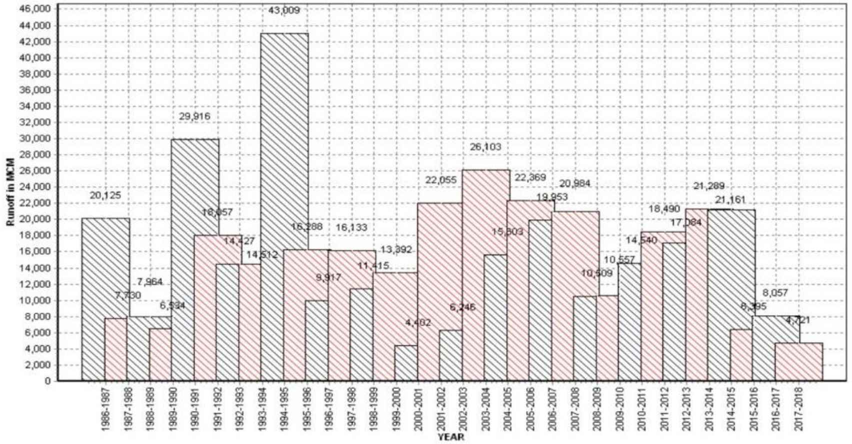
Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018



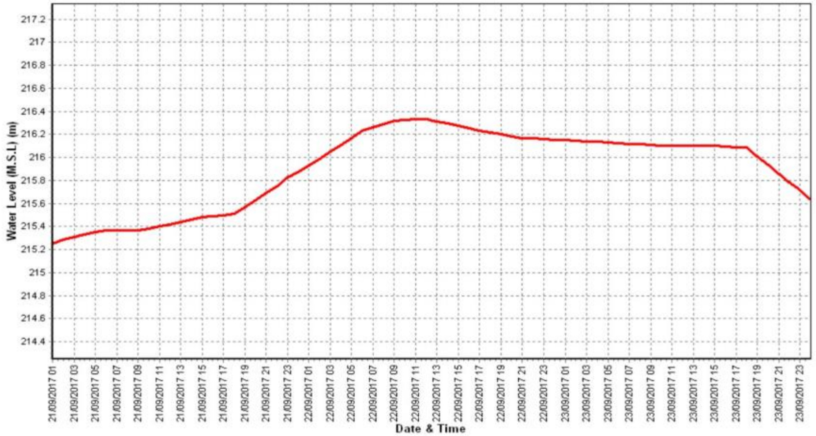
Annual Sediment Load: 1973-2018



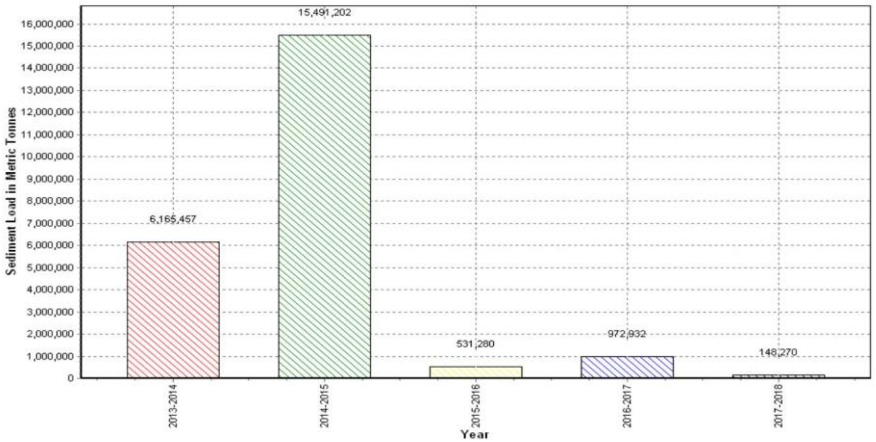
Histogram Hydrograph for the Water Year 2017-18



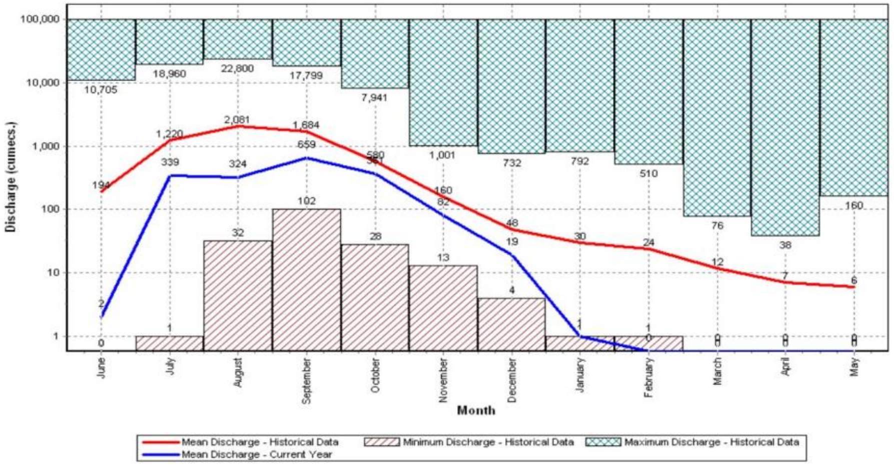
Annual Runoff Values between 1986-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

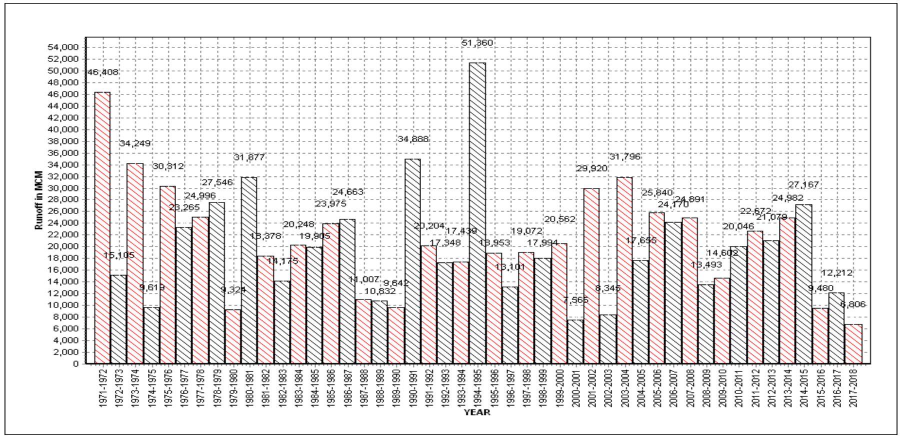


Annual Sediment Load: 2013-2018

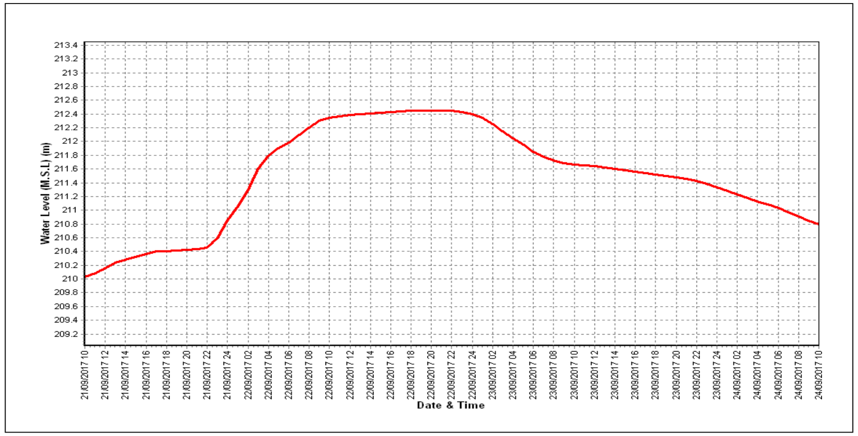


Histogram Hydrograph for the Water Year 2017-18

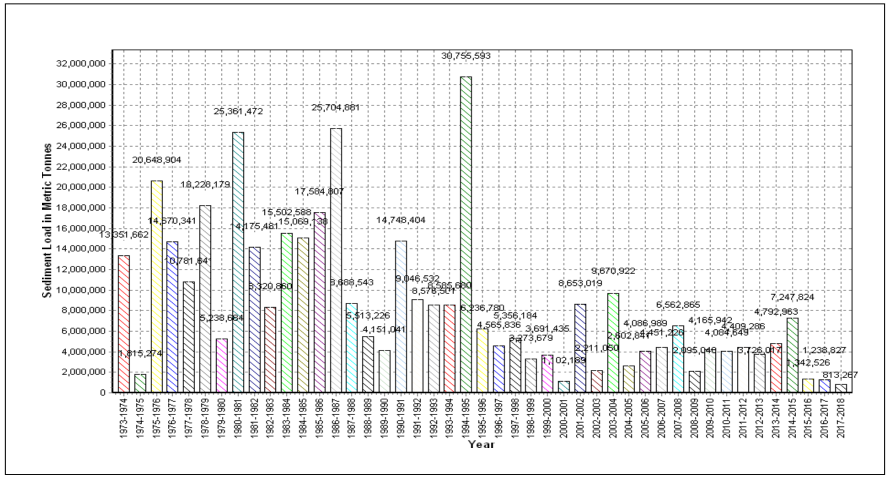
Appendix-IV (Hydrological Observations as per CWC, Site: Basantpur, Mahanadi Sub Basin)



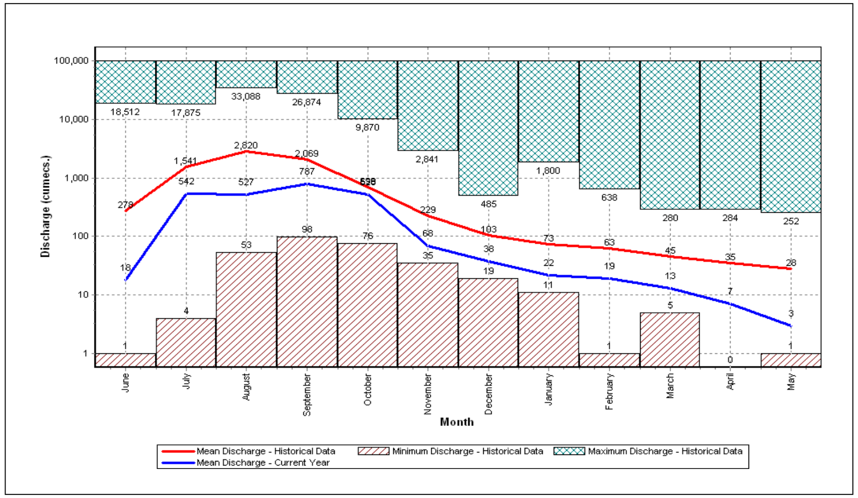
Annual Runoff Values between 1971-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

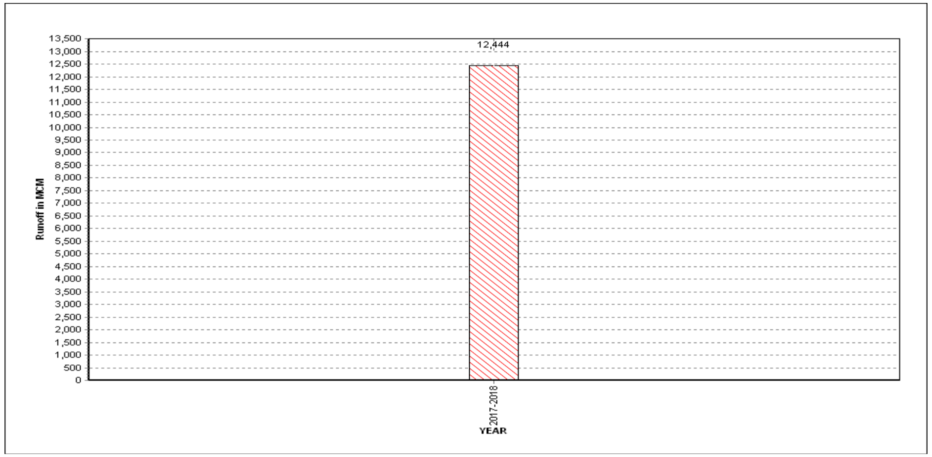


Annual Sediment Load: 1973-2018

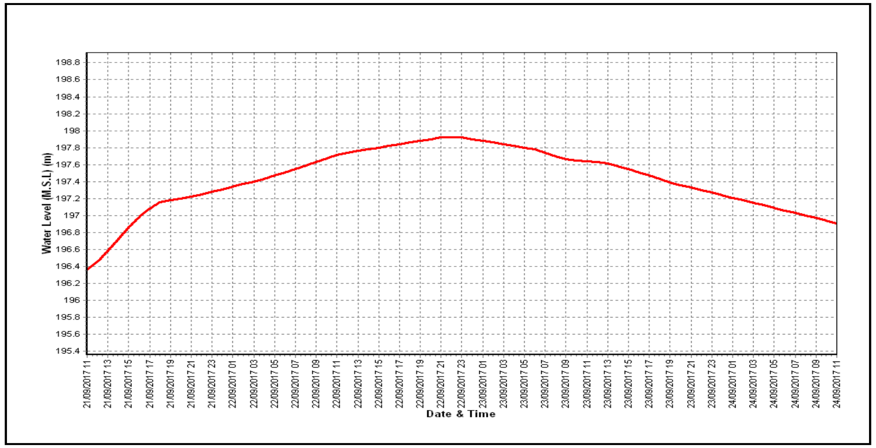


Histogram Hydrograph for the Water Year 2017-18

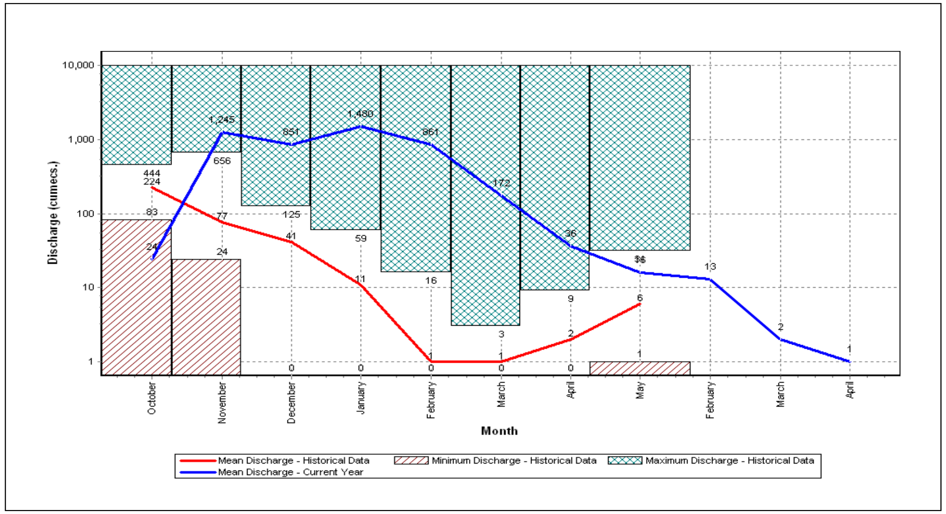
Appendix-V (Hydrological Observations as per CWC, Site: Kalma, Mahanadi Sub Basin)



Annual Runoff Values between 2017-2018

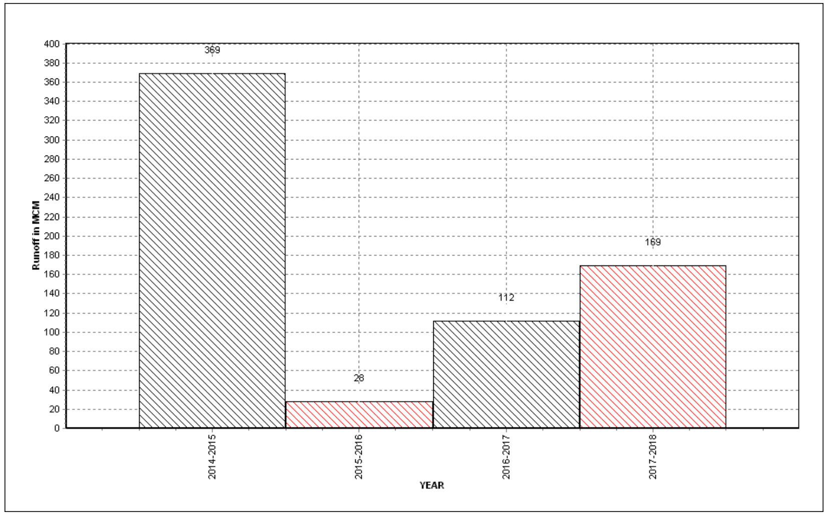


Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

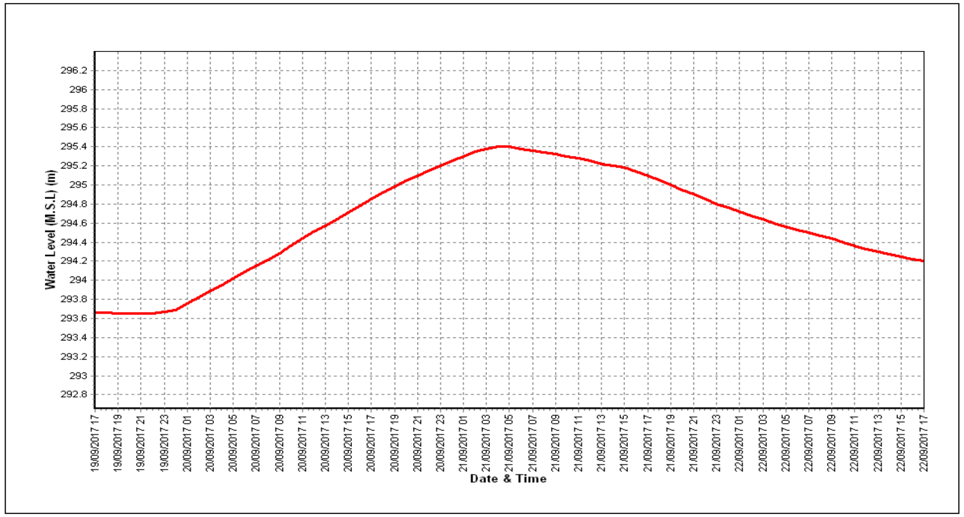


Histogram Hydrograph for the Water Year 2017-18

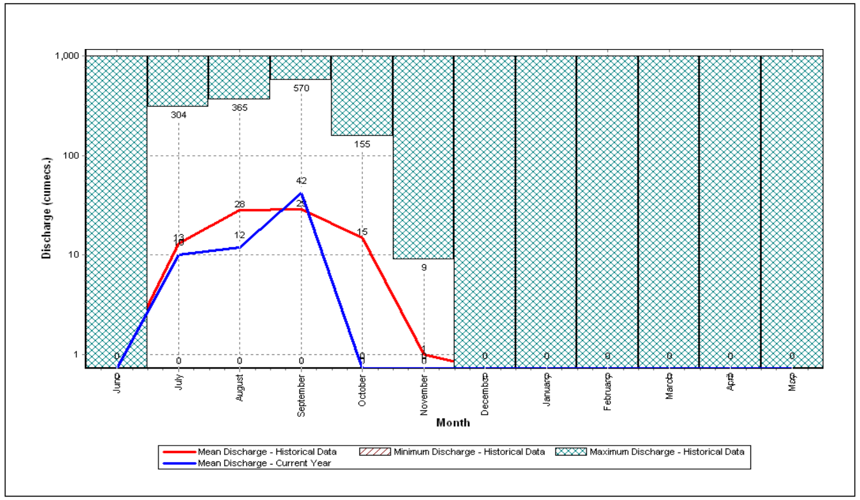
Appendix-VI (Hydrological Observations as per CWC, Site: Gunderdehi, Seonath Sub Basin)



Annual Runoff Values between 2014-2018

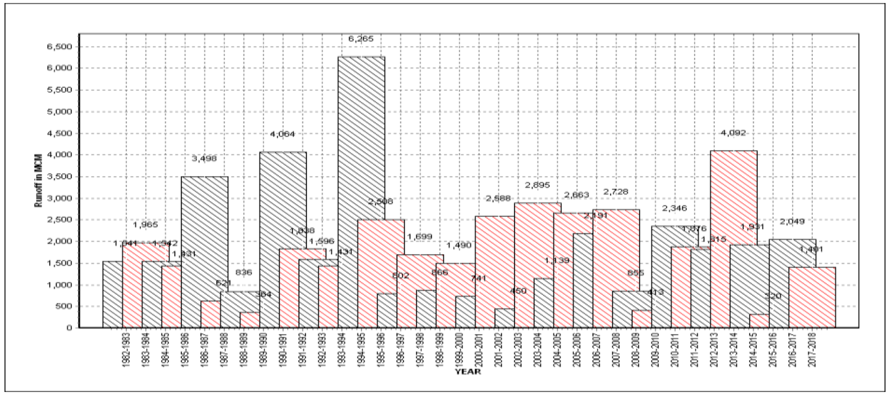


Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

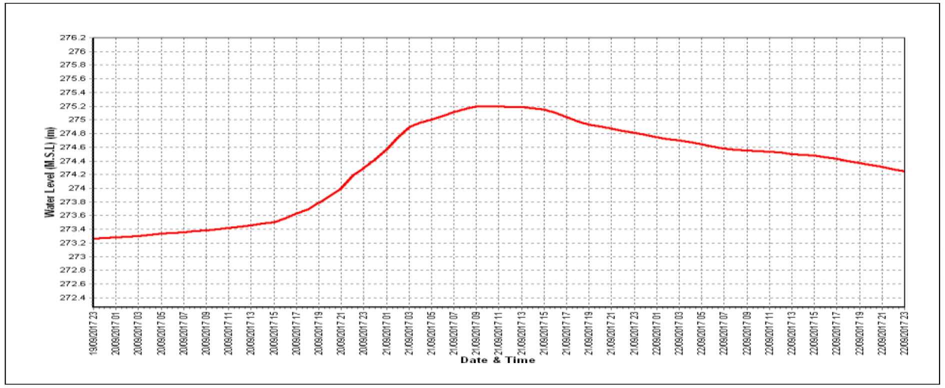


Histogram Hydrograph for the Water Year 2017-18

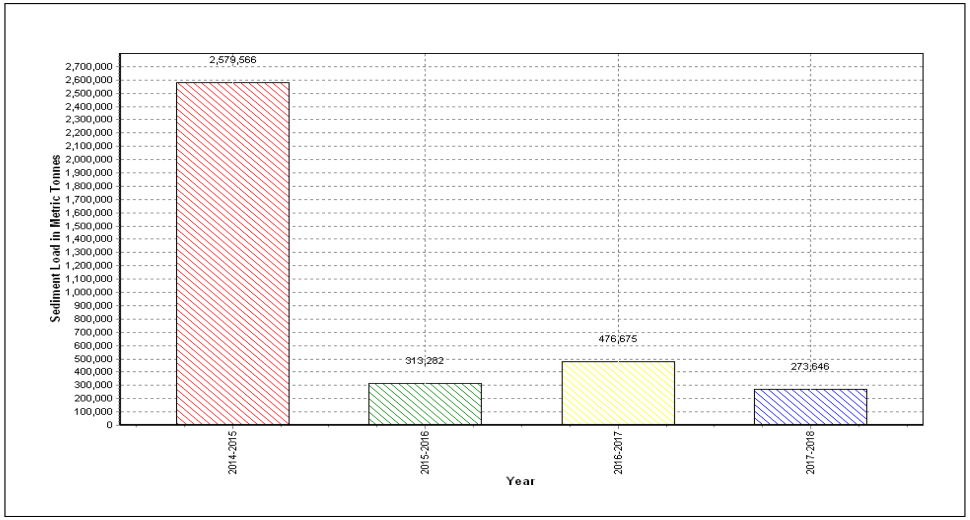
Appendix-VII (Hydrological Observations as per CWC, Site: Kotni, Seonath Sub Basin)



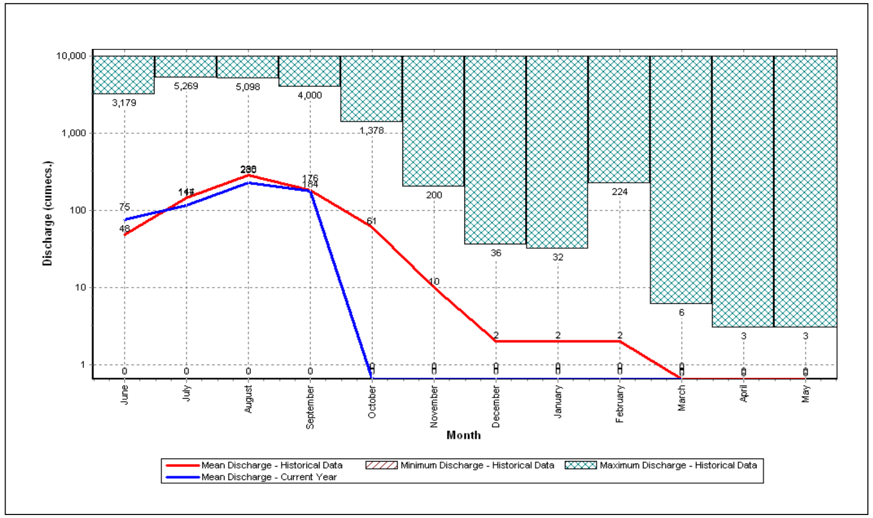
Annual Runoff Values between 1982-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

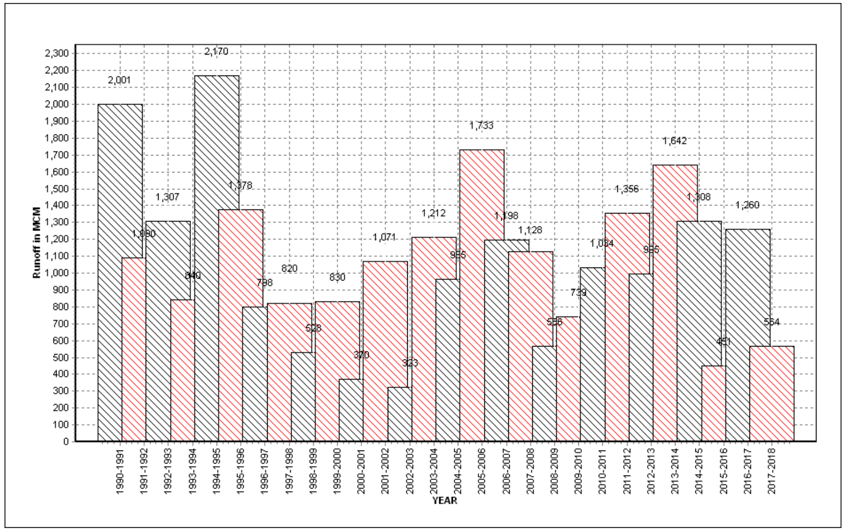


Annual Sediment Load: 2014-2018

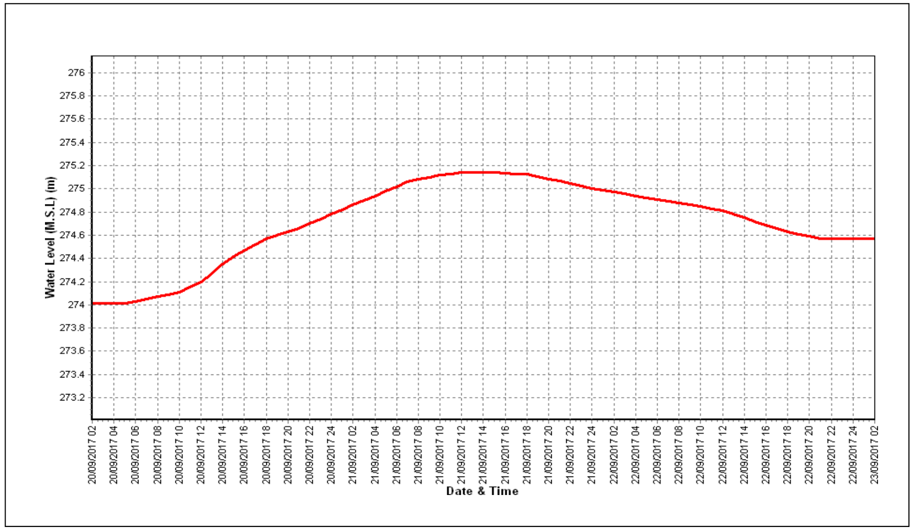


Histogram Hydrograph for the Water Year 2017-18

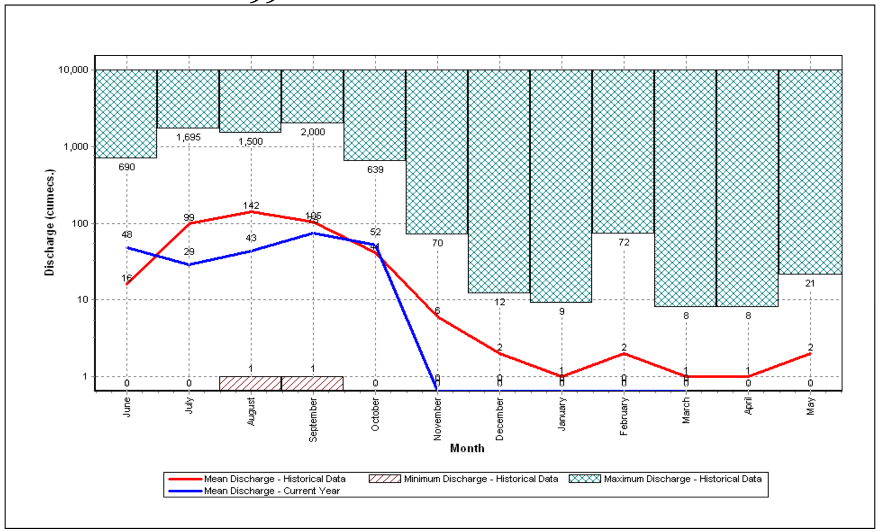
Appendix-VIII (Hydrological Observations as per CWC, Site: Pathardih, Seonath Sub Basin)



Annual Runoff Values between 1990-2018

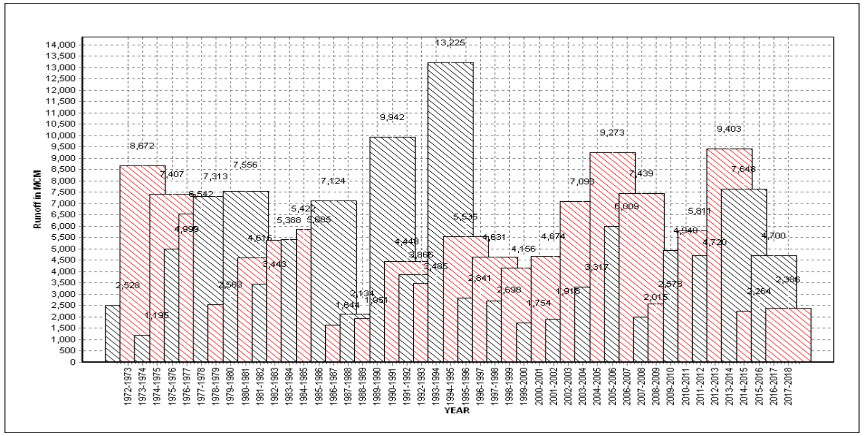


Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

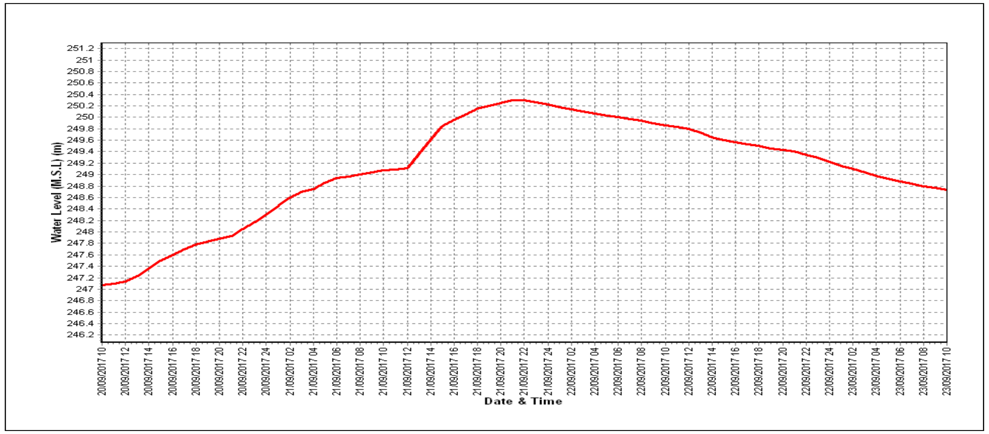


Histogram Hydrograph for the Water Year 2017-18

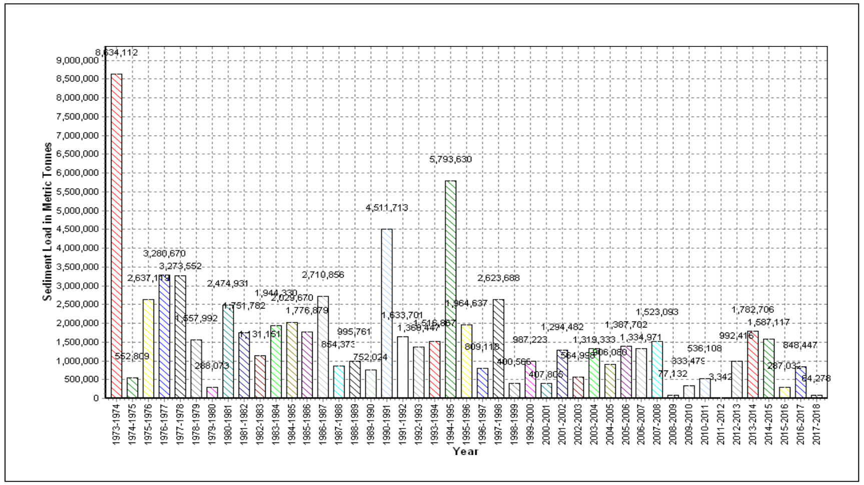
Appendix-IX (Hydrological Observations as per CWC, Site: Simga, Seonath Sub Basin)



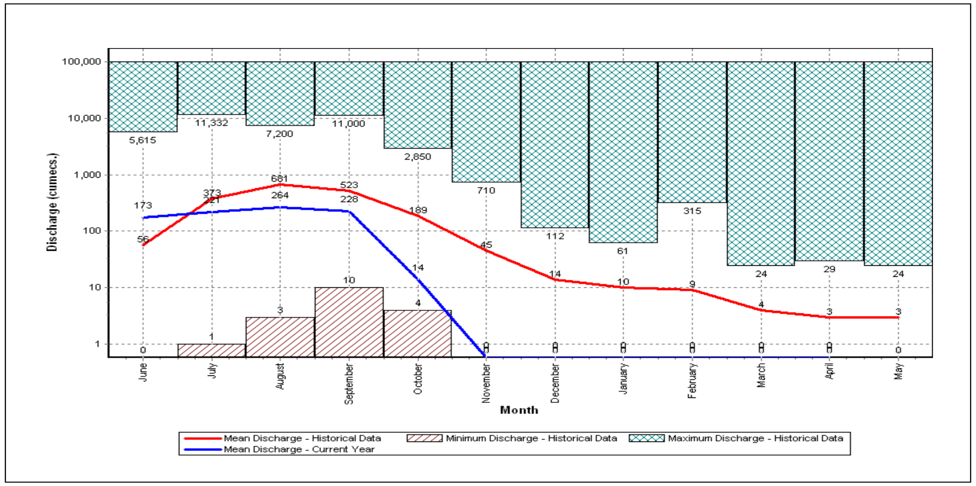
Annual Runoff Values between 1972-2018



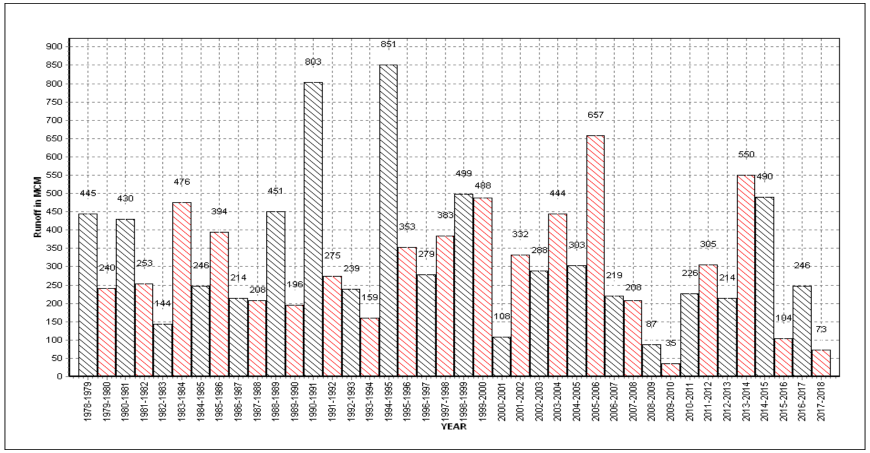
Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018



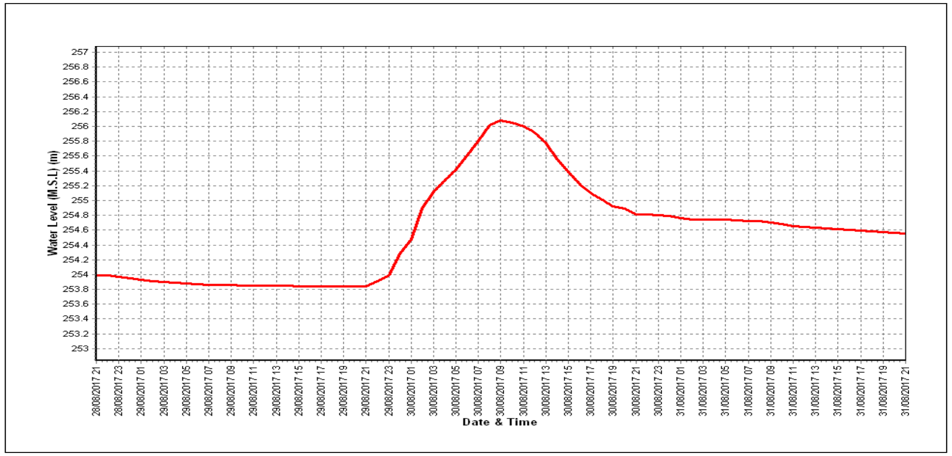
Annual Sediment Load: 2014-2018



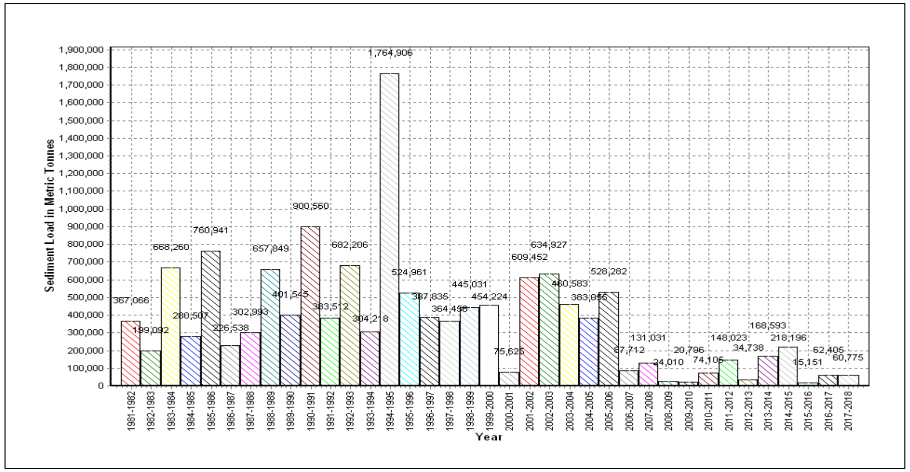
Histogram Hydrograph for the Water Year 2017-18



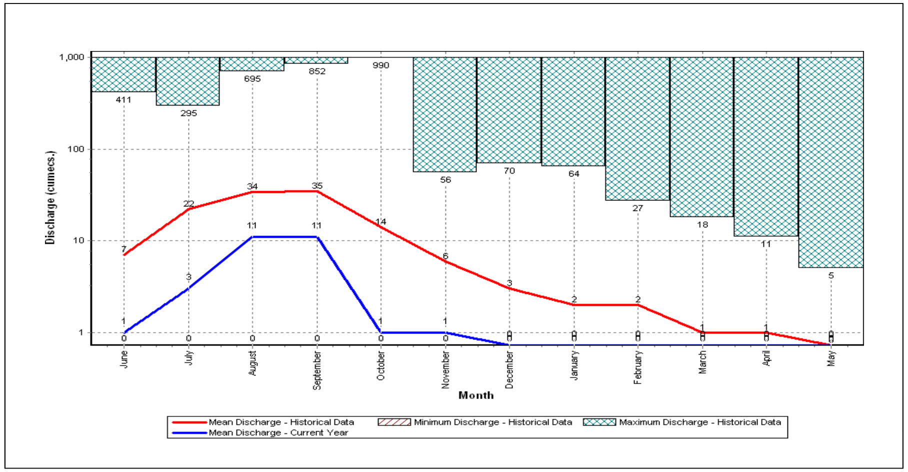
Annual Runoff Values between 1978-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

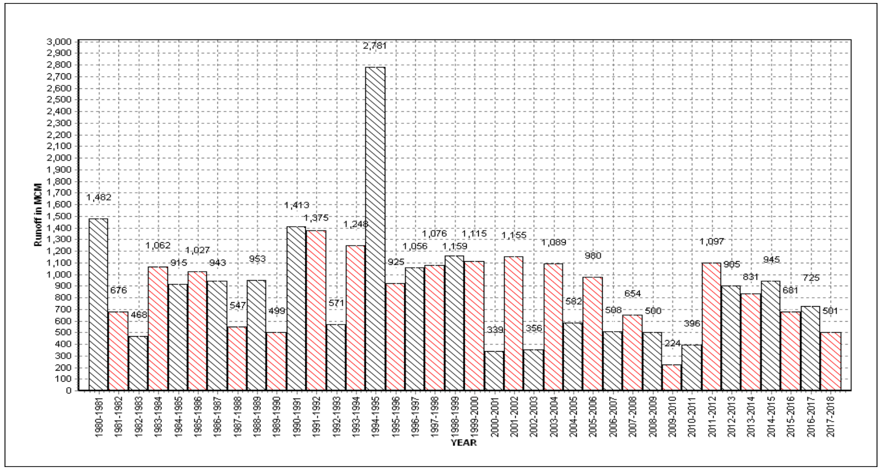


Annual Sediment Load: 1981-2018

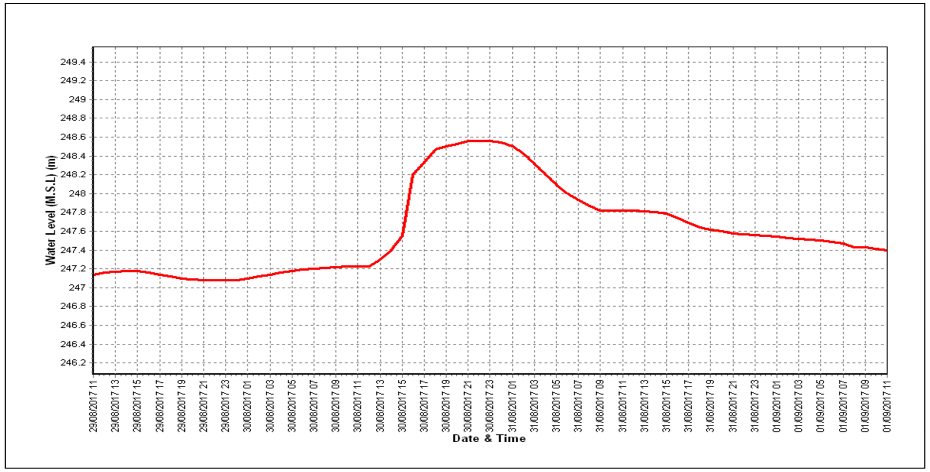


Histogram Hydrograph for the Water Year 2017-18

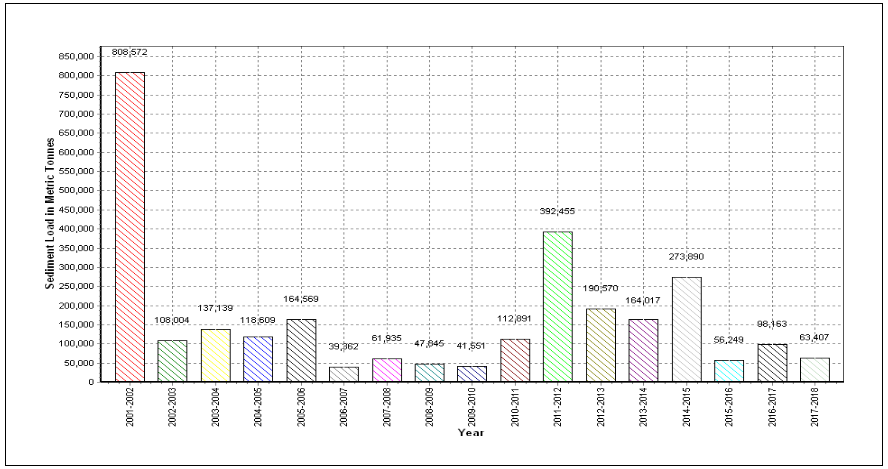
Appendix-XI (Hydrological Observations as per CWC, Site: Ghatora, Seonath Sub Basin)



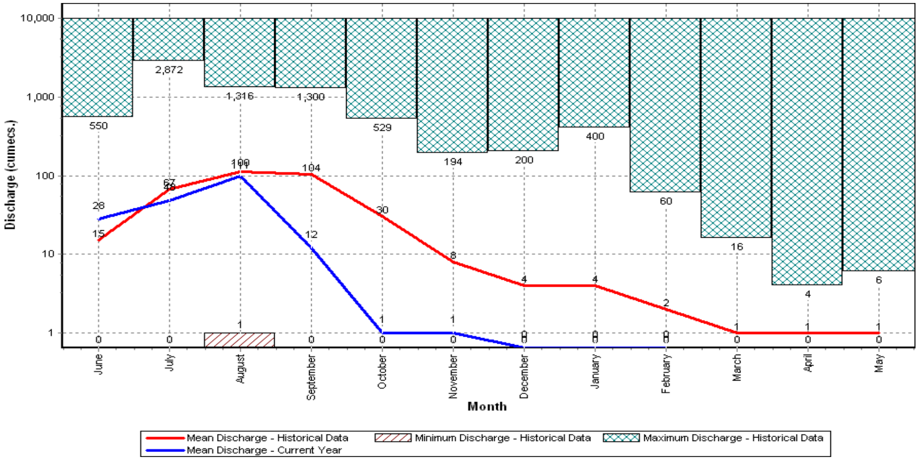
Annual Runoff Values between 1980-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

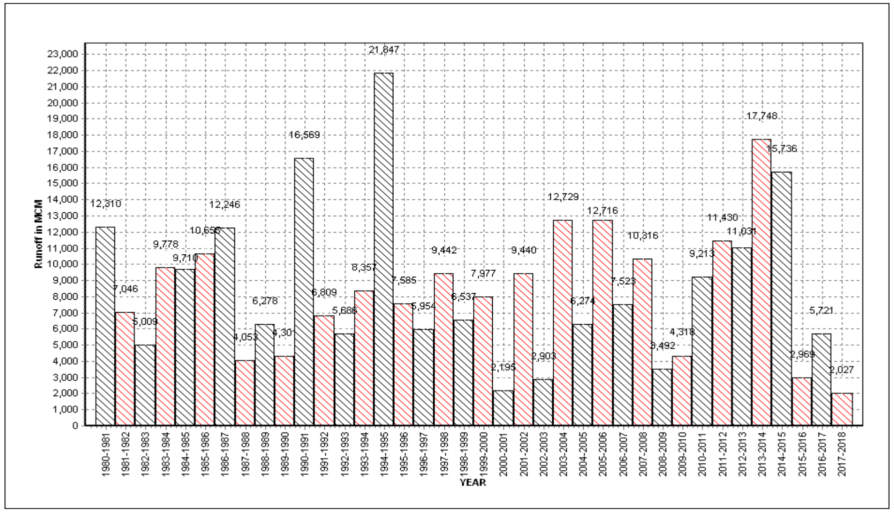


Annual Sediment Load: 2001-2018

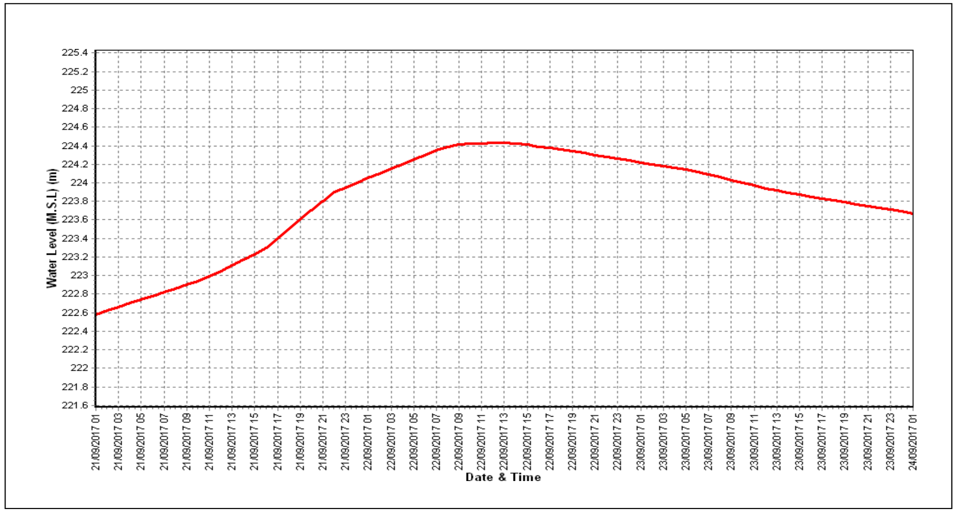


Histogram Hydrograph for the Water Year 2017-18

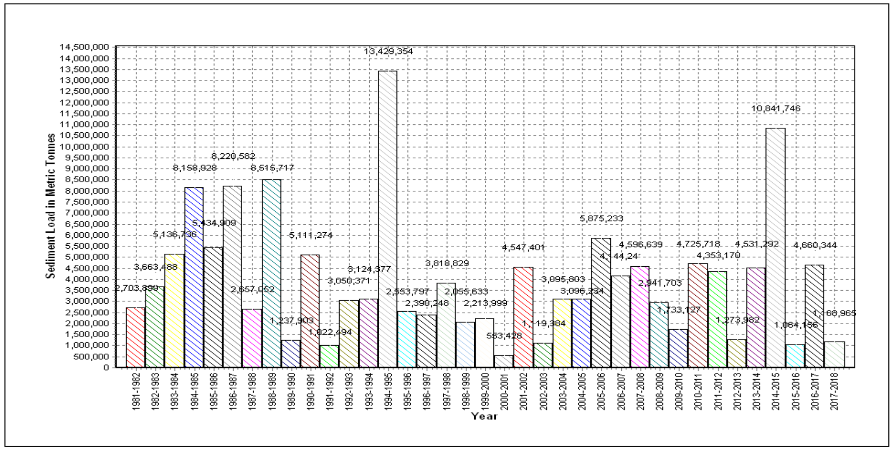
Appendix-XII (Hydrological Observations as per CWC, Site: Jondhra, Seonath Sub Basin)



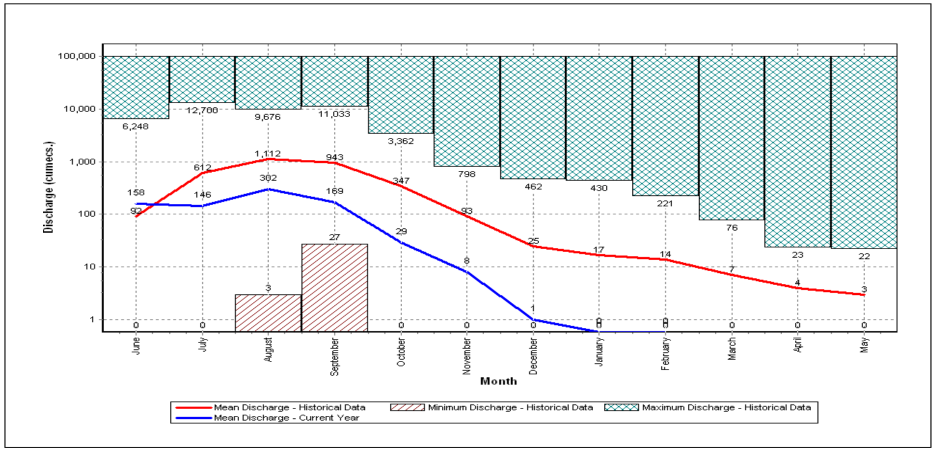
Annual Runoff Values between 1980-2018



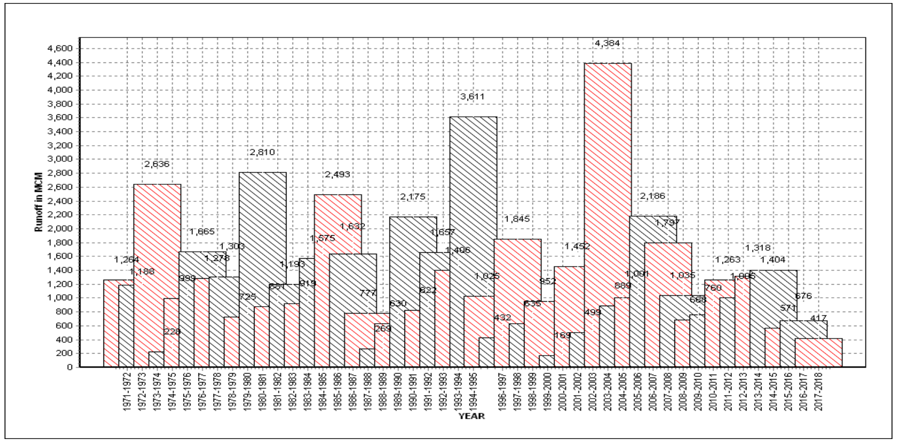
Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018



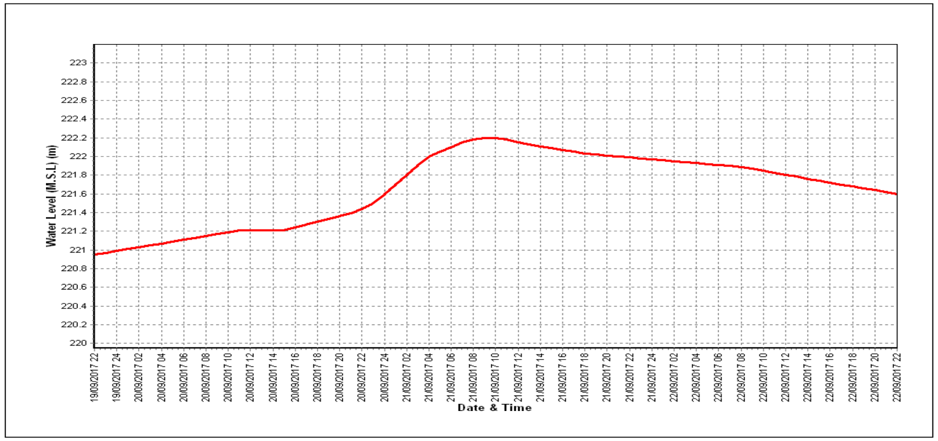
Annual Sediment Load: 1981-2018



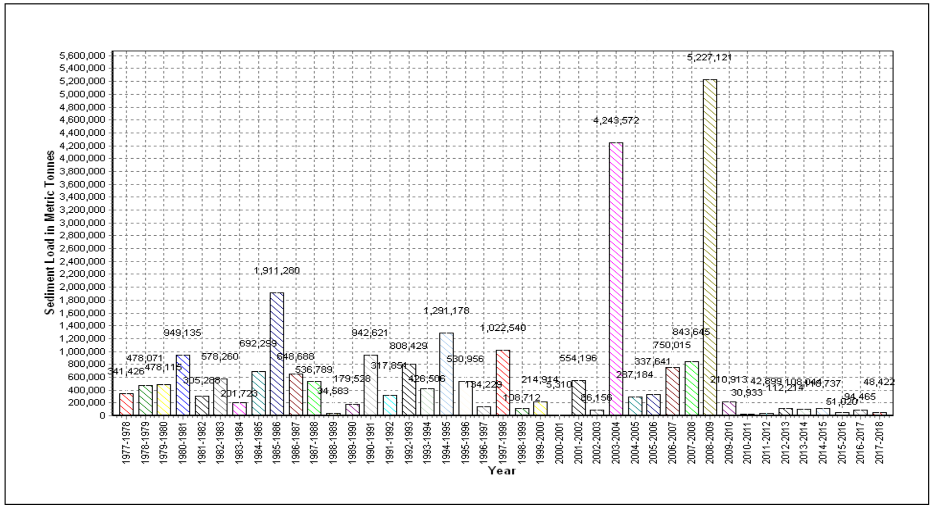
Histogram Hydrograph for the Water Year 2017-18



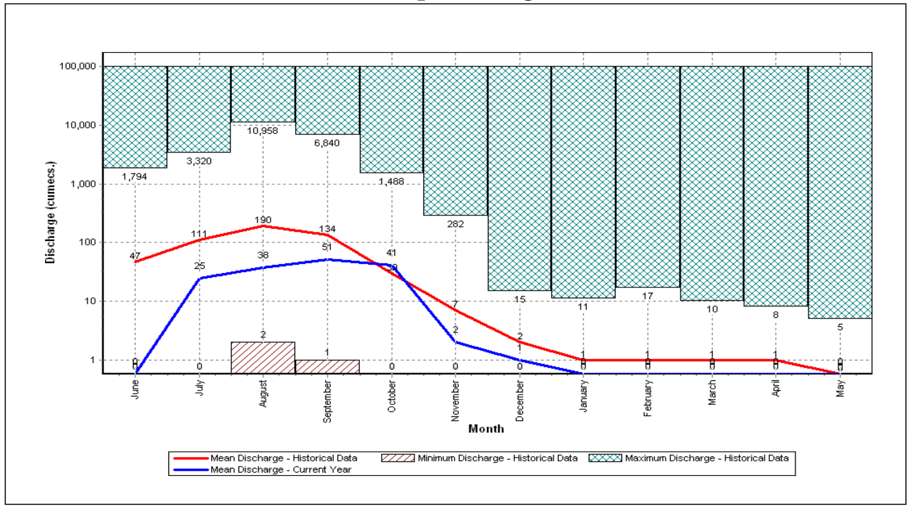
Annual Runoff Values between 1971-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

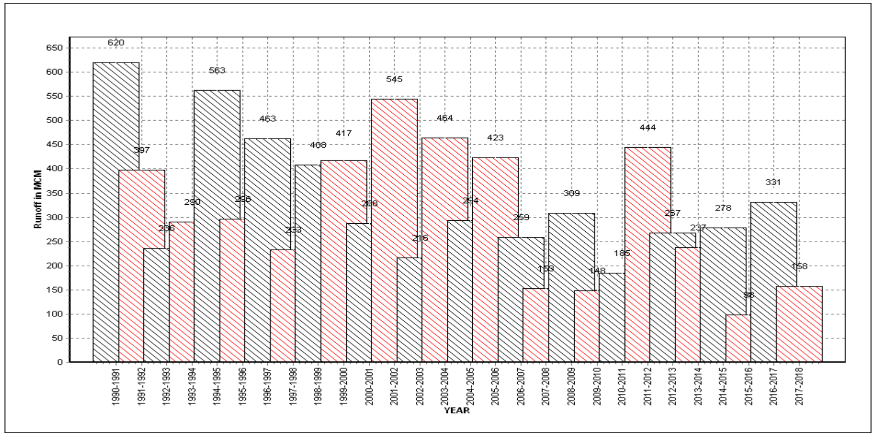


Annual Sediment Load: 1977-2018

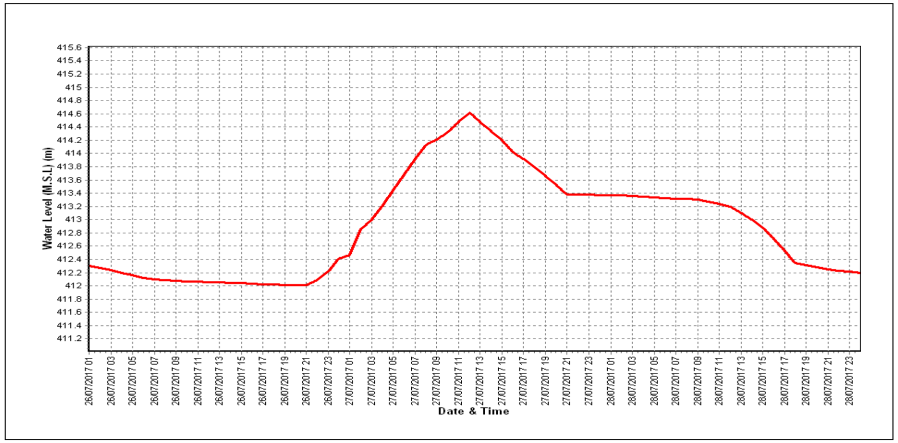


Histogram Hydrograph for the Water Year 2017-18

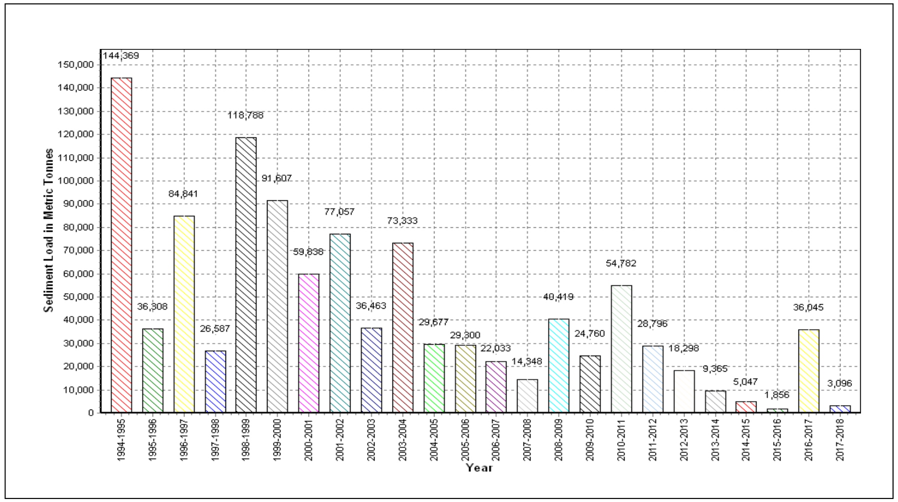
Appendix-XIV (Hydrological Observations as per CWC, Site: Manendragarh, Hasdeo Sub Basin)



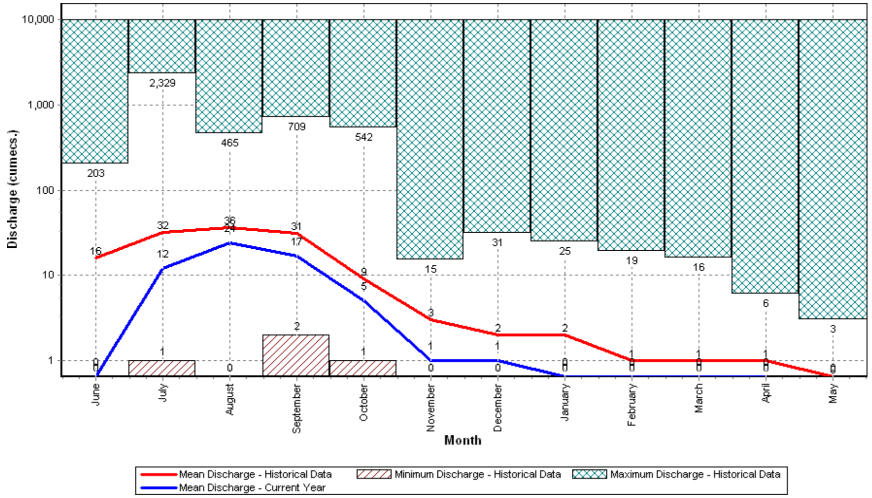
Annual Runoff Values between 1990-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

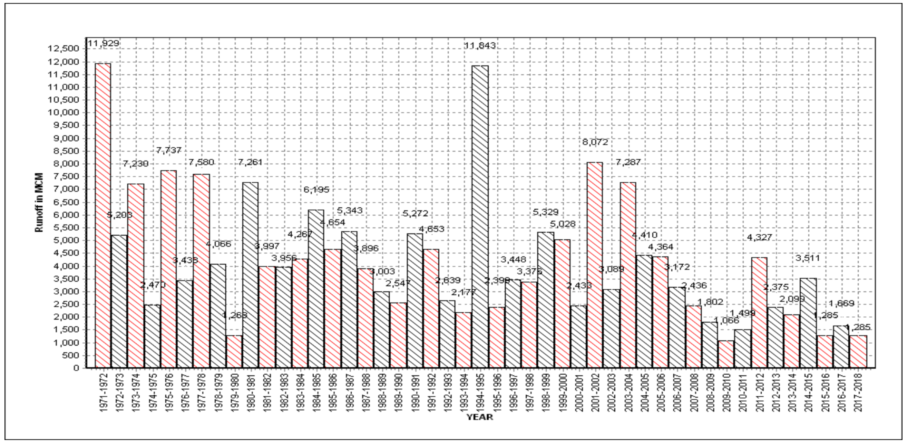


Annual Sediment Load: 1994-2018

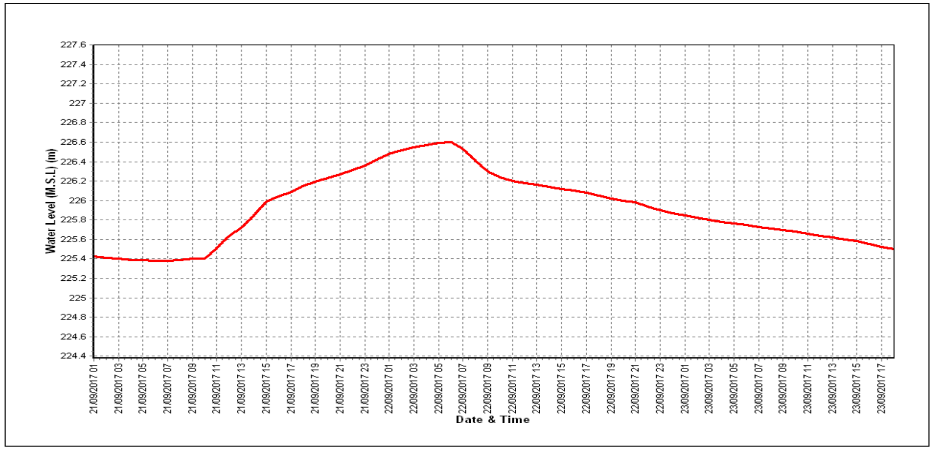


Histogram Hydrograph for the Water Year 2017-18

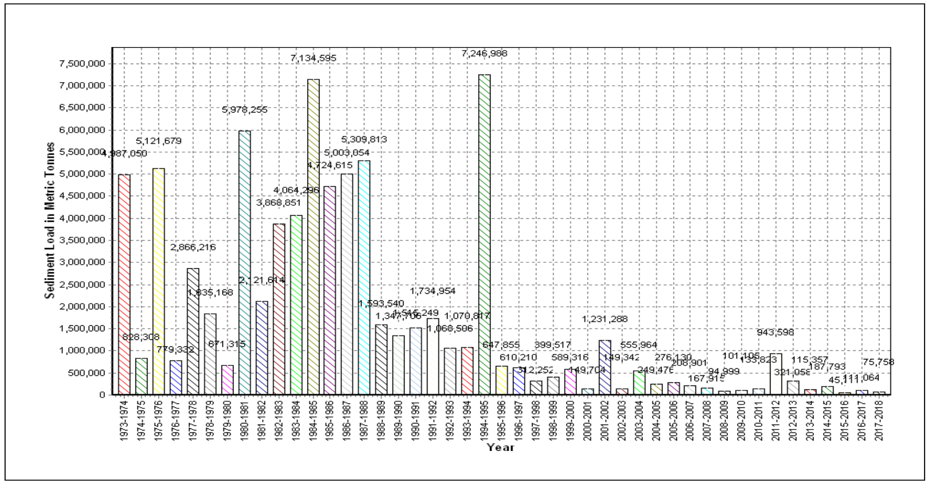
Appendix-XIV (Hydrological Observations as per CWC, Site: Bamnidhi, Hasdeo Sub Basin)



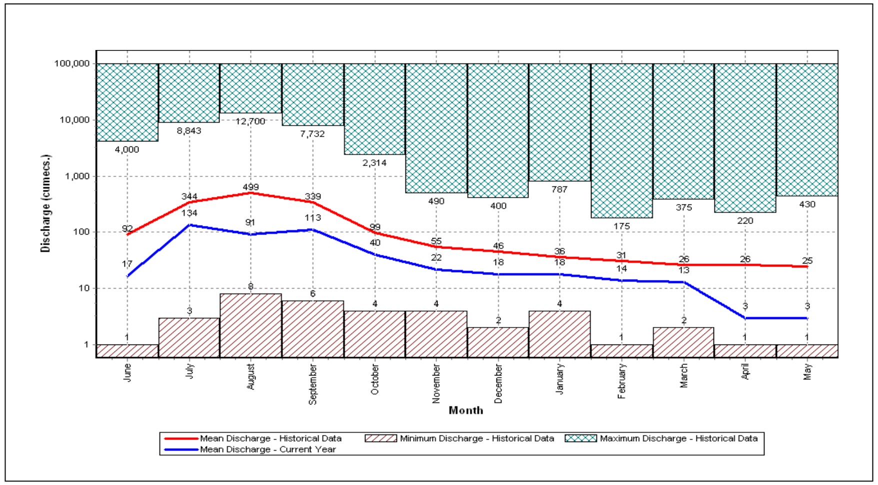
Annual Runoff Values between 1971-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

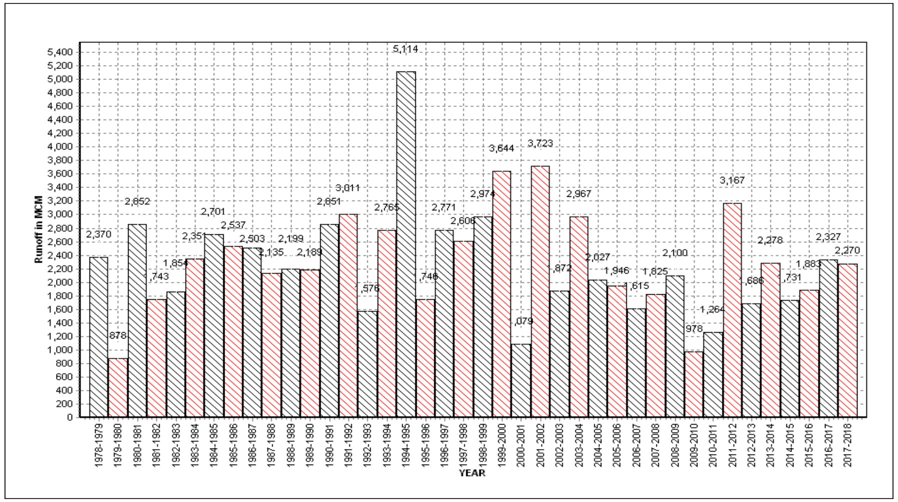


Annual Sediment Load: 1973-2018

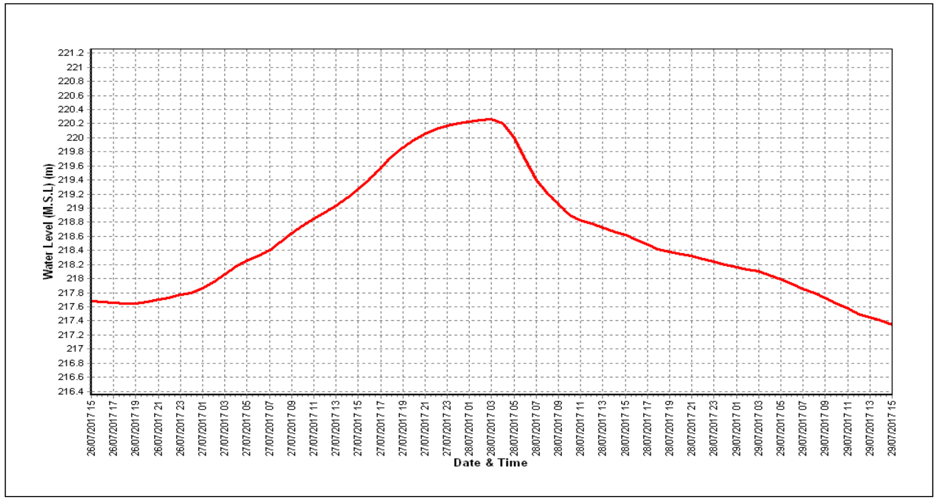


Histogram Hydrograph for the Water Year 2017-18

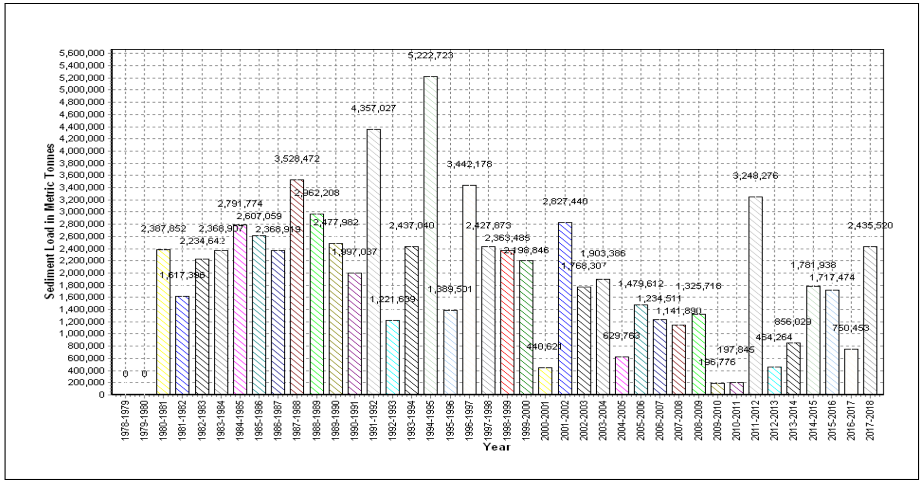
Appendix-XV (Hydrological Observations as per CWC, Site: Kurubhata, Mand Sub Basin)



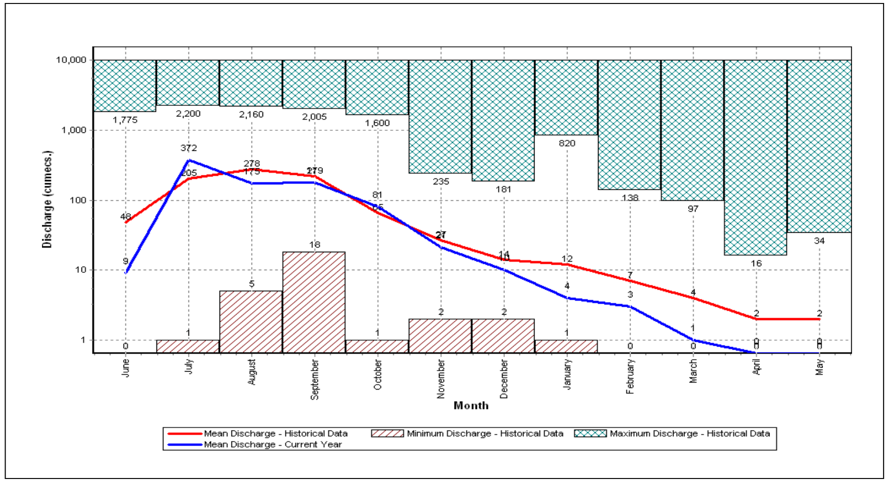
Annual Runoff Values between 1978-2018



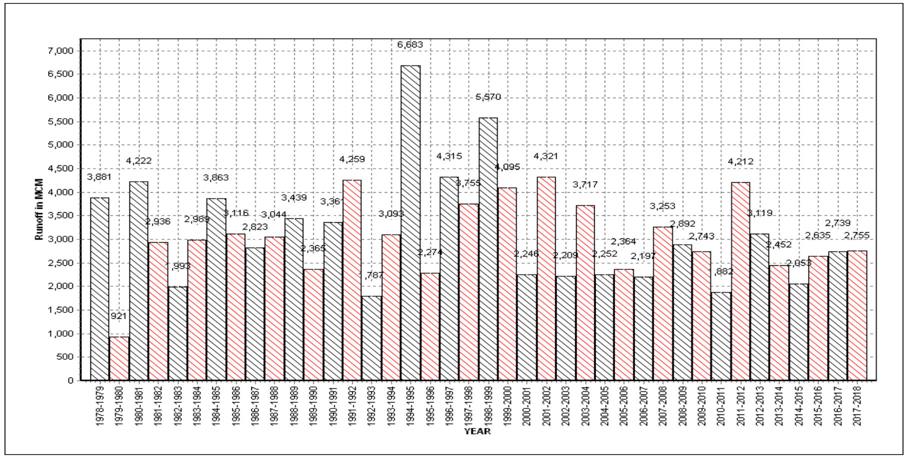
Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018



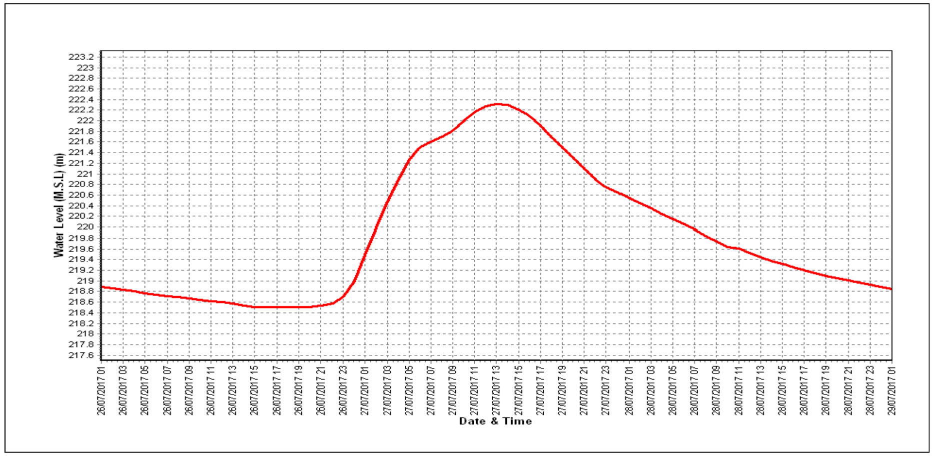
Annual Sediment Load: 1973-2018



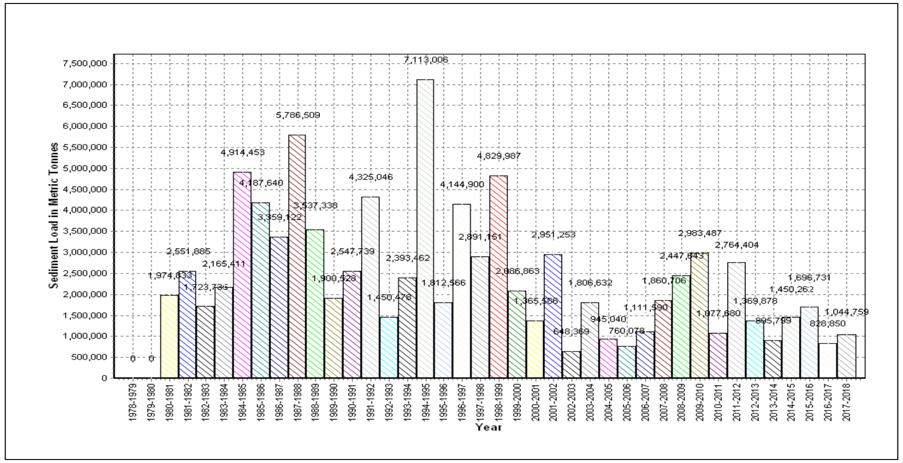
Histogram Hydrograph for the Water Year 2017-18



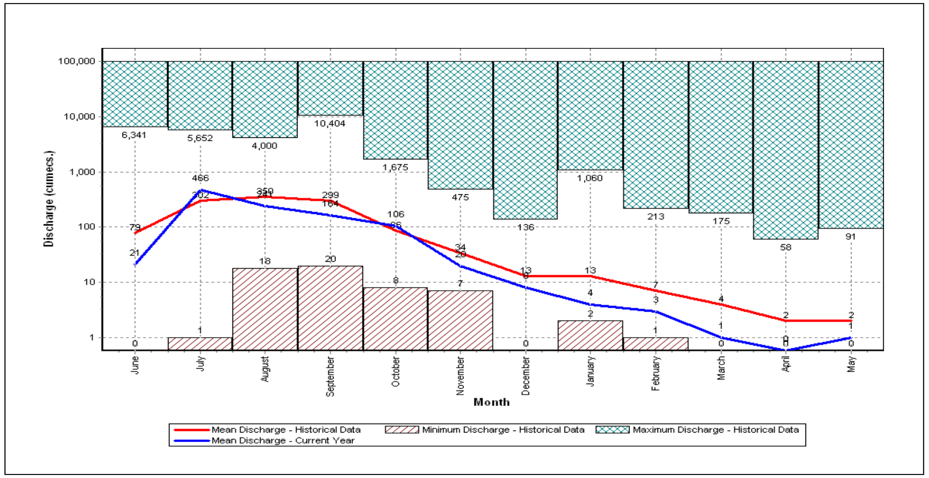
Annual Runoff Values between 1978-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

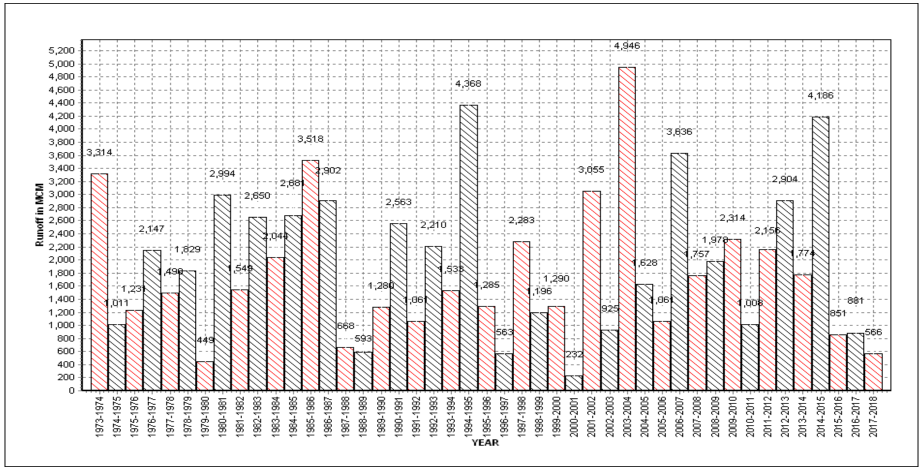


Annual Sediment Load: 1978-2018

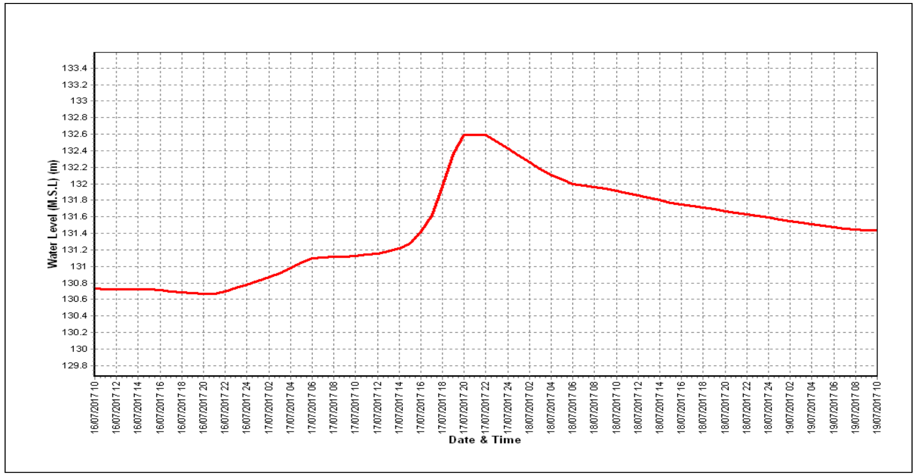


Histogram Hydrograph for the Water Year 2017-18

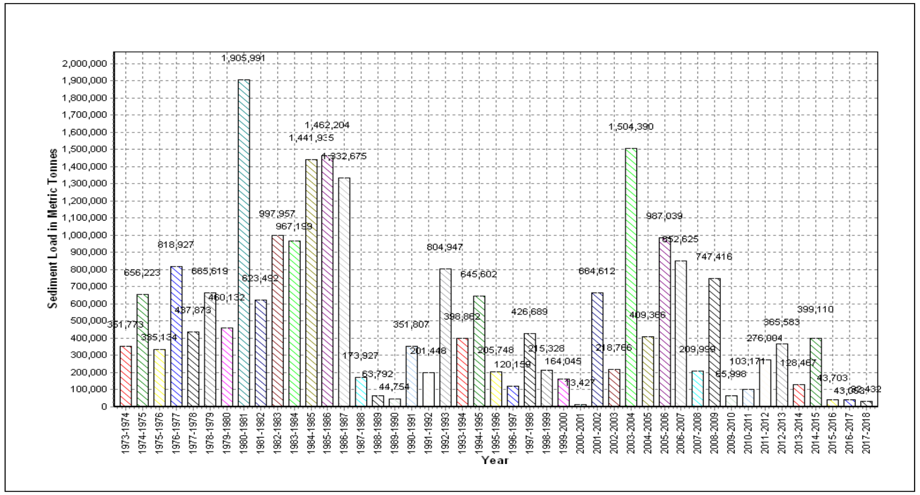
Appendix-XVII (Hydrological Observations as per CWC, Site:Salebhata, Ong Sub Basin)



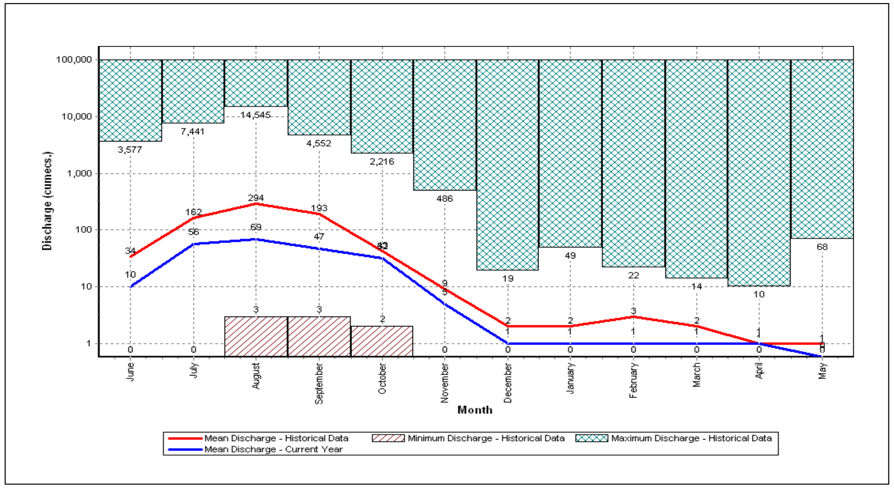
Annual Runoff Values between 1973-2018



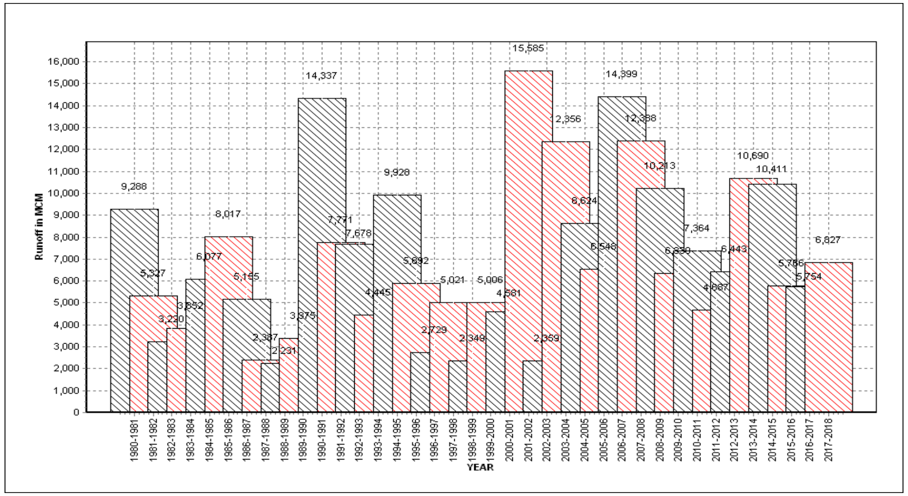
Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018



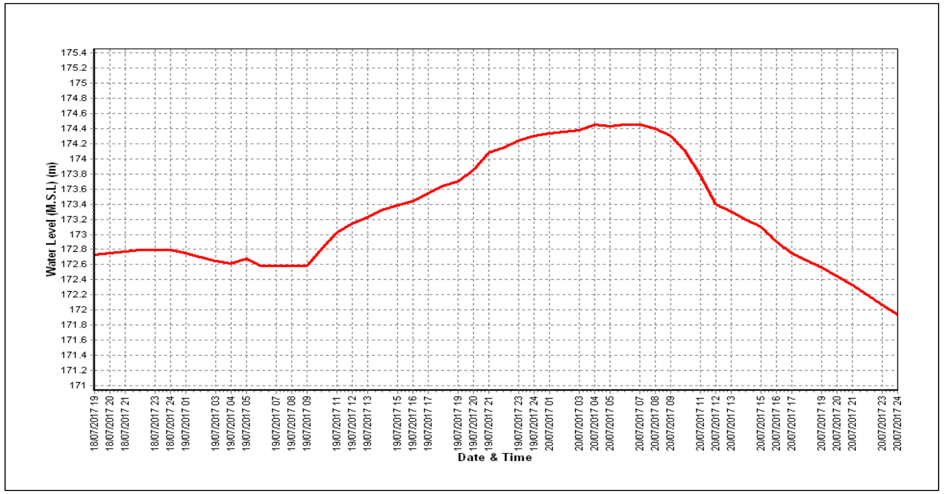
Annual Sediment Load: 1973-2018



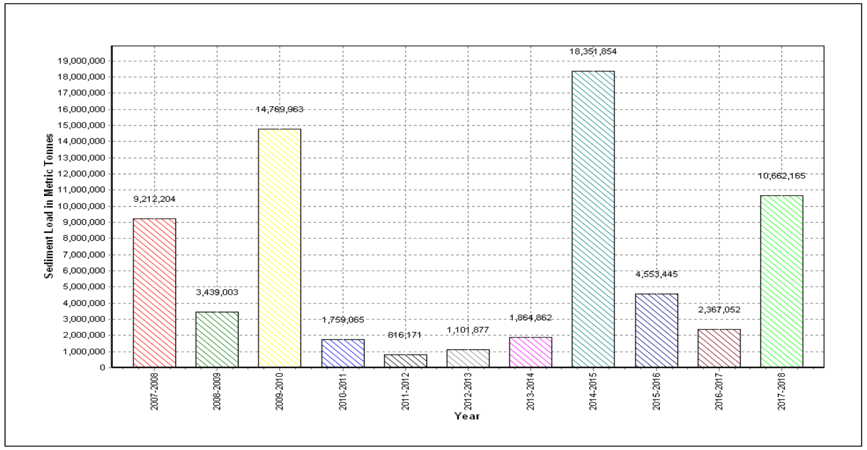
Histogram Hydrograph for the Water Year 2017-2018



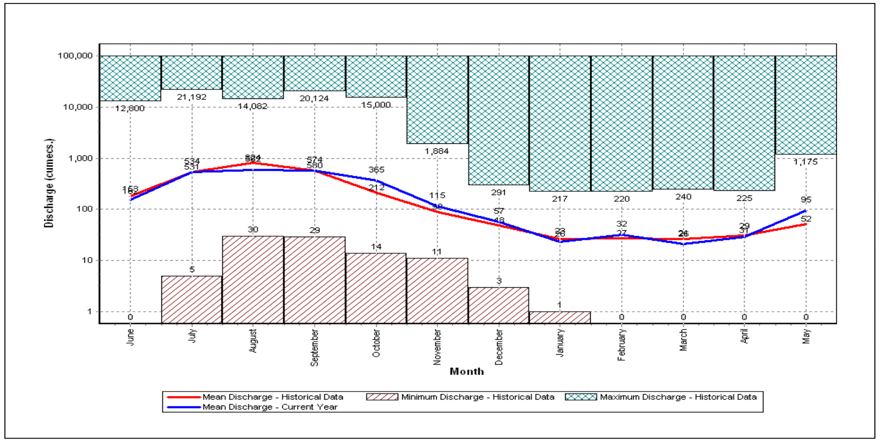
Annual Runoff Values between 1980-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

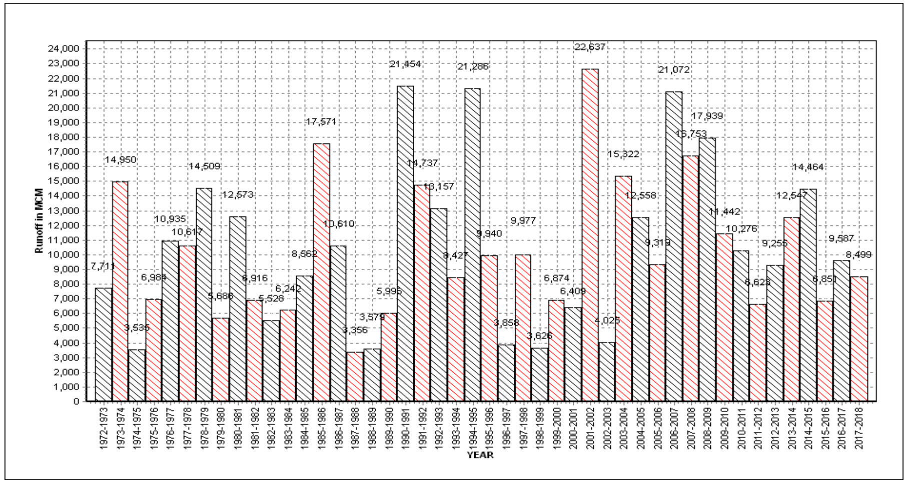


Annual Sediment Load: 2007-2018

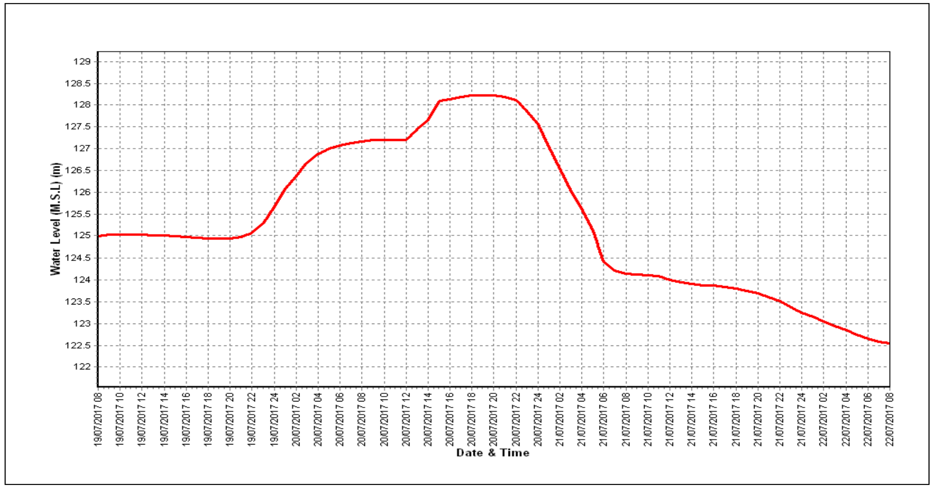


Histogram Hydrograph for the Water Year 2017-2018

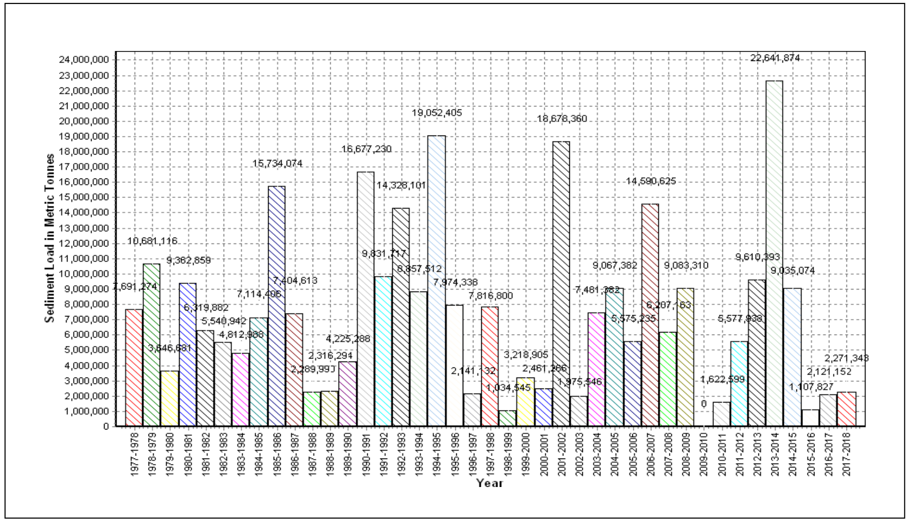
Appendix-XIX (Hydrological Observations as per CWC, Site:Kantamal, Tel Sub Basin)



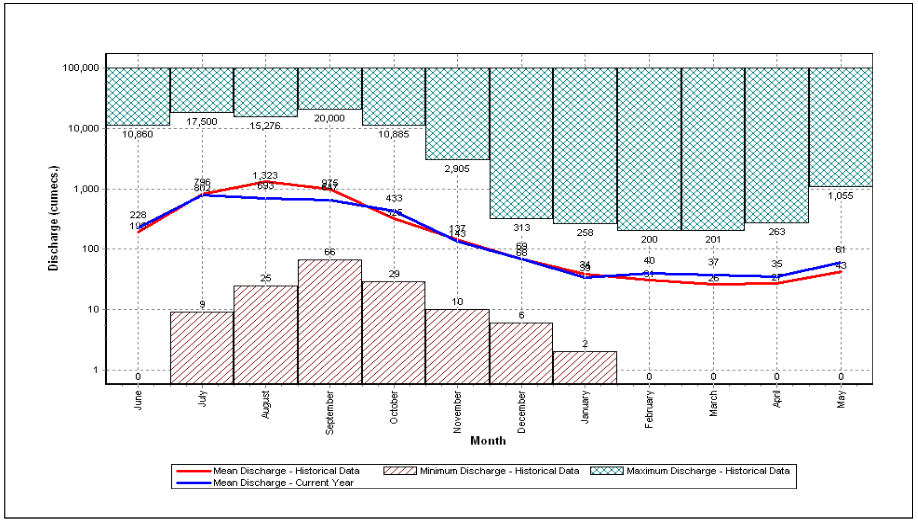
Annual Runoff Values between 1972-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018

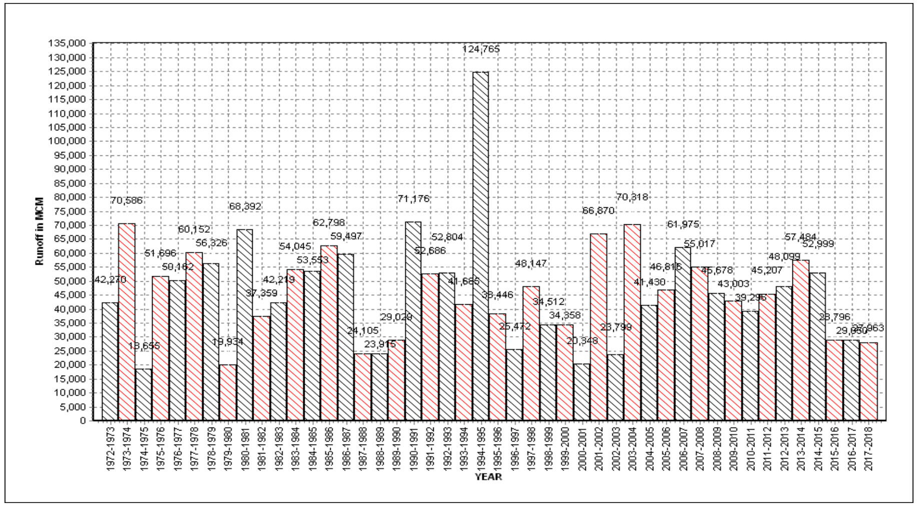


Annual Sediment Load: 1977-2018

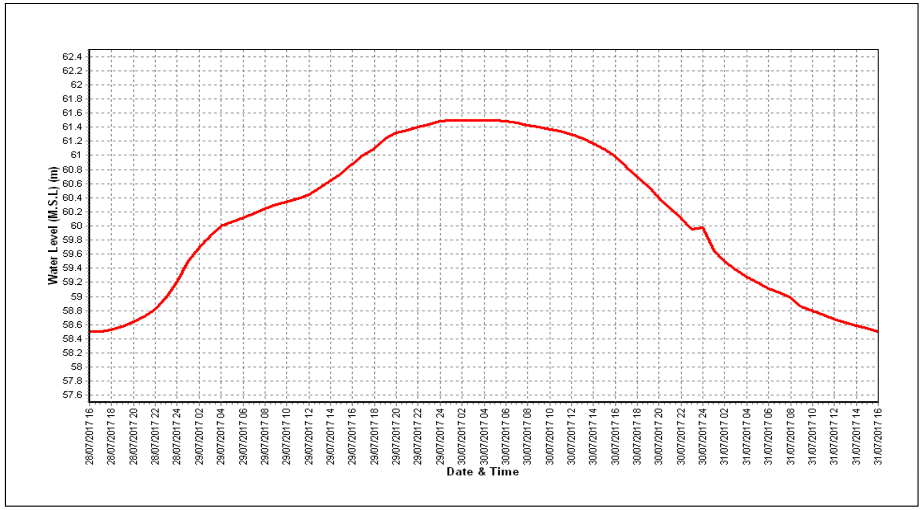


Histogram Hydrograph for the Water Year 2017-18

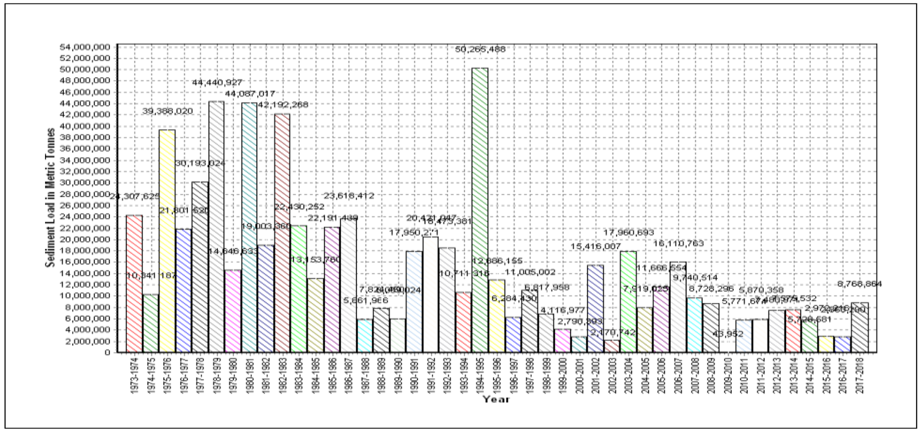
Appendix-XX (Hydrological Observations as per CWC, Site:Tikarpara, Lower Mahanadi Sub Basin)



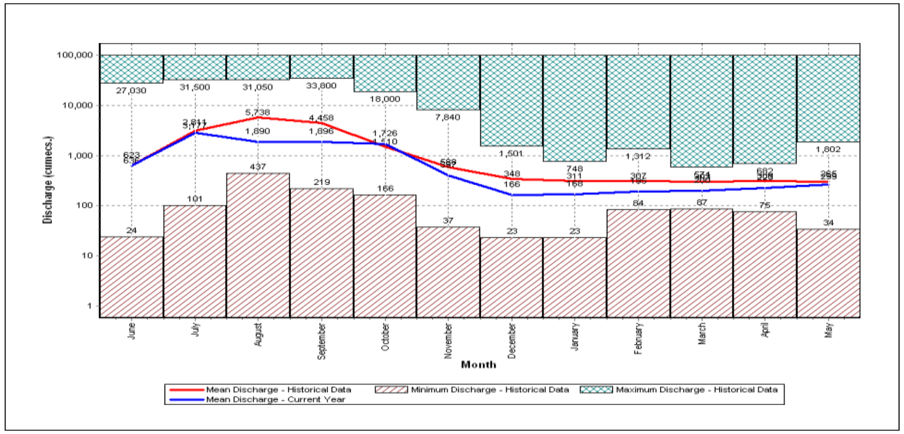
Annual Runoff Values between 1972-2018



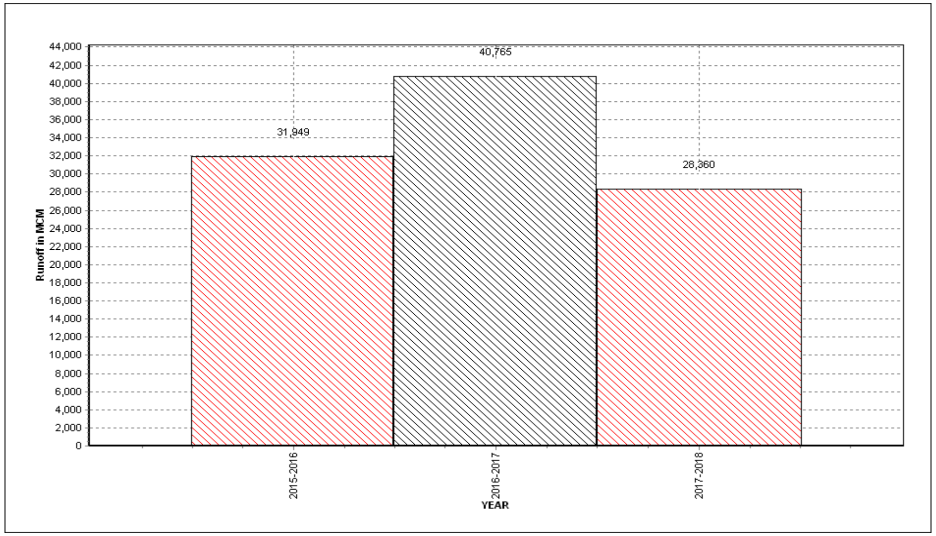
Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018



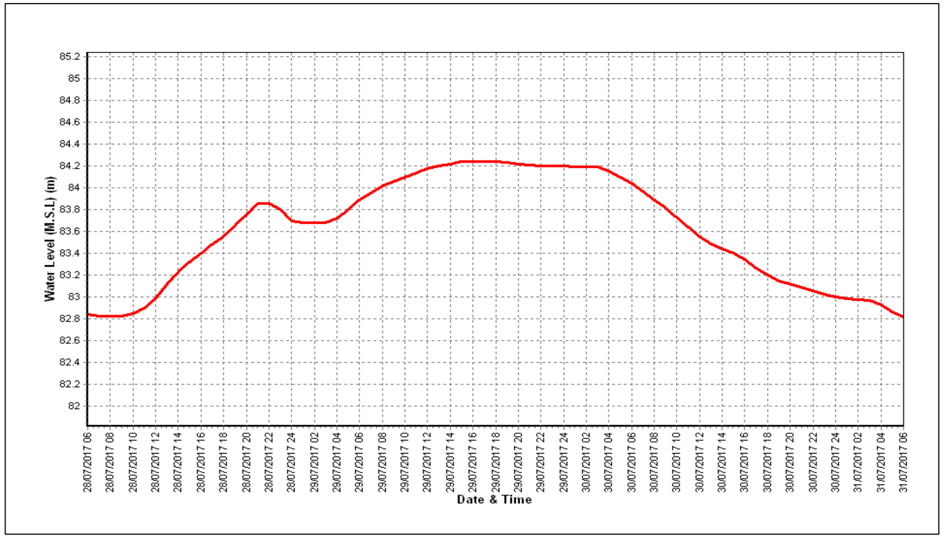
Annual Sediment Load: 1973-2018



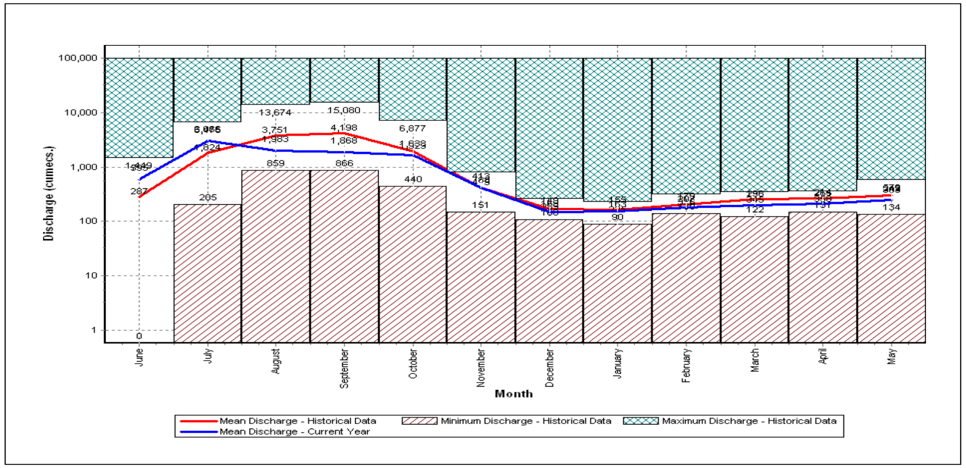
Histogram Hydrograph for the Water Year 2017-18



Annual Runoff Values between 2015-2018



Water Level vs. Time - Graph of Highest Flood Peak: 2017-2018



Histogram Hydrograph for the Water Year 2017-18

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