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A Comprehensive Review of the Mahanadi River Basin in Chhattisgarh, India

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ABSTRACT

The Mahanadi River is an interstate (Chhattisgarh and Odisha) river in India that flows for 851 kilometers, 357 of which are in Chhattisgarh. It is the lifeline of Chhattisgarh and Odisha. The Mahanadi River Basin (MRB) in Chhattisgarh covers an area of 75,136 km^2. This paper provides a detailed database on water demand and use, LULC changes, biodiversity, pollution status, and man-made structures, such as dams/ reservoirs, built in the Mahanadi river basin in Chhattisgarh. The significance of this overview paper stems from the fact that it improves river management and water distribution for various sectors in Chhattisgarh. Furthermore, it aids in the mitigation and adaptation to climate change, as well as the achievement of sustainable development goals.

Key words: *Mahanadi River Basin, Chhattisgarh, River management, Water study, LULC*

Introduction

River basins have been the potential source of human settlement and foraging ground for wildlife for thousands of years. Various civilizations were established on the banks of rivers, since water is one of the main components for the survival of living organism (Singh *et al.,* 2019; Chandrakar and Dhuria, 2022). River basins serve as a repository for natural, ecological and cultural resources, as well as for storing, channeling, and regulating surface water and groundwater which makes them a multifunctional unit in hydrology, biodiversity and socio-economy (Dawei and Jingsheng, 2001; Wagner *et al.,* 2002; Chandrakar and Dhuria, 2020). Literature research illustrates different approaches of the study of MRB (Table 1).

There are twenty major river basins in India, the Mahanadi basin being the eighth largest basin and the second largest river basin in the Deccan plateau, which is acting as the lifeline of Chhattisgarh and Odisha (Samuel *et al.,* 2017; Dsouza*et al*., 2017). The State of Chhattisgarh has six river basins: Mahanadi river basin, Godavari river basin, Ganga river basin, Brahmani river basin and a small part of Narmada river basin. The MRB accounts for around 56% of the land area of Chhattisgarh state (Fig. 1). The river Mahanadi is the inter-state east-central flowing river in Peninsular India with a drainage basin of 1,41,589 km^2 (Swetapadma and Ojha, 2020). Most part of the river catchment is in Chhattisgarh (73,214 km^2), followed by Odisha (65,847 km^2) and comparatively smaller areas in the state of Jharkhand (145 km^2), Maharashtra (322 km^2) and Madhya Pradesh (151 km^2) (Fig. 2).

The MRB is divided into three sub-basins namely Mahanadi upper, Mahanadi middle and Mahanadi Lower for the management and administrative pur-

poses (CWC, 2014). The Mahanadi Upper, covering a catchment area of 29796.64 sq. km in Eastern Chhattisgarh and part of Maharashtra and Madhya Pradesh, includes the Seonath river (largest tributary of Mahanadi in Chhattisgarh) and its tributaries with 48 watersheds. There are 62 dams, 4 barrages and 4 weirs in the Upper Mahanadi basin (CWC, 2014, SCCC, 2019). The central sub-basin of Mahanadi covers a catchment area of 51895.91 sq. km, with most of it in Chhattisgarh and some parts in Jharkhand and Odisha. This sub-basin having 88 watersheds, 116 dams, 3 barrages and 5 weirs. The lower Mahanadi sub-basin flows in the state of Odisha with a catchment area of 57958.88 sq. km. and drains its water into the Bay of Bengal on the Odisha coast and forms the Mahanadi delta near the town of Cuttack. This sub-basin includes 91 watersheds, 75 dams, 7 barrages and 4 weirs. The main tributaries in this sub-basin are Tel and Ong. In the lower reaches (delta region), the Mahanadi gives off

Table 1. Approaches for studying the Mahanadi River Basin (MRB).

S.N.	Approach	Brief description	RB/WS	References
1.	Streamflow trend	Linkages between climate variability and stream flow trends.	MRB	Panda *et al*., 2013
		Low flow trend and change detection.	MRB	Sahoo and Jha, 2020
		Relationship between Standardized Precipitation Index (SPI) and percentage of annual flow has been studied.	Ghatora, Kurubhata, Salebhata and Andhiyarkhore watersheds	Amrit *et al.,* 2017
2.	Trend in variability of rainfall	Seasonality Index (SI) of Mahanadi River Basin (MRB) for 35 years has been studied (1979-2013).	Mid- MRB	Panda and Singh, 2016
3.	Flood frequency estimation	Different statistical methods of flood frequency estimation of four stations of Mahanadi River have been studied.	Rampur, Sundargarh, Jondhra, Basantpur gauge stations of MRB	Samantaray and Sahoo, 2020
4.	LULC change detection and analysis	Decadal land use land cover change of MRB using satellite data.	MRB	Behera *et al*., 2018
		Impact of LULC change on the runoff, base flow and evapotranspiration dynamics.	MRB	Das *et al.,* 2018
		Timely Hydrological change of and its impact of Land Use and Land Cover change on surface runoff.	MRB	Dadhwal *et al*., 2010
5.	Hydrological modeling	Soil moisture data used for hydrological model preparation.	MRB	Behera *et al.,* 2019
6.	Morphometric analysis	Detailed morphometric analysis (linear, aerial and relief aspects).	Rampur watershed (Jonk river) and its nine sub-watersheds	Gunjan *et al.,* 2020
7.	Water Quality	Water pollution of rice mill	Mahanadi River, Chhattisgarh	Shrivastava and Sharma, 2020
		Organic and inorganic pollution	Hasdeo River, Chhattisgarh	Bhaskar *et al.,* 2020
8.	Bio-diversity	Fish diversity	Mahanadi River (Odisha)	Singh *et al.*,2020
		Fish diversity	Mahanadi (C.G.)	Patel *et al*., 2016
		Water bird diversity	Mahanadi river	Jyethi, 2020

a number of tributaries i.e., Kathjori, Paika, Birupa, Chitroptala, Ghunguti and Lun. The Kathjori further divides into a series of streams such as Kuakhai, Devi and Surwa which drain into the Bay of Bengal.

The Mahanadi have five major tributaries in Chhattisgarh viz; Seonath, Hasdeo, Mand, Ib and Jonk. The Seonath river originates from small groups of hills in Rajnandgaon district of Chhattisgarh. It drains about 25% of the MRB, covering a total catchment area of 30,761 sq. km. There are 62 dams, 4 barrages and 4 weirs in the Seonath river catchment (Das *et al.*, 2018; CWC, 2014). The river Jonk rises from the Khariar hills of Naupada district of Odisha having a length of 210 km, most of its length it defines boundary between Chhattisgarh and Odisha. Jonk river meet Mahanadi near Shivrinarayan, in Chhattisgarh. The Mand river rises from upper part of Mainpat platue and travels a length of 260 km to its meet with Mahanadi river in Chandrapur (Janjgir-Champa district, Chhattisgarh) and having a catchment area of 5332 sq. km. The Ib river originates near hills of Pandrapet in the Raigarh district of Chhattisgarh, having a length of 252 km and a total catchment area of river Ib is 12447 sq km (CWC, 2014).

The present study overviews the Mahanadi River basin, its catchment area, drainage network, tributaries, barrages/dams/reservoir reservoirs, river health, etc. flowing in the Central Indian state of Chhattisgarh. The study also illustrates the water consumption, dependency and pressure on the tributaries of the Mahanadi River. This study will provide a database of the Mahanadi River in Chhattisgarh state.

Study area of MRB

The Mahanadi River originates near Sihawa hill, 6 km from Farsiya village of Dhamtari district of Chhattisgarh (India-WRIS, 2018). Its geographical extent is between 80°26′E and 86°50′E longitude and 19°20′N and 23°35′N latitude (Panda *et al.*, 2013). The Mahanadi River (MR) is 851 km long and flows over 357 km at Chhattisgarh, and drains its water into the Bay of Bengal on the Odisha coast and forms the Mahanadi delta near the town of Cuttack. In the lower reaches (delta region), the Mahanadi gives off a number of distributaries i.e., Kathjori, Paika, Birupa, Chitroptala, Genguti and Lun. The Kathjori further divides into a series of streams such as Kuakhai, Devi and Surua which drains into the Bay of Bengal. (CWC, 2014; Samantharay and Sahoo, 2020). The catchment area of MRB is mainly comprises plains with an elevation range of 1-1500 m (Behera *et al.*, 2018). The major soil types of the area are red and yellow soil, black soil and mixed red.

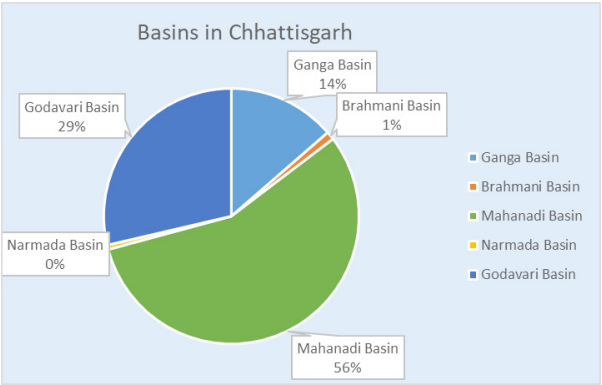

Fig. 1. Percentage contribution of catchment area of River basin in Chhattisgarh states

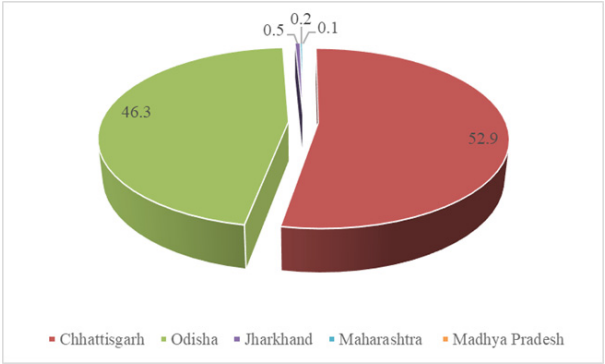

Fig. 2. Percentage contribution of catchment area of Mahanadi River basin in Indian states

Climatic status of MRB

The MRB's geographical and climatic conditions vary due to its large catchment area. The south-western monsoon is the main source of precipitation in MRB, especially from June to October. The average annual rainfall is 1438.1mm, with monsoon season accounting for 90% of total rainfall (Swetapadma and Ojha, 2020). During the months of December and January, the minimum temperature ranges from 4 to 12 °C. The warmest month is May, with temperatures ranging from 42 to 45 degrees Celsius (Panda *et al.*, 2013). The drainage area of the MRB in Chhattisgarh is mostly of dendritic structure and covers 73,214 sq. kms (Fig. 3).

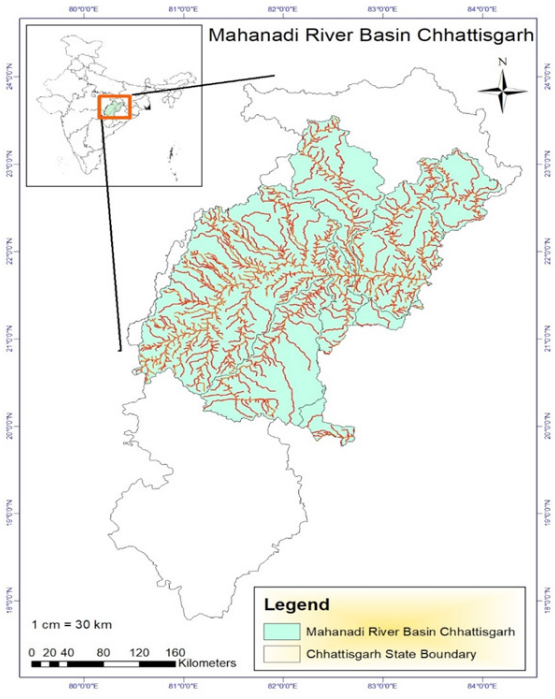

Fig. 3. Drainage map of MRB in Chhattisgarh state

MRB Water usage and management in Chhattisgarh

MRB covers an area of 73,214 km^2 in the state of Chhattisgarh, accounting for approximately 52% of the catchment. The average total annual runoff of the river Mahanadibasin is 66.80 Billion Cubic Meter (BCM)out of which 50 BCM is utilizable surface water. In Chhattisgarh there are 76 irrigation projects (22 major and 54 medium) in MRB having a potential of irrigating 1711 thousand hectares of culturable land. The total storage capacity in the basin is around 14.244 BCM of which 12.799 BCM is completed and the rest are under construction. The main industries in Chhattisgarh include Coal based thermal power plant, Iron and steel industry, mining of coal and bauxite and related industries (Samuel *et al*., 2017; Dsouza *et al.*, 2017, CSCCC, 2019). The allocation of surface water resources between industrial and agricultural uses is becoming a more contentious issue in Chhattisgarh. In contrast to Odisha, where the farmers' movement has been effective in preventing plans to deliver more water to companies, substantial recent building in Chhattisgarh has focused on providing water for industries, particularly thermal power plants. While the quality of the water is a major worry in the Chhattisgarh region of the MRB, inter-sectoral allocation is seen as a major challenge in Odisha. The inter-sectoral issue will likely gain more attention in the near future as a result of the new barrages and anicuts being built in Chhattisgarh to meet industrial demand (MRB, 2017; Samuel *et al.*, 2017; Dsouza *et al*., 2017). Due to the disproportionate allocation of water the farmers are being pushed towards groundwater sources.

The distribution of water from the MRB by the upper riparian area in the stateis already a contentious issue. Every industry seeking to establish manufacturing facilities along the Mahanadi River was assured access to water as the state of Odisha underwent rapid industrialization. As a result, by 2012, the water resources department had allocated nearly 62% of all water to industries in the state, up from only 13% five years earlier (CSCCC, 2019). As per the National Register of Large dams (up to 2014) there are 5254 large dams in India of which 248 large dams are in Chhattisgarh, and in addition to that 10 dams are under construction in Chhattisgarh.

In order to meet human, agricultural and industrial water demand, the river and its tributaries are dammed at various points by man-made structures such as dams, reservoirs etc. altering the natural course of the river. Das *et al.* (2018) reported that LULC changes alter runoff and stream flow discharge, thus impacting the hydrology of the catchment. There are a number of man-made structures on the Mahanadi River and its tributaries for water conservation and utilization by Chhattisgarh state. The most important is the Minimata Bango Dam, built on the Hasdeo River (a tributary of Mahanadi River) (Singh *et al.*, 2012).

Manimata Bango dam is located at latitude 22^0 36′275" N and longitude 82^{0}35′874" E at an elevation of 1206 ft above the mean sea level (MSL). The dam is about 555 m long, 87 m height and has 11 spillway gates. There is a 177 m long rock filled dam and a 1778 m long earthen dam to the left and right of Bango Dam (Fig. 4 & 5). The dam was completed in 1990 and has a reservoir area of 188.47 Sq. km. It is one of the 59 dams of National importance. The river exhibits significant inter-annual variations in water flow; independent analyses have indicated decreasing flow in the basin, primarily attributable to reduced precipitation in the upper and middle catchments and to changes in basin land use (CSCCC, 2019). The dam has one big power house. The catchment area of the dam is approximately

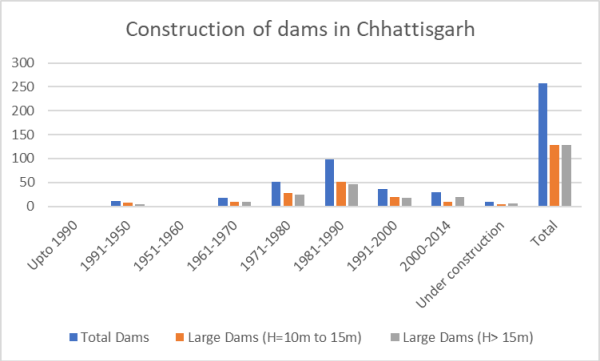

Fig. 4. Construction of dams/ surface water management structure in Chhattisgarh (Source: CWC, 2017)

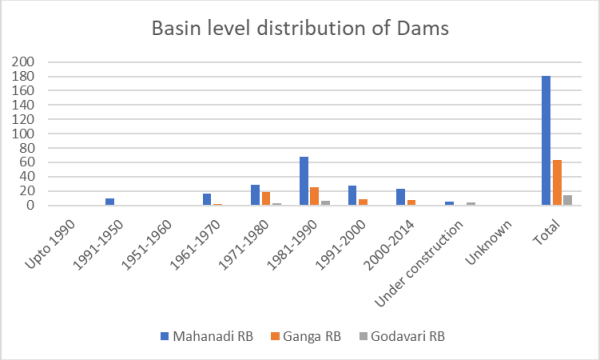

Fig. 5. The construction of dams/ surface water management structure in different River basin (RB) in Chhattisgarh (Source: CWC, 2017)

6,730 km^2. The mean annual inflow to the reservoir of this dam is 3,540 mcum. The power house has 3 units of 40 MW. Apart from reservoirs and dams, there are more than a dozen of gauging stations at different locations at Mahanadi River (Table 2)

Water resource projects in MRB

The MRB has a total storage capacity of 14467.30 MCM of which finished project have a capacity of 13006 MCM. The total live storage capacity of projects under construction is 1461.30 MCM (Fig 4 & 5). Irrigation projects and hydroelectric projects are the two primary categories for water resource projects(CWC, 2014, CSCCC, 2019).

Irrigation projects: The river and its tributaries provide water for agriculture, enabling the cultivation of crop such as rice, wheat, pulses and oilseeds. Total 74 irrigation projects exist in the catchment area of MRB. The irrigation projects which exist in Chhattisgarh state on MRB are Ravishankar Sagar dam, Dudhwaha dam, Murusilli dam, New Rudri barrage, Minimata Hasdeo Bango irrigation project, Tandula major irrigation project, Jonk diversion project and Pairy project. Minimata Hasdeo Bango irrigation project provides irrigation facilities for Bilaspur, Korba, Raigarh and Janjgir Champa districts. While, Tandula major irrigation project is constructed in Tandula river which benefits the Durg district (India-WRIS, n.d.).

Hydro Electric project: The MRB in Chhattisgarh has significant hydroelectric potential. The major dams in the basin includes the Gangrel dam, Dudhawa dam, and Hasdeo Bango dam. The hydropower generation from MRB is 1184.5 MW. It comprises Five hydroelectric projects and 6 power houses. The maximum power (600 MW) is being generated from Indravati hydroelectric project, Minimata Hasdeo Bango Project generates 120 MW, Gangrel hydro- electric project generates 10 MW and Sikaser project generates 7 MW (Register of Large Dams, 2017, WC, 2014, India-WRIS, n.d.).

Water health in MRB

According to CPCB, 2020, a comparative study between the pre-lockdown period of Covid-19 and the lockdown period of Covid-19 on the MRB in Chhattisgarh part shows a decreasing trend of BOD (7% to 25%) at three locations and faecal contaminant (90-95%) (CPCB, 2020). Untreated industrial effluents and raw sewage discharged from towns and cities along the banks of the Mahanadi river and its tributaries (in MRB) cause biochemical and bacterial contamination of river water, particularly in discharge stretches that serve as water intake points for significant towns and cities. Water pollution has a significant impact on the amount of water available for ecological and human needs (CSCCC, 2019).

Threats to MRB

MRB has undergone numerous changes throughout its history. Several researchers (Amrit *et al.*, 2017, Behera *et al.*, 2019, Panda *et al.*, 2013, Sahoo and Jha, 2020) have reported variability in precipitation in the MRB, which is an important hydro-meteorological variable. According to Panda and Singh (2016), MRB has an asymmetric rainfall distribution that spans 3-4 months. Changes in the MRB mean monthly, seasonal, and annual precipitation are likely to affect the Mahanadi River's entire catchment area. The correlation between precipitation patterns, rainfall trends, and other parameters is useful for studying the climate change scenario and

taking preventive/adaptive measures in the MRB (Panda and Singh, 2016). Amrit *et al.* (2017) used the rainfall and flow data of different watersheds of the Mahanadi River and predicted that the percentage of the mean annual flow in the river basin will increase in future. An increase in stream flow from MRB due to a decrease in forest cover has been reported (Mishra, 2008).

Variable water flows in MRB

According to a report by the Chhattisgarh State Centre for Climate Change, Raipur, the 40-year mean annual discharge of the Mahanadi river in Chhattisgarh from 1971-1972 to 2010-2011 was 21,369 MCM, with the maximum flow being 51,360 MCM (in 2000-2001) and the minimum flow being 7,564 MCM. Flooding occurs in the deltaic region of Odisha during rainy years due to excessively high flows, while drought occurs in the Chhattisgarh portion of the basin during dry years. The variable amount of rain each year has an impact on groundwater recharge (CWC, 2014; CSCCC, 2019).

High risk of climatic variability in MRB

The MRB water economy is poorly insulated from the effects of climatic variability due to the inadequate water infrastructure (in terms of reservoir capacity offering multi-annual storage). In the Chhattisgarh portion of the basin, for instance, just 39% of the total farmed area is covered by irrigation, and the rainfed crops are stressed when the monsoon fails, leading to crop failure. Poor groundwater potential in the Chhattisgarh portion of the basin due to largely shallow hard rock formations with low capacity for production and storage, meaning that there is no static groundwater and insufficient recharge (CWC, 2014; Dsouza *et al.*, 2017; CSCCC, 2019).

MRB's catchment area is densely populated and mostly covered by forests and agricultural land (Behera *et al.*, 2018). Agriculture is concentrated in the Western Uplands (Kawardha, Rajnandgaon, and Bilaspur) and Central Plains (Durg, Dhamtari, Raipur, Mahasamund, and Janjgir-Champa) in Chhattisgarh (Dsouza *et al.*, 2017; Samuel *et al.*, 2017). Reduced Mahanadi River water flow may have an impact on the fishing community and crop cultivators (Ratha, 2019).

Along the entire course of the Mahanadi river and its tributaries, Chhattisgarh has numerous urban centers. Some important urban centers include Raipur, Bilaspur, Korba, and Durg. This river meets the water needs of rapidly expanding urban areas, either directly or indirectly. According to Das *et al.* (2018), urbanization, deforestation, and cropland expansion will be prominent and likely to continue in the MRB in the coming decades. Human settlement, proximity zones around habitat, and other socioeconomic factors all contributed to Mahanadi River Basin land use land cover change (Behera *et al.*, 2018). Several studies have been conducted on the tributaries and sub-tributaries of MRB (Singh and Singh, 2012, Singh *et al.*, 2011; Singh *et al.*, 2019). Singh *et al.* (2019) studied the LULC pattern of Gej subwatershed (a tributary of Hasdeo river) flowing in Chhattisgarh state using IRS 1D and P6, LISS 3 satellite imageries. The study reported that between 2000 and 2013, the LULC classes such as settlements, agricultural land, scrub land, riverbed and water resources increased while dense forest, open forest and barren land decreased. Mahato (2022) studied the decadal changes at the Khudia dam located on the Maniyari river. The study reported found that between 2004 and 2013 there was a significant drop in water covered area and an increase in agricultural area in the surrounding area.

Behera *et al.* (2018) investigated the MRB's Land Use Land Cover Change (LULC) since 1985. According to the study, agricultural land accounts for 55% of the rain-fed. Direct conversion of forest to agricultural land, as well as conversion of scrub land to waste land and crop land, has been documented since 1985. MRB's most common land use category is agricultural land and major crops are paddy. The non-paddy crops such as pulses, oil seeds, and cotton is also cultivated in the area (Amrit *et al.*, 2017).

Ashokan and Dutta (2008) investigated the availability and demand for MRB water resources between 2000 and 2100 under various climatic conditions. This analysis predicted that the irrigation sector would use a lot of water. If the MRB's climate and rainfall patterns change, agriculture and the catchment's ecosystem will suffer (Panda *et al.*, 2013). MRB's LULC was mapped by the Central Water Commission in 2004-05. The map shows that the major classes in the basin area are double/triple crop (25.99%), current fallow (25%) and scrub/degraded forest (11.80%) (CWC, 2017). They also investigated the MRB's water resources under various climatic conditions and projected the MRB's status at the sub-catchment level for 2025, 2050, 2075, and 2100. According to their research, MRB runoff is ex-

pected to increase (38%) during September for the period 2075-2100. The study also concluded that irrigation will consume a lot of water in the coming decades. Das *et al.* (2019) investigated the LULC of MRB using satellite images from 1995, 2005, and 2015, and landscape changes over the last three decades were examined. Decadal changes in the LULC classes revealed an increase in built-up land and a decrease in forest area. Their research also predicted that by 2025, LULC classes would exhibit similar trends, such as continued deforestation, agricultural land loss, and an increase in urban areas.

Ratha (2019) described how industrialization and thermal power plants are affecting the Mahanadi river in Chhattisgarh. The state receives approximately 1130 MCM of MRB water, while Odisha receives 944 MCM. Since 1997, industrial distribution of river water has increased sixfold in Chhattisgarh, making the entire catchment area vulnerable to climate change (Panda, 2016). Mining, power, cement, iron and steel, and other industries are rapidly expanding in the state.58000 MW plants in the state rely on the Mahanadi River for water (Ratha, 2019). According to Forum (2017) and Dsouza *et al.* (2017), the amount of water allocated to industries has increased dramatically from 364 MCM in 2007 to 1661 MCM today. Ganasri and Dwarakish (2015) found similar trends in the Harangi catchment area of Karnataka, where industrialization and urbanization are the primary drivers of the conversion of forests and wetlands to agricultural land and settlements.

To ensure water supply to the state's emerging industrial units, the government has accelerated efforts to construct larger barrages on the Mahanadi river (Ratha, 2019; CSCCC, 2019). Ratha (2013) also reported that the Chhattisgarh government planned to keep about 30% of the Mahanadi River's flow by constructing 600 check dams. In the state, the river is exploited 5-7 kilometers upstream. Figure 6, depicts a list of major projects and thermal power plants in the MRB catchment area. These projects obtain water from the river and its tributaries directly or indirectly (CWC, 2014). Chhattisgarh state, industrial water use is rapidly increasing, particularly for thermal power generation, making it more difficult than ever to allocate usable water among different sectors while also protecting the Mahanadi and its tributaries. In years of drought when river flows are reduced, a quantity of 2,172 MCM of water designated for industrial uses can pose a significant threat to

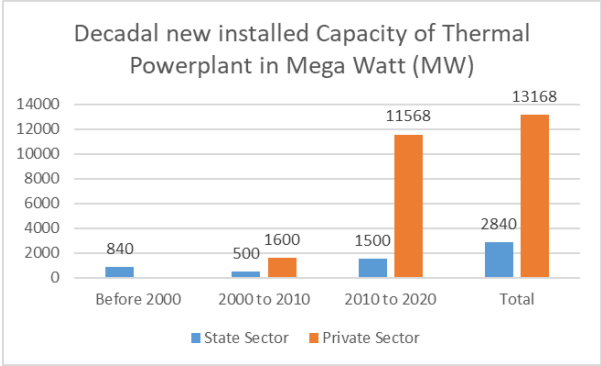

Fig. 6. List of industries and power plants in the catchment area with their installed capacity

water-based livelihoods such as agriculture, livestock husbandry, and fisheries (CSCCC, 2019).

Apart from gauging stations and dams (Table 2&3), the water has been used for various activities, there are more than a dozen of upcoming projects that are likely to draw water from the Mahanadi River and its tributaries at various barrages in Chhattisgarh. Some of the projects are Super Thermal Power plant which are likely to use water from Saradih barrage, Industrial Units in Janjgir Champa which are likely to use water from Shivrinarayan and Basanthpur barrage, Electronic manufacturing Units (EMU) in Naya Raipur using water directly from the Mahanadi River (Ratha, 2019). This overextraction from water at various points, particularly near the source, can reduce the overall flow of the river. Therefore, there is an increased chance of over-utilization and low flow of the river in coming decades.

The natural course of the river is endangered if it is exploited to such an extent and it is likely to be transformed into an inferior river. With increasing levels of pollution and the establishment of new industries in the region, there is enormous ecological pressure on the Mahanadi River Basin. Anthropogenic interference with the natural ecosystem impedes the free flow of the Mahanadi River on its way. Bhaskar *et al.*, 2020 studied the organic and inorganic contamination of Hasdeo riverat Korba. Their study evaluated the presence of heavy metals in river water exceeding the permissible concentration as prescribed by WHO and BIS which makes the water unfit for drinking and aquatic life but can be used for irrigation.

Few places have records of severe flooding in the Mahanadi River basin and its tributaries. Monsoon

Table 2. The basin characteristics and its gauging stations of Mahanadi River in Chhattisgarh state.

S. No.	Dam/Gauging station	Station type	River/Tributary/ Sub tributary	Catchment (Km^2)	Mean annual flow (Cumecs)
1	Andhiyarkore	GDSQ	Mahanadi/ Shivnath/ Kharun	2217.47	290.31
2	Bamindihi	GDSQ	Mahanadi/ Hasdeo	9730	1742.60
3	Bango Dam	G	Mahanadi/ Mand/ Kurkut	NA	NA
4	Baronda	GDSQ	Mahanadi/ Pairi	3180.69	2189.49
5	Basantpur	GDSQ	Mahanadi	58506.65	12750.54
6	Dharamjaigarh	G	Mahanadi/ Mand	NA	NA
7.	Jondhra	GDSQ	Mahanadi/ Seonath	29623.54	5000.85
8.	Korba	G	Mahanadi/ Hasdeo	NA	NA
9.	Rampur	GDSQ	Mahanadi/ Jonk	2920	NA
10.	Sankara	G	Mahanadi/ Kharun	NA	NA
11.	Simga	GDSQ	Mahanadi/ Seonath/ Kharun	16703.35	4373.50
12.	Ghatora	GDSQ	Mahanadi/ Seonath/ Arpa	3035	349.30
13.	Kelo at Raigarh	GD	Mahanadi/ Kelo	1111.10	656.65
14.	Kotni	GD	Mahanadi/ Seonath	6946.87	2092.08
15.	Kurubhata	G	Mahanadi/ Mand	4750.21	1516.66
16.	Manendragarh	GDSQ	Mahanadi/ Hasdeo	1021.25	2160.14
17.	Pathardihi	GDQ	Mahanadi/ Seonath/ Kharun	2486.61	1026.77
18.	Rajim	GDSQ	Mahanadi	8400.82	3782.72
19	Seorinarayan	GD	Mahanadi	47750.21	10845.75

(*Source:* Hussain *et al.,* 2020; Swetapadma and Ojha, 2020; Sahoo and Jha, 2020)
GSDQ : Gauge, Discharge, Sediment and Water Quality, GD : Gauge and Discharge, G : Gauge

Table 3. Major gauging location in Chhattisgarh with details:

S. N.	Particulars	Andhiyarkore	Pathardi	Kurubhata	Manendragarh
1	Total Catchment Area (sq. km)	2210	2511	4625	1100
2	Average annual rainfall (mm)	1300	1300	1250	1250
3	Average annual stream flows (MCM)	331	1023	2352	337
4	Highest annual flows (MCM)	851	2170	5114	620
5	Lowest annual flows (MCM)	35	323	878	198
6	CV in annual stream-flow (%)	56	47	36	40
7	Average annual runoff/unit area (MCM/sq. km)	0.15	0.41	0.51	0.31

floods and water inundation are the regular occurrences of this watershed, often controlled by the construction of man-made structures such as dams/reservoirs (Das *et al.*, 2018). Samantharay and Sahoo (2020) estimated the flood frequency of MRB at four gauge stations of Odisha using different statistical methods. Panda *et al.* (2013) reported on the climatic vulnerability of the MRB and also assessed its flow trends. Guru and Jha (2015) analyzed the flood frequency of many hydraulic structures such as dams, barrages, check-dams and urban drainage systems of MRB. Swetapadma and Ojha, 2020 also examined flood frequency analysis of the MRB using a basin-scale model.

Bastia and Equeenudin (2016) studied the sediment runoff and spatio-temporal variation of water flow in the Mahanadi river. Their study reported that the sediment runoff originates from the Mahanadi River Basin (MRB). Their study also reported that the sediment discharge from MRB was $0.515x10^6$ tons/year between 1980 and 2010. Their study also reported that in terms of water discharge and sediment flow into the ocean, the Mahanadi river ranks second among the peninsular rivers in India.

Behera *et al.* (2019) evaluated the hydrological model of the Mahanadi river using remote sensing soil moisture data. Their study reported that 22% of the total population in the basin contributes to runoff and 76% is lost as evaporation. Rajput and Sinha (2020) have done the geo-spatial evaluation of drought resilience of the Upper Seonath, Kharun

and Arpa River Basin of Chhattisgarh. The study evaluated that 3.86% of Upper Sheonath, 15.59% of Kharun and 48.23% of Arpa River Basin are not vulnerable to drought. All the three are the tributaries of Mahanadi River flowing in Chhattisgarh. Patel *et. al.* (2016) studied the fish diversity of the Mahanadi river flowing in the Raigarh district of Chhattisgarh. Their result gave 54 species in 21 families. Findings concluded that the river in Raigarh district is rich in fish diversity and requires conservation measures. Singh *et al.*, (2020) studied the fish diversity of Mahanadi river in the state of Odisha state and recorded 57 fish species from 19 families. Their study found that 26% of the fish are under threat categories and needs urgent conservation measures.

Conclusion

With increased industrialization, urbanization and changing lifestyles of people, the demand and consumption of fresh water from the Mahanadi river and its tributaries in the state of Chhattisgarhis increasing rapidly. As the Mahanadi is a rain-fed river, most of the water falls duringthe monsoon season. Studies on Land Use Land Cover by various researchers found that there is a steady increasein built-up land, decrease in forested land and increase in agricultural activities in MRB. Therefore, constant changes in the areas LULC pattern are putting pressure on the dams and reservoirs to meet the human water needs. More than 250 water conservation structures are being constructed in Chhattisgarh to meet human, industrial and irrigation needs. Many studies also reported that changes in flow patterns and climatic influences could further impede and alter river waterflow. Higher water consumption and the return of waste water to the water body can affect its quality and quantity. This will result in heavier stress on the currently flowing river. Assessing the impact of dam construction is important to study infrastructure resilience and climate change adaptation in large cities and communities that rely on surface water from nearby dams. If this water resource is not used sustainably, the state could face water shortages in the near future due to overexploitation and climate change projections. And if this water resource is not used sustainably, the state could face water shortages in the near future due to overexploitation and climate change projections. Prajapati *et al.* (2017) reported temporal changes in the river course of Tapi river. No such study has been done on meandering nature of MRB, which can be potential area of research in near future.

The present paper also highlights that there is more research and literature available on MRB flowing in Odisha state as compared to Chhattisgarh. So, there is a huge opportunity for research in this area.

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