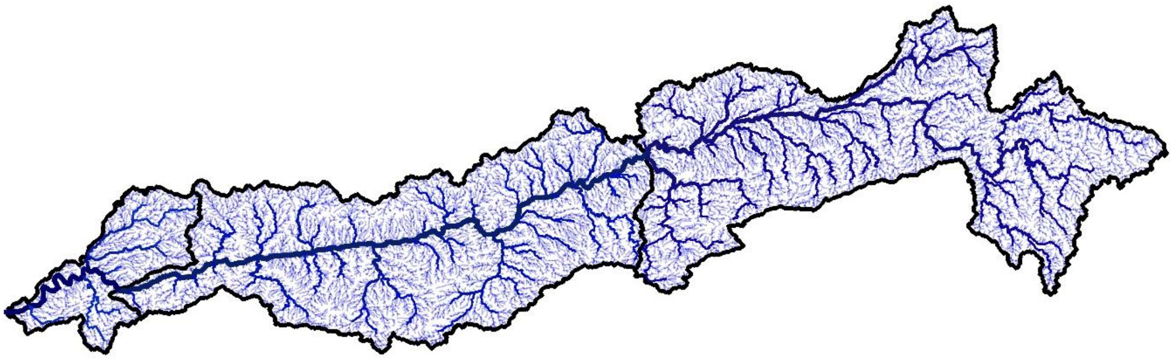
National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Narmada: River at a Glance



July 2024

Narmada:
River at a Glance

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 Narmada River Basin Management and Studies (cNarmada)

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

www.cnarmada.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 IIT Gandhinagar (Lead Institute) and IIT Indore (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.

Centres for Narmada River Basin
Management and Studies (cNarmada)
IIT Gandhinagar, IIT Indore

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Abbreviations and Acronyms

BCM	:	Billion Cubic Meter
Cumec	:	Cubic meter per second
CWC	:	Central Water Commission
DEM	:	Digital Elevation Model
GIS	:	Geographic Information System
HE	:	Hydroelectric
km	:	Kilometre
RS	:	Remote Sensing
LULC	:	Land Use and Land Cover
m	:	Meter
mm	:	Millimeter
MW	:	Mega Watt
NHPC	:	National Hydroelectric Power Corporation
SoI	:	Survey of India
sq. km	:	Square Kilometer
SWAT	:	Soil & Water Assessment Tool
CCA	:	Culturable Command area

1 INTRODUCTION

India's diverse landscapes are defined by its magnificent river systems, originating from the Himalayas to the Western and Eastern Ghats. These rivers are the nation's lifelines, nourishing its vast plains, nurturing its ecosystems, and sustaining its people. These are integral to its geographical, cultural, and economic landscapes. These river systems not only shape the country's topography but also sustain its agriculture, provide drinking water, enable transportation, and support hydroelectric power generation.

The Narmada River, once referred to as Narbada and anglicized as Nerbudda, ranks as the fifth-longest river in India and is the longest river flowing westward. It is also the largest river in Madhya Pradesh. The Narmada traverses the states of Madhya Pradesh and Gujarat and is often called the "Lifeline of Madhya Pradesh and Gujarat" due to its substantial contributions to these states. The Narmada is a crucial source of water for irrigation, drinking, and hydroelectric power and holds immense cultural and spiritual importance. It is worshipped as a goddess in Hindu mythology, with numerous temples and pilgrimage sites dotting its banks and festivals like Makar Sankranti celebrating its sacred essence.

Originating from the Amarkantak Plateau in the Anuppur district of Madhya Pradesh, the Narmada forms the traditional boundary between North and South India. It flows westward for 1,312 km before emptying into the Arabian Sea through the Gulf of Khambhat, situated 30 km west of Bharuch city in Gujarat. The Narmada basin extends from 21° 40' 12" to 23° 41' 24" N latitudes and 72° 48' 36" to 81° 45' 36" E longitudes, covering a total area of 95,959.70 sq. km, which is nearly 3% of the total geographical area of India (3,297,427.32 sq. km). The geographical location of the Narmada Basin is shown in Figure 1.

The Narmada basin exhibits an elongated shape with a maximum length of 915.65 km from east to west and 236 km from north to south. The upper part of the river basin primarily comprises hilly regions, whereas the middle and lower reaches are fertile and broad, making them well-suited for cultivation. The annual water potential of the basin is 45.65 billion cubic meters (BCM), with a utilizable water potential of 34.50 BCM (75.57%).

The entire stretch of River Narmada can be primarily divided into three sub-basins/segments based on their geomorphology, ecology and rheology (Figure 2). The issues in each of the sub-basins should also be addressed separately.
Upper Narmada sub-basin: ≈ 720 km Amarkantak to Hoshangabad
Middle Narmada sub-basin: ≈ 485 km Hoshangabad to Navagam
Lower Narmada sub-basin: ≈ 145 km Navagam to Gulf of Khambhat
The drainage network of the Narmada River consists of 19 major tributaries (a total of 41 tributaries), as shown in Figure 3. According to the 2011 Census, the total population of the basin is 61,243,103, with 32,396,859 males (52.89%) and 30,264,244 females (47.11%).

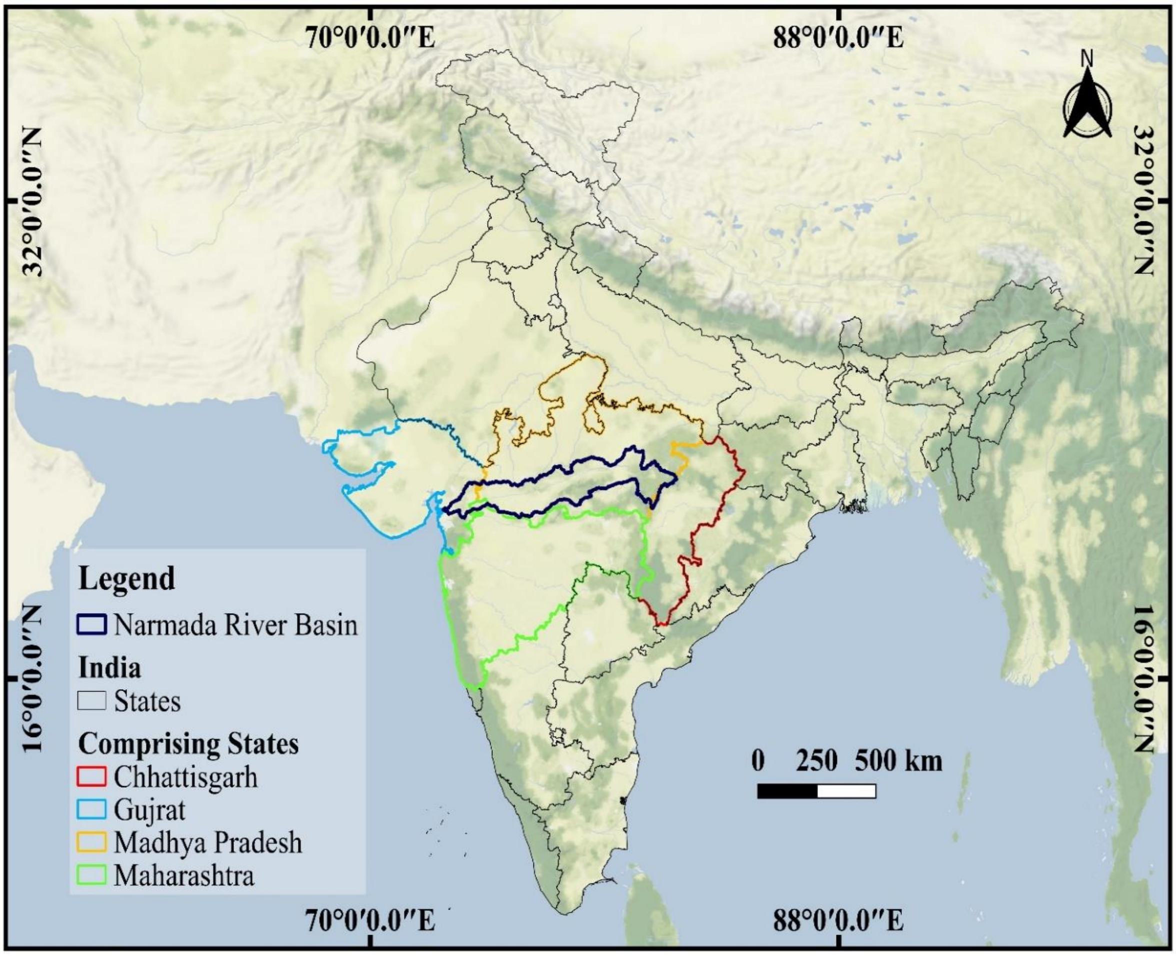


Figure 1 Geographical location map

The Narmada flows through a rift valley, surrounded by the Vindhyas to the north, the Maikala range to the east, the Satpuras to the south, and the Arabian Sea to the west. It lies at the northern extremity of the Deccan plateau and covers major portions of the states of Madhya Pradesh and Gujarat, along with smaller parts of Chhattisgarh and Maharashtra. The Narmada River travels through Madhya Pradesh (1,077 km), Maharashtra (74 km), including along the border between Madhya Pradesh and Maharashtra (39 km), then the border between Maharashtra and Gujarat (74 km), and finally Gujarat (161 km). The salient features of the basin are listed in Table 1. The state-wise distribution of the basin's geographical area is shown in Figure 4. The basin spreads broadly over 40 districts, comprising 27 districts of Madhya Pradesh, seven districts of Gujarat, four districts of Chhattisgarh, and two districts of Maharashtra.

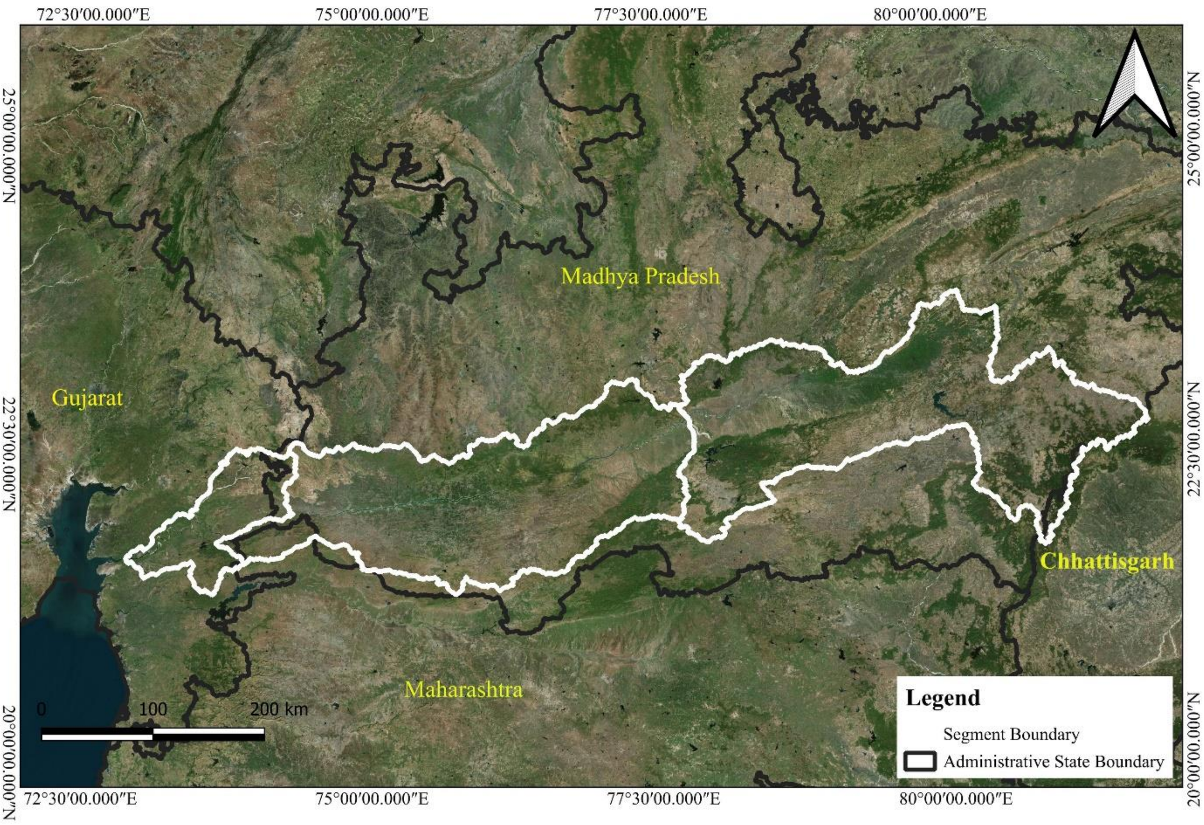


Figure 2 Drainage area of the Narmada River with its three segments

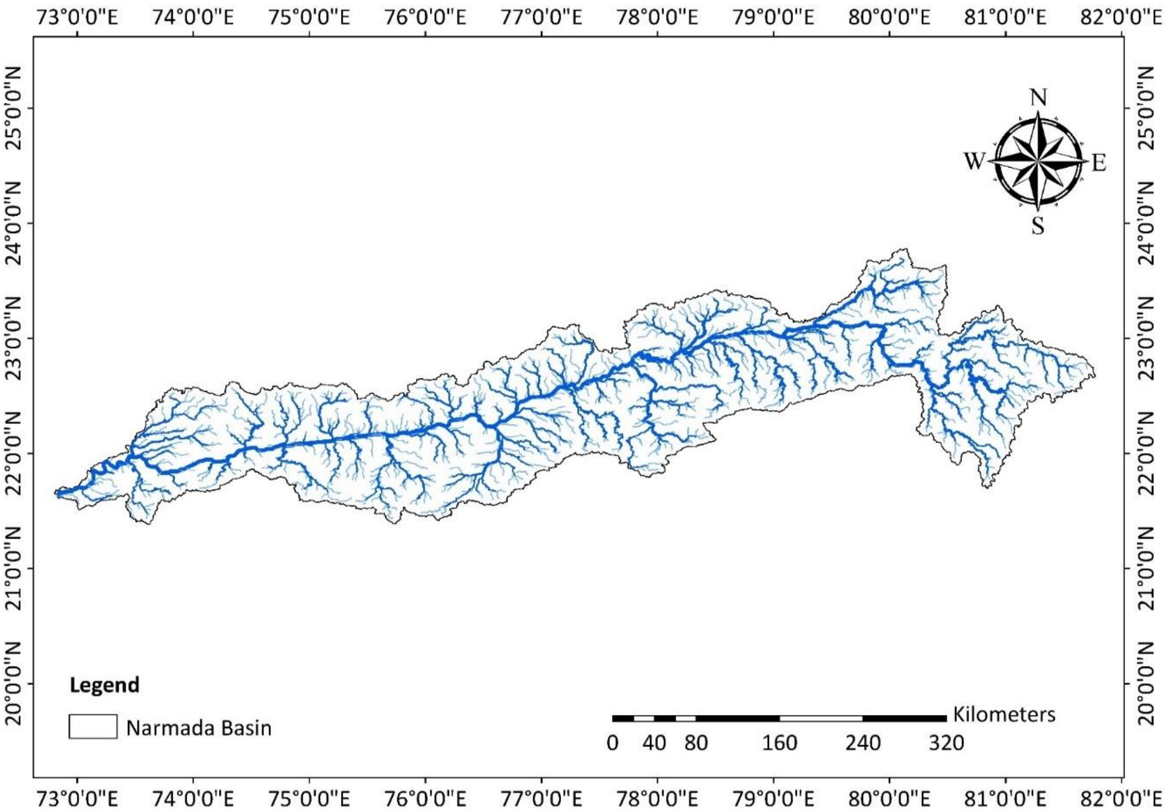


Figure 3 Narmada basin drainage map

Table 1: Salient features of the Narmada basin

S. No	State	District	Area (sq. km)	Population (Census 2011)	Growth Rate (%)	Population Density
1	Chhattisgarh	Gaurela Pendra Marwahi	0.01	336420	33.29	168.78
2		Kabirdham	627.25	822526	40.71	196.22
3		Mungeli	0.48	36450	38.29	13.13
4		Raj Nandgaon	86.61	1537133	17.79	190.61
5	Maharashtra	Dhule	1429.88	1551019	13.16	309.56
6		Nandurbar	185.66	6081322	42.24	1381.05
7	Gujrat	Bharach	65.23	2127086	29.98	577.30
8		Surat	2447.56	590297	14.75	206.64
9		Dahod	133.71	2390776	18.05	718.34
10		Narmada	3713.01	4165626	14.38	1002.59
11		Panch Mahals	3138.15	728999	19.45	216.41
12		Vadodara	535.41	749237	12.30	198.69
13	Madhya Pradesh	Alirajpur	2284.89	1701698	13.60	184.10
14		Anuppur	4029.79	1385881	27.57	253.07
15		Balaghat	3859.38	157362	12.92	15.62
16		Barwani	10.59	2371061	28.62	854.61
17		Betul	387.75	757847	19.37	233.83
18		Bhopal	3546.72	2090922	13.07	176.95
19		Burhanpur	421.55	1264219	16.63	173.15
20		Chhindwara	3936.77	1563715	19.53	221.97
21		Damoh	4977.80	2185793	25.60	265.77
22		Dewas	4769.24	704524	21.32	122.71
23		Dhar	6773.58	1310061	21.50	174.62
24		Dindori	3288.84	570465	20.25	170.19
25		East Nimar	6696.69	1241350	14.49	185.37
26		Harda	1050.92	3276697	32.88	833.15
27		Hoshangabad	4792.21	2463289	14.51	483.82
28		Indore	8.30	1025048	30.70	294.84
29		Jabalpur	1137.12	1292042	21.41	255.80
30		Jhabua	6646.46	1054905	17.97	140.53
31		Katni	4997.58	1091854	14.01	212.57
32		Mandla	4628.55	1331597	18.35	156.86
33		Narshimapura	373.65	2378458	17.63	231.53

34		Raisen	3314.78	1311332	21.54	199.02
35		Sagar	2252.39	1379131	18.22	157.48
36		Sehore	0.01	644758	24.96	140.94
37		Seoni	7690.62	1873046	22.85	231.86
38		Umaria	10.38	2050862	20.08	282.41
39		West Nimar	1679.65	1648295	25.66	273.62
40		Dhule	0.01	336420	33.29	168.78
41		Nandurbar	627.25	822526	40.71	196.22

* GIS-based calculated area: 95959.70 sq. km

Source: Narmada Basin Document, India-WRIS, Ministry of Water Resources

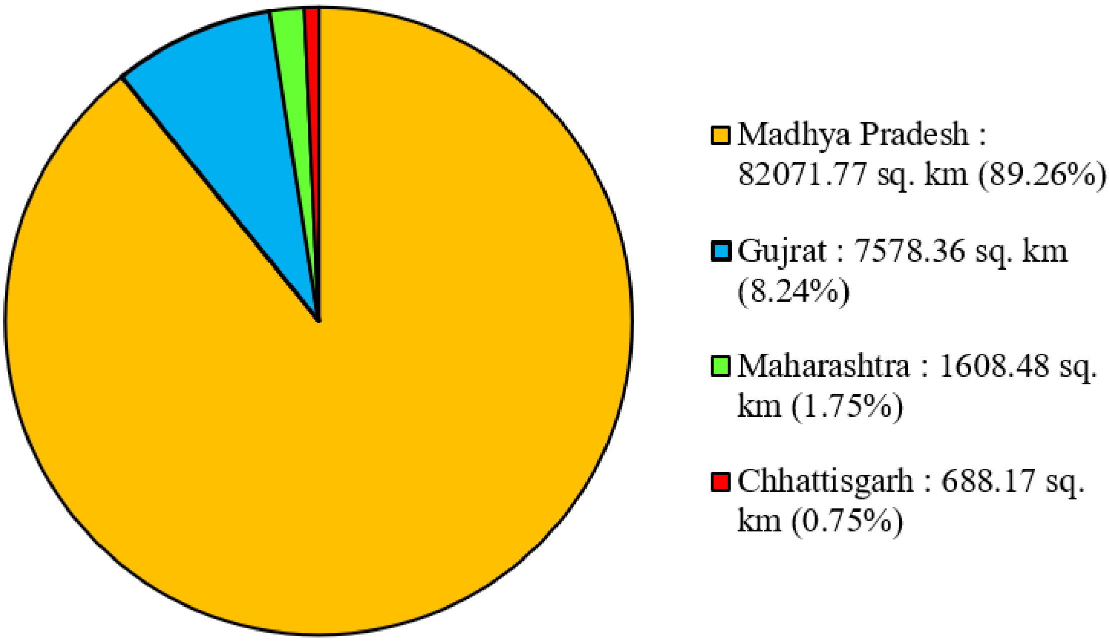


Figure 4 State-wise basin area

2 BASIN-SCALE FEATURES

2.1 Demography of the Narmada Basin

The Narmada River basin spans four Indian states: Chhattisgarh, Maharashtra, Gujarat, and Madhya Pradesh, each exhibiting diverse demographic patterns. The data reveals significant variations in area, population, growth rates, and population densities across these districts. In Chhattisgarh, Raj Nandgaon district, despite covering only 86.61 sq. km, supports a substantial population of over 1.5 million with a moderate growth rate of 17.79%, indicating a dense demographic spread. Kabirdham, with 627.25 sq. km, shows a significant population growth of 40.71%, reflecting rapid development and increasing population density.

Madhya Pradesh shows diverse demographic characteristics. Harda district, with a population growth rate of 32.88% and a density of 833.15 people per sq. km, emphasizes rapid urbanization and potential stress on resources. Conversely, the Mandla district, with a larger area of 4,628.55 sq. km and a lower population density of 156.86, indicates less demographic pressure. Districts like Hoshangabad and East Nimar are almost entirely within the basin, underscoring their geographical significance and dependence on basin resources. The demographic dynamics within the Narmada River basin suggest that areas with higher population densities and growth rates, particularly in Maharashtra's Nandurbar and Gujarat's Narmada district, may experience significant strain on water resources, agricultural land, and urban infrastructure. This variation in population densities implies differing levels of environmental impact and resource management challenges across the basin. Consequently, tailored strategies for sustainable development and conservation efforts are crucial to managing these impacts and ensuring the basin's long-term sustainability. Thus, this demographic analysis of the Narmada River basin highlights the varied degrees of dependence on the river across different districts, substantial population growth in urban areas, and significant demographic changes. These insights are vital for developing effective planning and targeted conservation efforts to ensure the sustainable development of the Narmada basin.

2.2 Topography

The Narmada basin comprises five well-defined physiographic zones: i) The Upper Hilly Areas, ii) The Upper Plains, iii) The Middle Plains, iv) The Lower Hilly Areas, and v) The Lower Plains. The elevation variation of the basin, along with their corresponding areas, is tabulated in Table 2. The highest elevation within the basin is observed to be 1231 m (CartoDEM). The spatial distribution of elevation in the basin is depicted in Figure 5. The maximum portion (27.26%) of the Narmada River basin lies within the elevation zone of 200 m to 300 m. The mean elevation of the entire Narmada basin is observed to be 355.60 m.

2.2.1 Upper hilly areas

The hilly regions of the upper part of the Narmada basin come under the Vindhyanchal-Baghelkhand region. This region is a hill-valley complex covering Annupur, Shahdol, Dindori, Mandla, Balaghat, Jabalpur, Narsimhapur, and Chhindwara districts of Madhya Pradesh within the Narmada basin. The main formations in this region include the scraps of Vindhyan sandstones and the Narmada-Son region Trough to its south. The latter is a structural dislocation along the junction of the Archeans and the Bijawars with the Vindhyans. The Narmada valley has a youthful appearance with falls, rapids, and gorges in its course. The Dhuandhar Falls (Bheraghat, 15 m), followed by a 3 km long marble gorge, is a notable example. South of the trough lies the geological and physiographic complex (eastern expansion of the Satpura), where the country's core of radial drainage, the Amarkantak (1,087 m) in the Maikala range, is located. The whole surface is an assemblage of flat-topped plateaus (Chhindwara, Seoni, Maikal, Deogarh, etc.) with a general elevation of 600-900 m.

2.2.2 Middle plains and lower hilly areas

The middle plains and the lower hilly areas fall under the Malwa region, covering Hoshangabad, Betul, East Nimar, West Nimar, Barwani, Dhar, Dewas, Sehore, and Jhabua districts of Madhya Pradesh within the basin. The Malwa region in the basin is divided into the following well-marked physiographic units: i) West Vindhyas, ii) West Narmada Trough, and iii) West Satpuras. The Vindhya range runs in a curve for the first 100 km from its western terminus, with its convex side facing the Narmada Valley. For the next 160 km, a more open type of country prevails, and the basaltic escarpment becomes more prominent near Hoshangabad. The rock type changes, and the Vindhya Range comes down very close to the Narmada River, presenting a terraced slope built of hard sandstones alternating with shales. The Western Narmada Trough is a tract of fertile land. The Narmada valley has a variable longitudinal slope and is broken up into parts separated by hills. Narmada flows through a gorge (the Mandhata gorge) carved out of Vindhyan sandstones. North of Narmada is the Dhar Upland, a hilly and forested area. The Nimar Upland stretches from east to west in the north of the Satpuras. The Western Satpuras separate the Narmada and the Tapi basins.

2.2.3 Lower plains

The lowermost part of the basin falls under the Gujarat region. The Gujarat Alluvial Plain is the outcome of extensive Pleistocene sedimentation called Coastal Alluvium. The elevation of this region ranges from 5-10 m or even less.
Understanding these physiographic zones is crucial for effective resource management and sustainable development of the Narmada River basin.

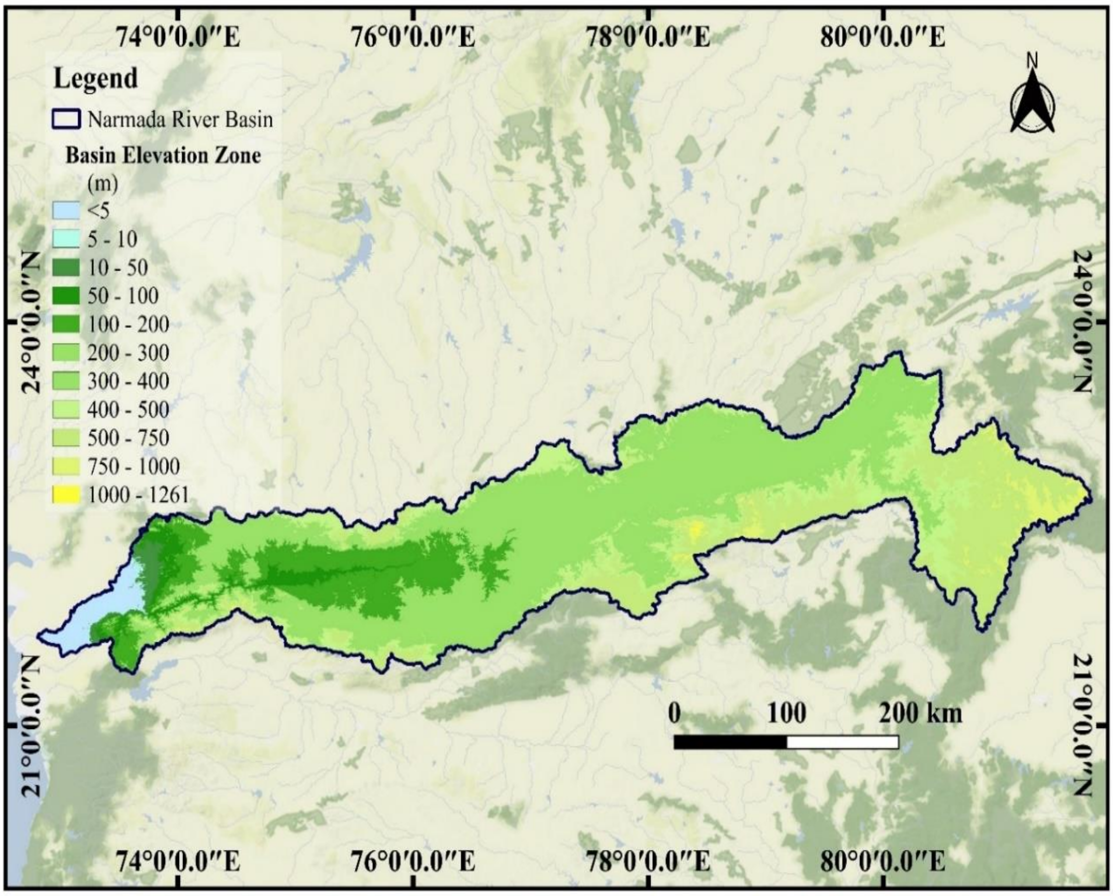


Figure 5 Spatial distribution of elevation zones

Table 2: Elevation zones of the Narmada basin

S. No	Elevation (m)	Area (sq. km)	% of Total Area
1	< 5	2325.72	2.42
2	5 - 10	145.22	0.15
3	10 – 50	1077.61	1.12
4	50 – 100	2325.01	2.42
5	100 -200	11208.4	11.68
6	200 – 300	26154.6	27.26
7	300 – 400	19481.9	20.30
8	400 – 500	12335.7	12.86
9	500 -750	17654.3	18.40
10	750 – 1000	3114.34	3.25
11	1000 - 1261	136.4	0.14
Highest Elevation: 1261 m			

(Note: based on Cartosat DEM)

2.3 Climate

The Narmada basin is crossed by the Tropic of Cancer in the upper plains area, with major portions of the basin lying just below this line. The basin's climate is humid and tropical, with scattered locations exhibiting extremes of heat and cold.

The basin experiences four distinct seasons: i) Cold weather, ii) Hot weather, iii) South-west monsoon, and iv) post-monsoon. The cold weather season commences in November and continues till the end of February, characterized by bright, cloudless weather. Light precipitation is observed in the basin during this season. The hot weather starts in March and continues up to the middle of June, with May usually being the hottest month. This season is generally dry. The south-west monsoon winds set in by mid-June and withdraw by the first week of October, making June to September the rainiest period. In the post-monsoon season, a few thunderstorms occur, especially in October. Thereafter, the weather clears up, and dry, pleasant weather prevails throughout the valley (Source: Report of Irrigation Commission, 1972).

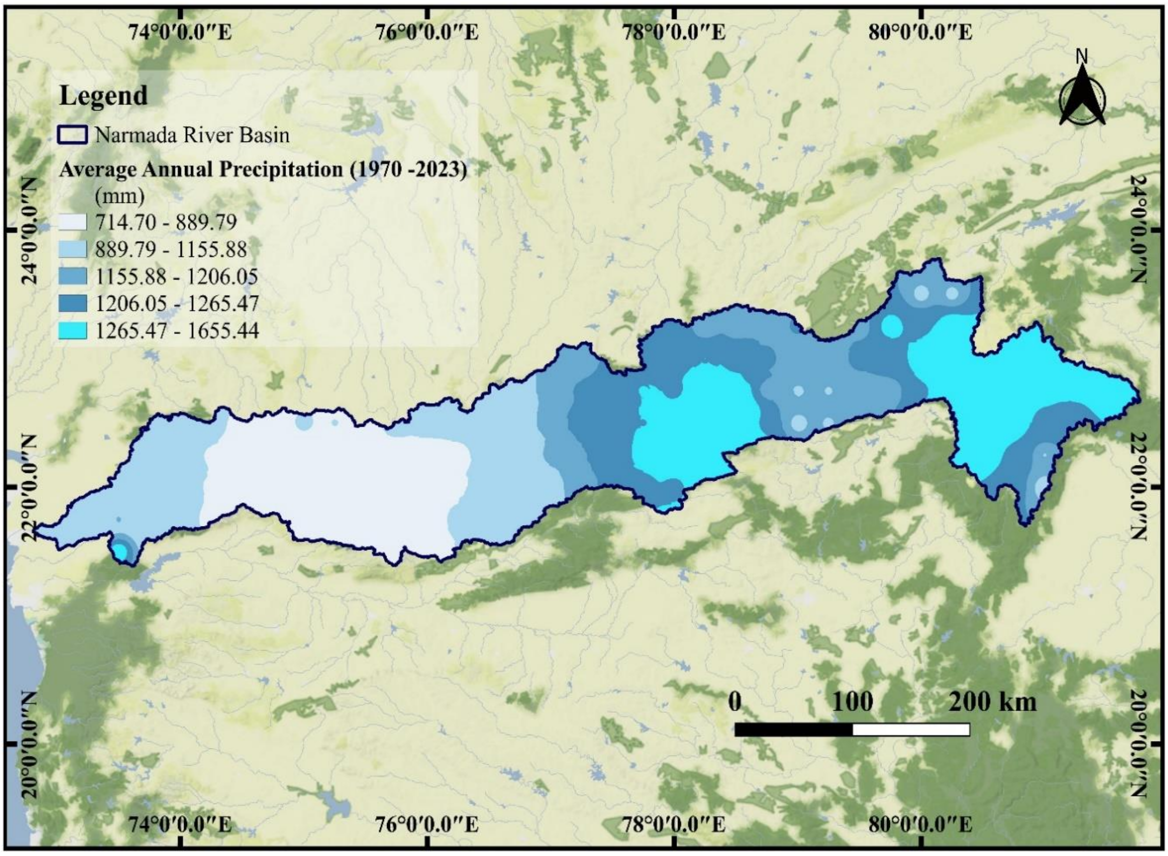


Figure 6 Spatial distribution of precipitation (1970 – 2023) Source: IMD gridded data (0.25° X 0.25°)

2.3.1 Rainfall

Rainfall is heavy in the upper hilly and upper plains areas of the northeastern portion of the basin. It gradually decreases towards the lower plains of the west, with scattered regions near the coastal and southwestern areas exhibiting higher precipitation. This spatial distribution of rainfall is depicted in Figure 6. Understanding the climate and rainfall patterns is essential for managing the water resources and agricultural activities in the Narmada basin effectively.

2.3.2 Temperature

Temperature variations in the Narmada basin are significant, with mean annual temperatures ranging from 24.92°C to 27.39°C. The spatial distribution of temperature is illustrated in Figure 7, showing higher temperatures predominantly in the western parts of the basin. This temperature gradient affects the local climate and agricultural patterns, making it essential to consider these variations in resource management strategies.

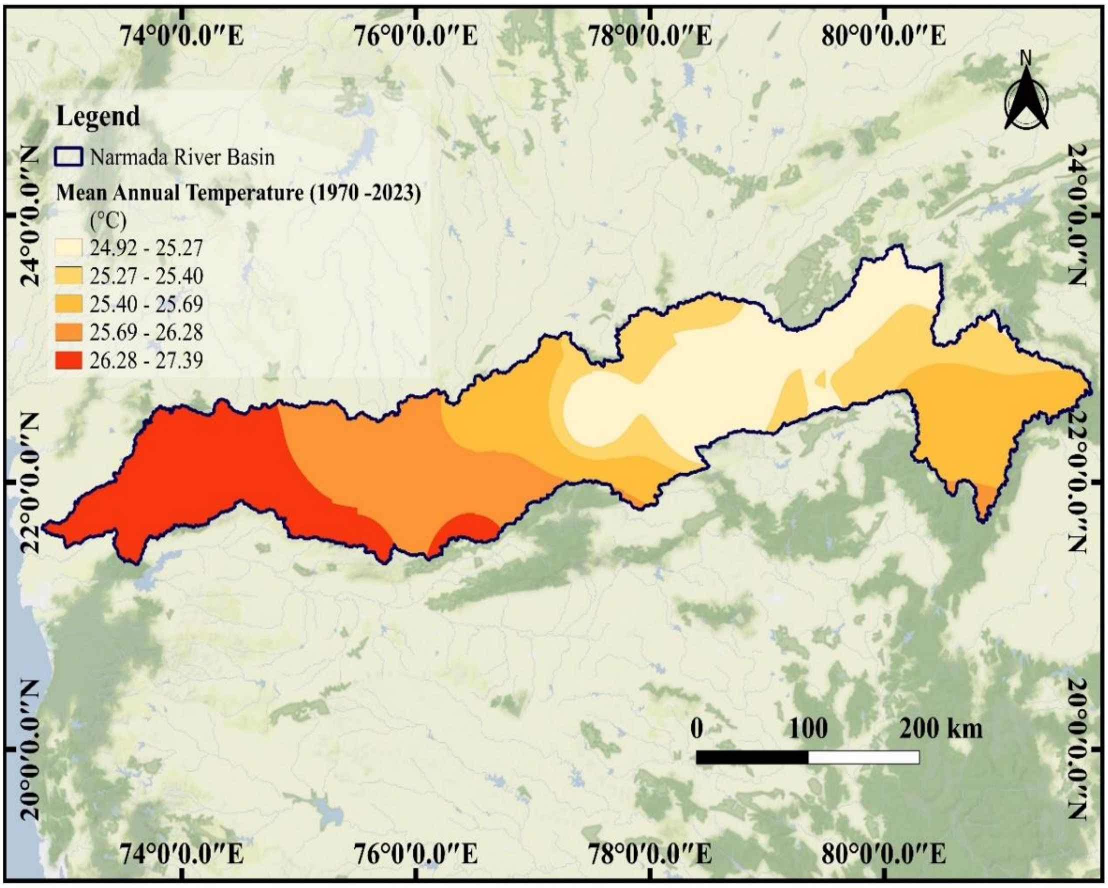


Figure 7 Spatial distribution of temperature (1970 – 2023) Source: IMD gridded data (0.5° X 0.5°)

2.3.3 Trends and Variability

The annual rainfall in the Narmada basin has shown considerable fluctuations over the years. Some years experienced significantly higher rainfall, such as 1972, 1975, 1980, 1990, 1994, 2013, and 2016, where the rainfall exceeded 1400 mm. Conversely, there were years like 1973, 1985, 1987, 2002, 2004, and 2009 where the annual rainfall was much lower, dropping below 800 mm.

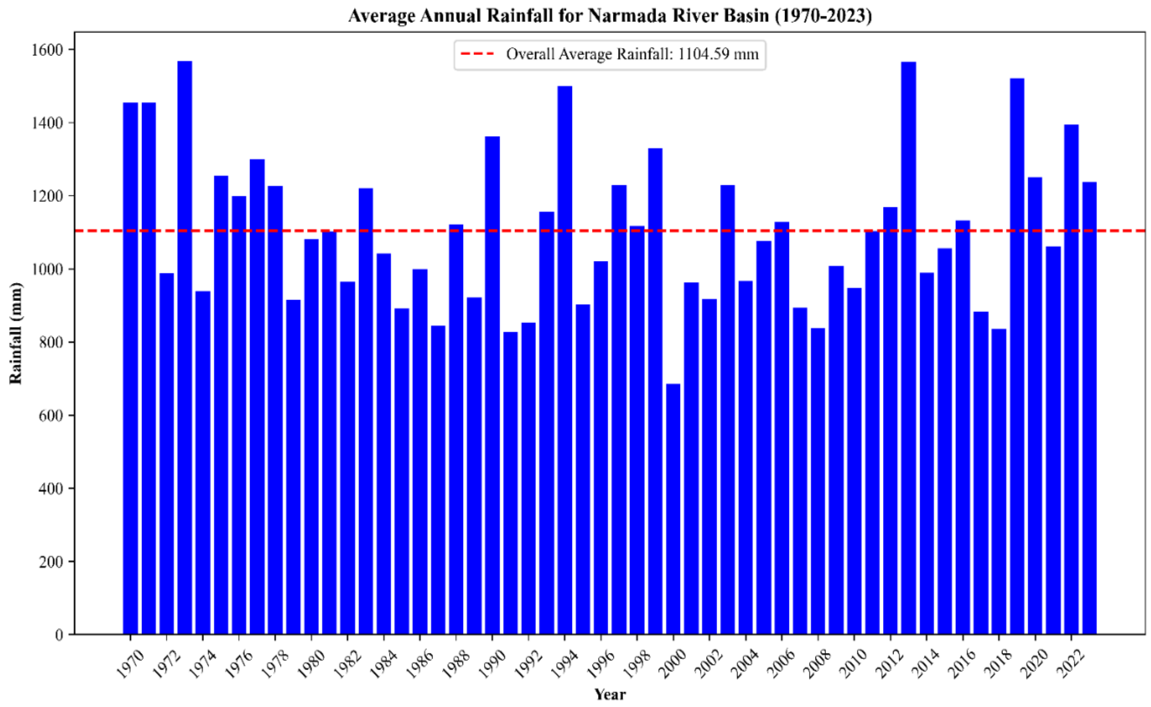


Figure 8 Trends of Annual Rainfall (1970 -2023)

Figure 8 illustrates the average annual rainfall for the Narmada River basin over a period from 1970 to 2023. The data is represented in the form of blue bars, with each bar corresponding to the total annual rainfall in millimetres (mm) for a particular year. A red dashed line indicates the overall average annual rainfall for this period, which is 1104.59 mm. Despite the fluctuations, there does not appear to be a clear increasing or decreasing trend in the average annual rainfall over the entire period. The overall average annual rainfall (1104.59 mm) provides a benchmark for assessing individual years. It can be observed that approximately half of the years recorded rainfall below this average, while the other half exceeded it.

The years 1972, 1980, 1990, 2013, and 2016 stand out as years with exceptionally high rainfall, significantly surpassing the overall average. On the other hand, 2002 and 2009 are notable for having some of the lowest recorded rainfall, indicating potential drought conditions during those periods.

Figure 9 presents the monthly average temperatures for the Narmada River basin from 1970 to 2023. It shows three sets of data for each month: maximum temperatures (in orange), mean temperatures (in blue), and minimum temperatures (in light blue). Additionally, the chart includes average temperature markers: the average maximum temperature (39.539°C, red dashed line), the average mean temperature (25.68°C, green dashed line), and the average minimum temperature (11.17°C, purple dashed line).

The minimum temperatures are at their lowest, particularly in January, where they drop close to 10°C. The maximum temperatures in these months remain below 30°C. The temperatures rise significantly, with the highest maximum temperatures observed in May, nearing 40°C. This indicates that May is typically the hottest month in the basin. There is a slight drop in maximum temperatures due to increased cloud cover and rainfall, but the temperatures remain high, with maximums around 30-35°C. Mean and minimum temperatures are relatively stable during this period. Temperatures begin to decrease, with maximum temperatures falling below 30°C by November and minimum temperatures dropping to around 15°C.

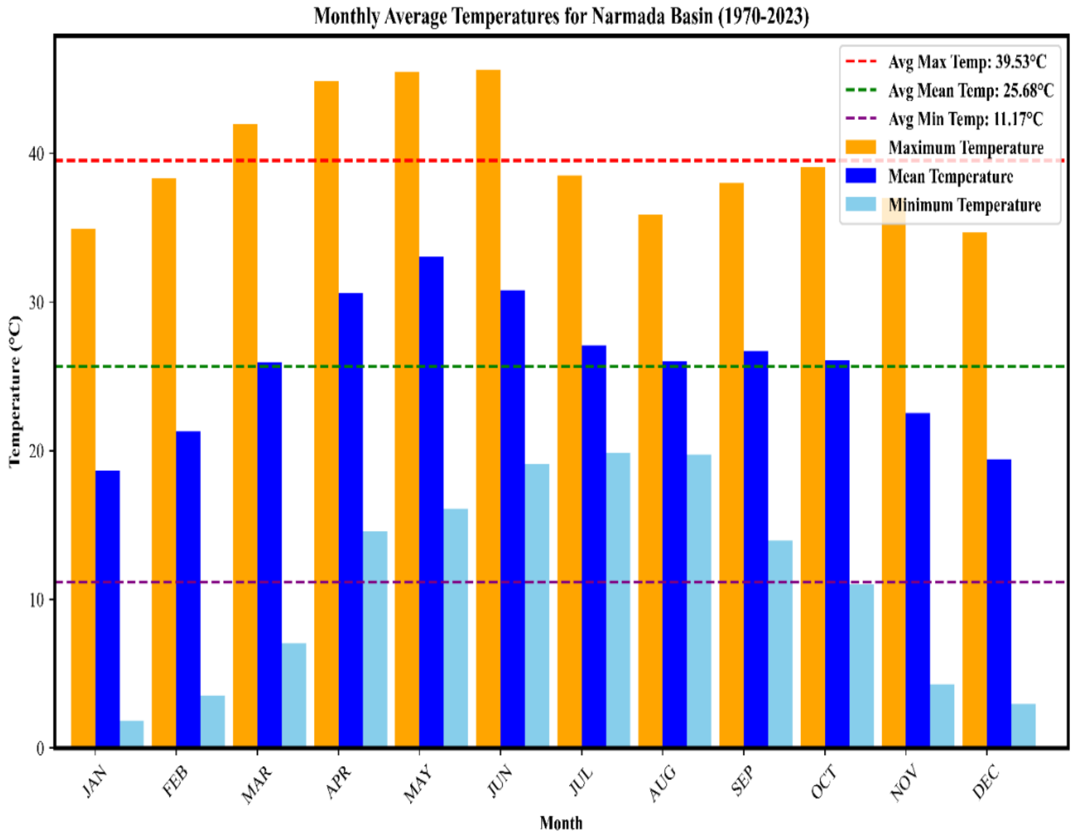


Figure 9 Trends in monthly average temperature (1970 -2023)

2.4 Major Rivers

The table detailing the sub-basins within the Narmada River basin reveals significant findings about their geographic characteristics. The Tawa sub-basin, with an area of 6,491.35 sq. km and a perimeter of 570.93 km, stands out as the largest, highlighting its substantial role in the basin's hydrology. Following closely is the Chota Tawa sub-basin, covering 5,236.47 sq. km with a perimeter of 549.18 km. Medium-sized sub-basins such as Hiran (4,683.41 sq. km), Burhner (4,285.23 sq. km), and Orsang (3,953.53 sq. km) indicate their significant but comparatively moderate contributions. In contrast, the smallest sub-basins, like Kolar (1,268.06 sq. km) and Man (1,524.14 sq. km), play a lesser yet still important role. The geographic spread of these sub-basins reflects the diverse topography (Table 3), including hilly terrains, plains, and valleys, influencing river flow and water distribution. This diversity necessitates tailored water management strategies, especially for larger sub-basins like Tawa and Chota Tawa, which demand extensive oversight. The varied sizes and perimeters of the sub-basins also suggest a range of ecological habitats, with larger areas supporting more biodiversity. Additionally, regions within these larger sub-basins likely experience more agricultural and economic activity due to better water availability. Consequently, effective management practices are crucial to sustaining agriculture, livelihoods, and ecological balance across the Narmada basin.

Table 3: Major sub-basin description

Sub-basin Name	Area (Sq. km)	Perimeter (km)
Banjar	3537.24	498.14
Barna	1658.98	267.62
Beda	3928.57	382.50
Burhner	4285.23	459.46
Chota Tawa	5236.47	549.18
Dudhi	1607.17	277.72
Ganjal	1908.31	318.33
Goi	1925.11	357.77
Hiran	4683.41	498.93
Karjan	1543.38	278.25
Man	1524.14	278.25
Orsang	3953.53	452.19
Shakkar	2308.72	338.65
Sher	2875.43	343.09
Tawa	6491.35	570.93
Tendoni	1665.24	294.54
Hatni	2011.86	295.47
Kolar	1268.06	243.83
Uri	1913.12	253.57

2.5 Land use and land cover

The land use and land cover analysis of the Narmada River basin in 2021 reveals a predominantly agricultural landscape, with cropland covering 55,150.10 sq. km, accounting for 57.47% of the total area. Tree cover is the second most extensive land cover type, spanning 16,320.09 sq. km and representing 17.01% of the basin (Table 4). Grassland areas, covering 15,641.39 sq. km, make up 16.30% of the basin, while shrubland occupies 2,080.93 sq. km or 2.17% of the area. Built-up areas, although small in comparison, cover 914.21 sq. km, constituting 0.95% of the basin. Bare or sparse vegetation accounts for 3,617.54 sq. km, making up 3.77% of the area. Permanent water bodies are significant, covering 2,233.22 sq. km, or 2.33% of the basin. Herbaceous wetlands are the least extensive, occupying only 2.22 sq. km, a mere 0.002% of the total area (Figure 10).

Table 4: Areal distribution of landuse and landcover

Land Use Land Cover Category	Area (Sq. km)	% of Total Area
Tree Cover	16320.09	17.01
Shrubland	2080.93	2.17
Grassland	15641.39	16.30
Cropland	55150.10	57.47
Built-up	914.21	0.95
Bare/Sparse Vegetation	3617.54	3.77
Permanent Water Bodies	2233.22	2.33
Herbaceous Wetland	2.22	0.002

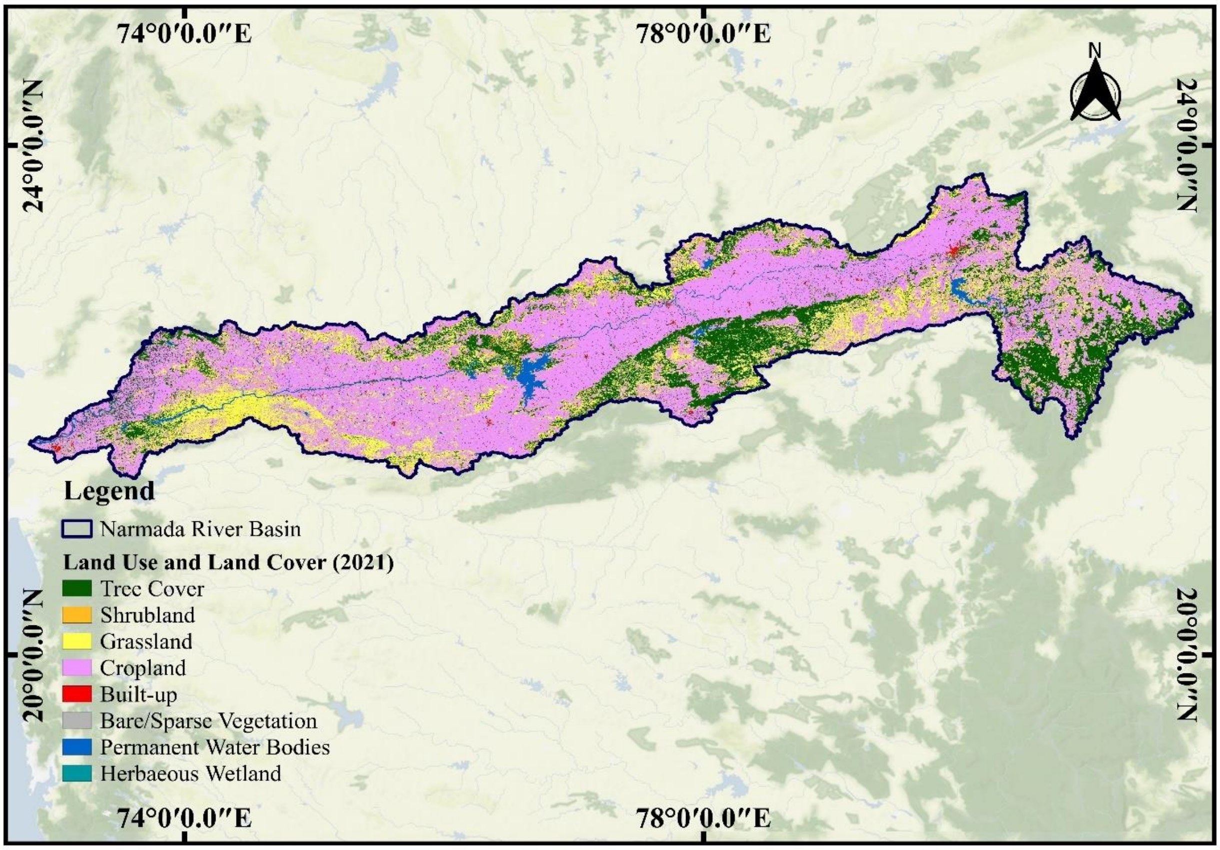


Figure 10 Spatial variation of landuse and landcover

2.6 Soil characteristics

The central and extensive parts of the basin are predominantly covered by clay loam soils, depicted in yellow, which are known for their balanced texture and fertility, making them highly suitable for agriculture

(Figure 11). Surrounding these areas, particularly towards the eastern and southeastern regions, loam soils are prevalent. These soils are also agriculturally productive due to their good drainage properties and nutrient content. In contrast, the northeastern and southwestern extremities of the basin exhibit pockets of clay soils, which tend to retain water and are ideal for crops requiring consistent moisture. Additionally, the northwestern fringes and small areas in the northeast contain sandy clay loam soils, which offer a mix of sandy and clay characteristics suitable for specific crop types that can tolerate varied moisture levels. This varied soil distribution highlights the basin's agricultural potential.

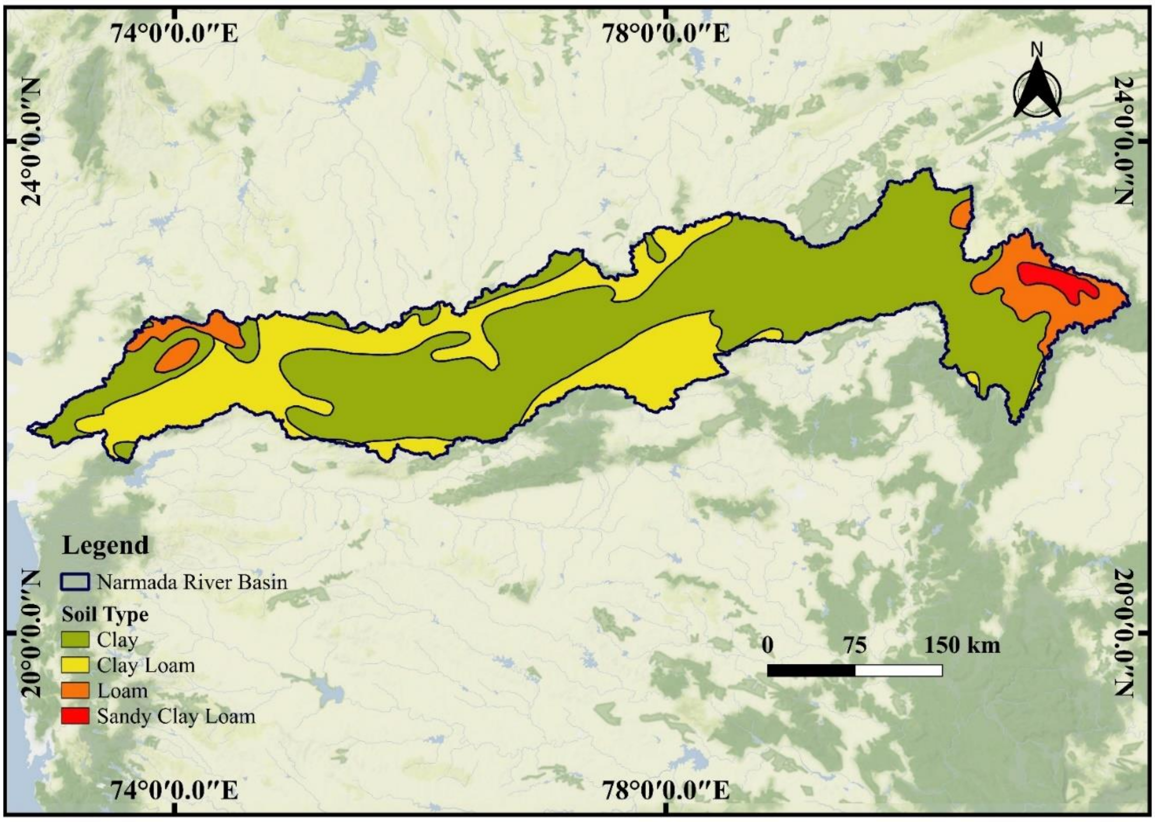


Figure 11 Spatial distribution of soil type

2.7 Distribution of slope

The slope map (Figure 12) of the Narmada River basin varies from nearly level to very steep slopes. The majority of the basin is characterized by nearly level and very gently sloping areas, particularly prominent in the central and northern parts, indicating large tracts of flat and arable land suitable for extensive agricultural activities and easy mechanisation. Moving towards the fringes of these central areas, gently sloping and moderately sloping terrains become more common, suggesting a gradual increase in elevation and a potential for diverse cropping patterns and minor terracing for agriculture.

In contrast, the southern and eastern edges of the basin exhibit strongly sloping and moderately steep to steep sloping regions, indicating significant elevation changes. These areas are likely to be less suitable for conventional farming but ideal for plantation agriculture, forestry, and possibly hydroelectric projects due to the steep gradients. The presence of very steep sloping zones in these peripheral areas underscores the challenging terrain, which may be prone to erosion and landslides, necessitating specialised soil conservation and watershed management practices.

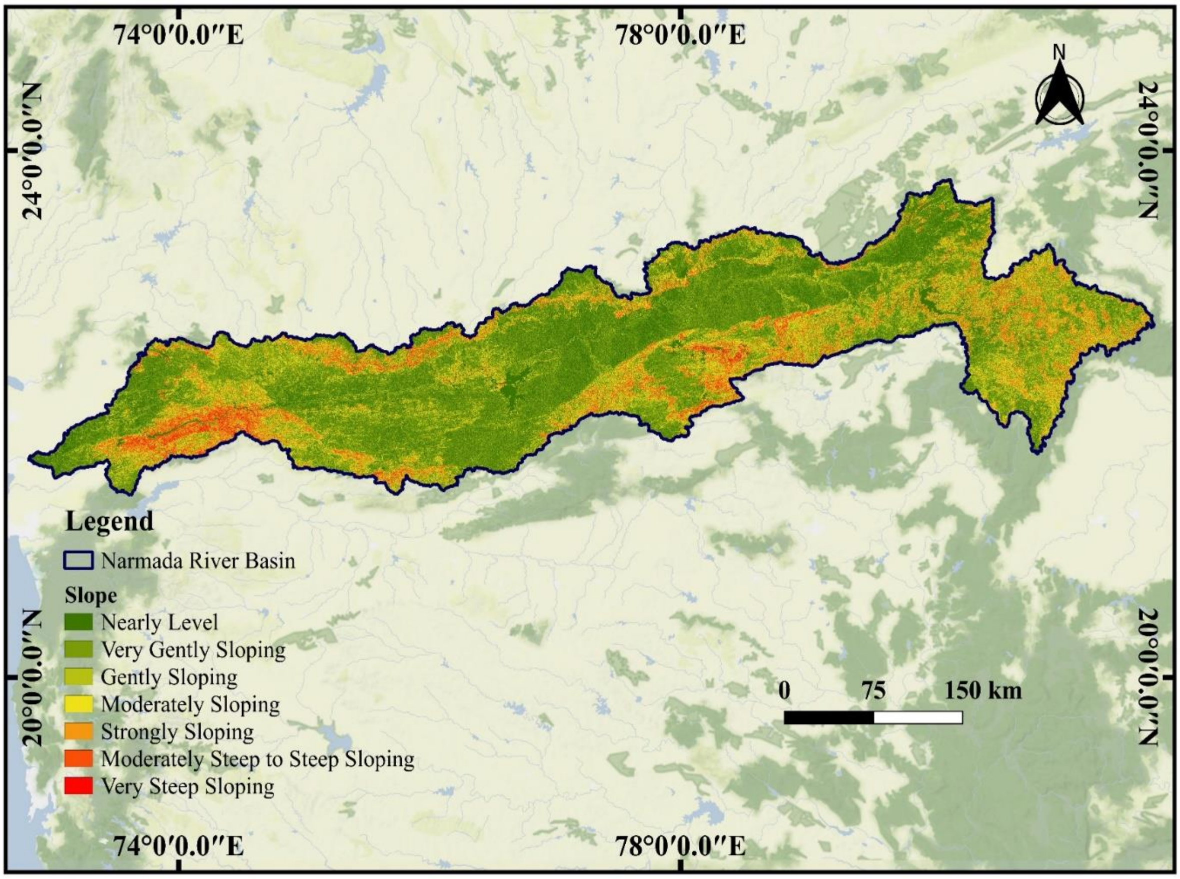


Figure 12 Spatial distribution of slope

2.8 Vegetation characteristics

The vegetation map depicts the density of the tree cover for the Narmada basin (Figure 13). The negative NDVI values in the map represent the waterbodies like reservoirs and other non-vegetative features. The areas having low NDVI are barren lands with little vegetation cover. Higher NDVI values show the areas in the Narmada basin which have deciduous forest cover, shrubs, grasslands, or crops.

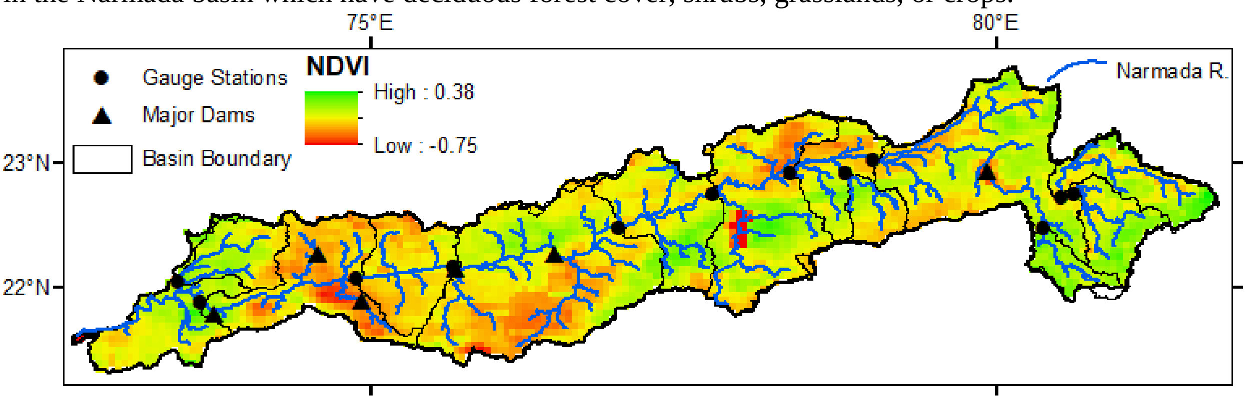


Figure 13 Vegetation map (NDVI)

2.9 Sediment yield

The sediment yield varies along the river stretches, with each sub-basin having varied yields (Figure 14). There is a temporal and spatial variation of sediment load throughout the basin. The annual sediment loads of Narmada River vary from 3.32×10^{6} t to 28.93×10^{6} t at various gauging stations in the basin. The sediment yield at Garudeshwar (downstream gauging station) is 329.24 t km^{-2} $year^{-1}$ (Gupta and Chakrapani, 2005). However, there has been a significant decrease in sediment flux over the years due to the construction of dams across the river, which trap the sediment in the reservoirs.

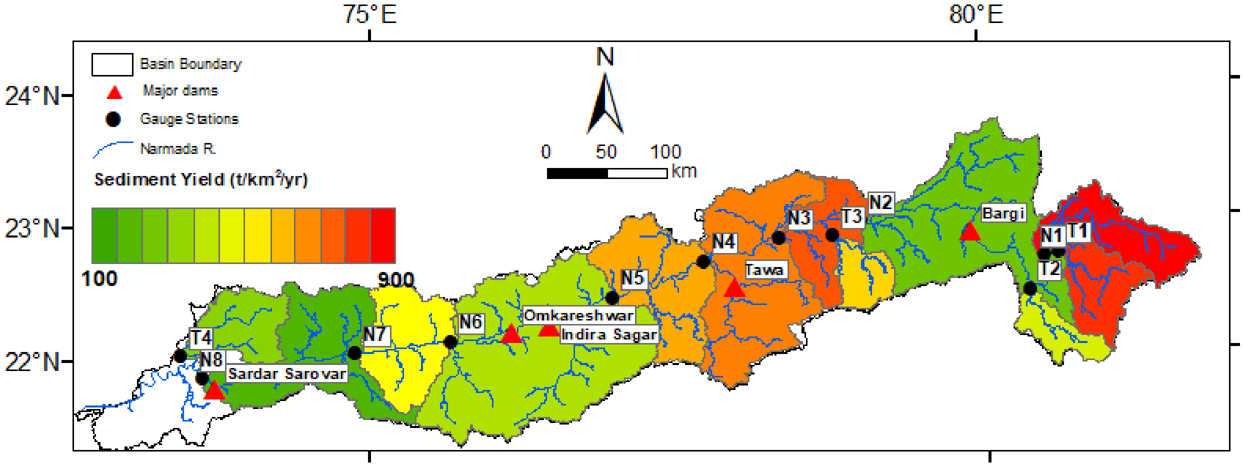
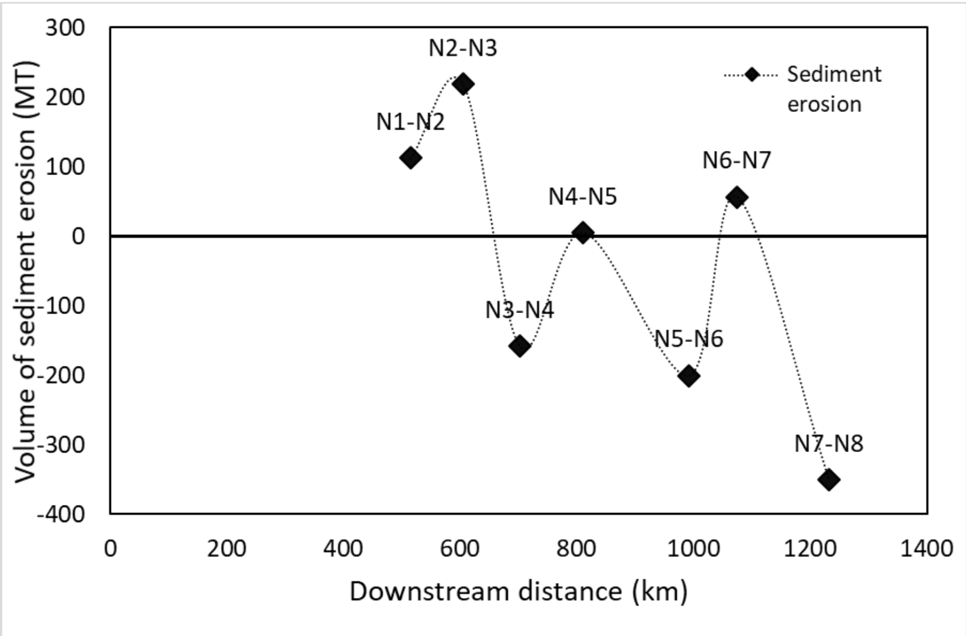


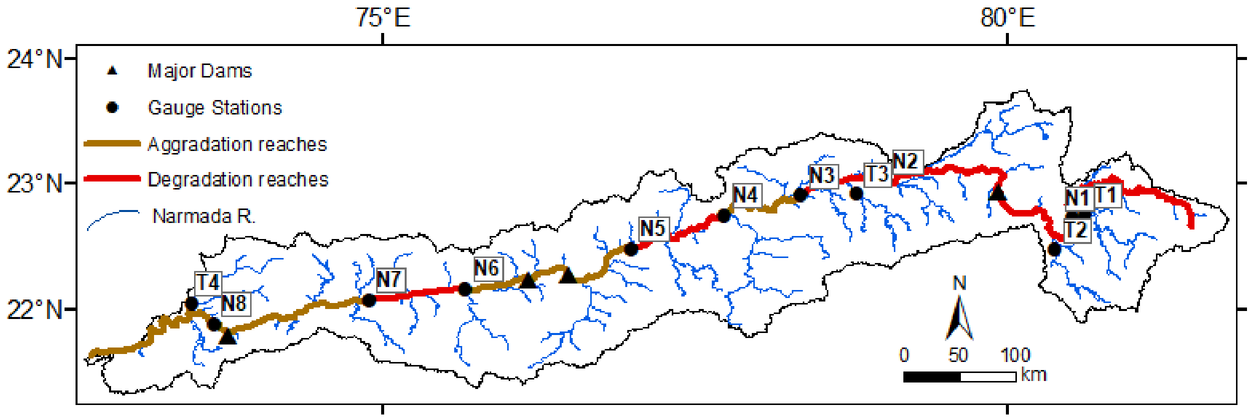
Figure 14 Sediment yield in the Narmada basin

2.10 Gradation

The gradation map of the Narmada River (Figure 15) shows the erosion and deposition characteristics of the various river stretches. The upstream reaches show degradation, while the mid-stream and downstream reaches are deposition-dominated. These downstream deposition sites could provide possible sediment mining sites.



(a)



(b)

Figure 15 (a) Volume of sediment erosion in Narmada River stretches, (b) Gradation characteristics in Narmada River stretches

3 SIGNIFICANCE OF NARMADA BASIN

3.1 Historical

The Narmada River basin encompasses early human history, religious and cultural heritage, strategic importance for historical kingdoms, and modern socio-economic and environmental issues.

3.1.1 Ancient Civilizations and Archaeology

The Narmada River basin is believed to have been inhabited by humans for thousands of years. Archaeological evidence of ancient human settlements, including stone tools and other artefacts from the Stone Age, has been found on the banks of the river, indicating the presence of early hunter-gatherer communities. Excavations in the basin have uncovered Palaeolithic sites, providing insights into early human life and activities. The region is rich in fossils, including those of prehistoric animals and early Humans. The Fossils National Park in Mandla district of Madhya Pradesh contains plant fossils from 40 to 150 million years ago collected from surrounding villages.

3.1.2 Historical Kingdoms and Empires

The Narmada basin has been home to several ancient and medieval kingdoms, including the Maurya and Gupta Empires. Due to its geographical location, the Narmada River basin has been strategically important for various empires and rulers. It served as a natural boundary and a crucial route for trade and military movements.

3.1.3 Heritage and Architecture

The region boasts several architectural marvels, including ancient temples and forts. Notable examples include the temples at Omkareshwar and Maheshwar, which are important centres of pilgrimage and architectural heritage. Numerous inscriptions, manuscripts, and literary works have been discovered in the Narmada basin, providing valuable information about the history, culture, and socio-economic conditions of the past.

3.1.4 Modern history

In recent history, the Narmada River gained international attention due to the Narmada Bachao Andolan (Save the Narmada Movement), which protested against the construction of large dams on the river. The movement highlighted issues related to displacement, environmental impact, and the rights of indigenous communities. The Narmada River basin currently plays a crucial role in the region's economic development. It supports agriculture, provides water for irrigation, and is a source of hydroelectric power.

3.2 Socio-cultural

3.2.1 Mythological

The Narmada is mentioned in ancient Indian texts such as the Mahabharata and the Ramayana. According to the Matsya Purana, the banks of the Narmada are considered sacred. The Rewa Khand states that the Narmada was created from Shiva's perspiration while he was performing penance on Mount Riksha, making it Shiva's daughter. Another legend speaks of two teardrops from Brahma's eyes that created the Narmada and the Son rivers. The river is also revered for the unique pebbles known as banalinga, found on its riverbed. These linga-shaped pebbles are considered the personified form of Shiva.

3.2.2 Religious

The Narmada Parikrama is a significant religious pilgrimage involving the circumambulation of the river. Pilgrims walk along the river's banks, visiting numerous temples and holy sites. Important religious sites along the Narmada include the Omkareshwar and Maheshwar temples (Figure 16), which draw devotees from across India. The river is worshipped as the mother goddess Muktidayani or liberating mother. Adi Shankara, a prominent Hindu philosopher, met his guru, Govinda Bhagavatpada, in Omkareshwar, a town on the banks of the Narmada. Considered a purifier in Hinduism, people come to the Narmada for holy dips, performing last rites, and seeking blessings. Festivals like Narmada Jayanti, celebrating the river's birthday, are significant cultural events involving rituals, prayers, and communal gatherings.

Nilkanthdham Poicha

Shoolpaneshwar temple

Omkareshwar

Narmada Udgam Temple, Amarkantak

Sidhdheshwar Mahadev temple

Neelkanth Mahadev temple

Figure 16 Religious Sites in the Narmada river basin

Sources: https://nilkanthdham.org/ , https://utsav.gov.in , https://shriomkareshwar.org , https://anuppur.nic.in , https://asibhopal.nic.in, https://bharuch.nic.in

3.3 Ecological

The Narmada River is ecologically significant for its role in sustaining biodiversity, providing essential ecosystem services, and supporting human livelihoods. The basin is a biodiversity hotspot with the Narmada River Valley and surrounding uplands home to dry deciduous forests with species such as Tectona grandis (teak), Diospyros melanoxylon, and Anogeissus latifolia. Riparian zones along the river support moist evergreen forests with dominant species like Terminalia arjuna and Syzygium cumini. The region hosts 76 species of mammals and 276 species of birds. The river supports aquatic life such as fish species, the critically endangered softshell turtle, and the endangered Gangetic dolphin.

The basin has several conservation areas like the Kanha National Park, known for its diverse wildlife, including tigers and various ungulates; Satpura National Park, which features species like the sloth bear, black buck, and flying squirrel, Mandla Plant Fossils National Park; which preserves fossilised plants dating back millions of years, providing insights into prehistoric life and past climatic condition, Pachmarhi Biosphere Reserve and Shoolpaneshwar Sanctuary Covers, supporting a wide range of plant, birds and animal species typical of the central highland region.

3.4 Political

The Narmada Bachao Andolan (NBA) is a prominent social movement protesting against the construction of large dams on the Narmada. The movement highlights the displacement of thousands of people and the environmental damage caused by these projects. Flowing through Madhya Pradesh, Gujarat, and Maharashtra, the Narmada has been the centre of water-sharing disputes. The Narmada Water Disputes Tribunal was established to address these issues. The Sardar Sarovar Dam is central to various development projects aimed at providing irrigation, drinking water, and electricity. However, these projects have been contentious due to their environmental and social impacts.

3.5 Narmada Biodiversity at a Glance

The Narmada River flows through the Satpura and Vindhya mountain ranges, which are known for their diverse ecosystems. These ranges support a wide variety of plant and animal species, many of which are endemic. The region's unique topography and climate enhance the high levels of biodiversity found here.

Several protected areas within the Narmada River Basin aim to conserve critical habitats and endangered species, including the Bengal tiger, Indian leopard, Indian bison (gaur), and various bird species.

3.5.1 Flora and Fauna

Several prominent national parks and wildlife sanctuaries grace the Narmada Valley with rich wildlife, including tiger, leopard, sambar, chital, nilgai, four-horned antelope, chinkara, gaur, wild boar, wild dog, sloth bear, black buck, fox, mouse deer, otters, bats, Indian flying squirrel, and Indian giant squirrel (Figure 17). The flora of these national parks mainly comprises Sal (Shorea robusta), Teak (Tectona grandis), Tendu (Diospyros melanoxylon), Aonla (Phyllanthus emblica), Mahua (Madhuca longifolia), Bael (Aegle marmelos), Bamboo (Dendrocalamus strictus), and various grasses and medicinal plants. Beyond protected areas, the forested regions harbour significant floral and faunal diversity.

The Narmada River Basin hosts a diverse range of amphibians and reptiles as well. Frogs and toads are commonly found, while freshwater turtles and water snakes are prevalent along the river. The critically endangered Gharial, a type of crocodile, also inhabits parts of the river, underscoring the need for conservation efforts. Both resident and migratory birds, such as kingfishers, egrets, herons, and the Indian Skimmer, hornbills and peafowl are commonly sighted. The basin is rich in invertebrates, including various insects, molluscs, and crustaceans.

Riparian vegetation along the Narmada includes bamboo, Sal, and Teak trees. The floodplains support grasses and shrubs, crucial for preventing soil erosion and maintaining riverbank stability. The river supports a variety of aquatic plants such as Hydrilla, Vallisneria, and Lotus. These plants are essential for maintaining the river's health, providing habitat and food for numerous aquatic organisms, and aiding oxygenation and water purification processes. The river hosts a high diversity of microorganisms, which facilitate nutrient cycling, decomposition, and maintaining water quality, thereby supporting higher trophic levels.

Indian Gaur Bison Bison (Bos gaurus)

Sambar (Rusa unicolor)

Bengal Tiger (Panthera tigris)

Leopard (Panthera pardus fusca)

Indian wild dog (Cuon alpinus)

Sloth bear (Melursus ursinus)

Barasingha/Swamp deer (Rucervus duvaucelii)

Wild Boar (Sus scrofa)

Peafowl (Pavo cristatus)

Indian paradise flycatcher (Terpsiphone paradisi)

Indian pitta (Pitta brachyura)

Common Emigrant (Catopsilia pomona)

Indian Roller (Coracias benghalensis)

Malabar Pied Hornbill (Anthracoceros coronatus)

Painted Stork (Mycteria leucocephala)

Crested Serpent Eagle (Spilornis cheela)

Figure 17 Notable animal and birds species in the Narmada basin

Sources: Satpura Tiger Reserve official website (https://www.satpuratigerreserve.org/), Kanha Tiger Reserve official website (https://www.kanhatigerreserve.org/), Kanha Jungle Camp website (https://kanhajunglecamp.com/)

3.5.2 Fisheries

The Narmada River is home to over 100 species of fish, including several endemic and migratory species. Notable species include the Mahseer, a prized game fish, and various catfish species, which are vital for local fisheries and the livelihoods of communities along the river (Figure 18). Research on the Narmada River system's fisheries shows significant changes in fish populations and production. Initially, 40 species were reported by Hora and Nair (1941), with later studies identifying up to 84 species. However, comprehensive documentation remains incomplete. Narmada's fish production ranked lower compared to East Coast river systems. Fish production in Madhya Pradesh rose from 269.8 mt in the 1960s to 300.0 mt in 1971-1972 but plummeted to 100.0 mt by 1991 post-impoundment. Carp and Catfish populations declined by 17% and 36% in two decades, while miscellaneous species increased by 410%, reflecting shifts in habitat conditions and species composition.

In the lower Broach-Baroda plains, fisheries consisted of Hilsa (Tenualosa ilisha), Freshwater Carps, Catfish, and estuarine species. However, the installation of the Sardar Sarovar dam upstream at Vedgam disrupted river flow dynamics, leading to substantial changes in hydro-ecological conditions and subsequent impacts on fisheries. Carp species (Tor tor, Labeo fimbriatus, and L. dyocheilus) and Gegra (Rita pavimentata) declined due to habitat loss affecting both commercial fisheries and egg production potential. Mahseer (Tor tor) production in the Narmada River dropped significantly from 330 t in 1992-1993 to 53 t in 1996-1997, underscoring conservation concerns. Giant freshwater Prawn (Macrobrachium rosenbergii) fisheries also declined due to altered habitats caused by controlled riverbed flooding and depth changes. Hilsa experienced shifts in migration patterns and breeding grounds due to dam impacts. Hilsa's breeding range reduced from 160 km to 100 km, and annual catches decreased from 16,000 t in 1990-1991 to 4,000 t by 2007-2008.

Mahseer

Catfish

Hilsa

Labeo fimbriatus

Macrobrachium rosenbergii

Tenualosa ilisha

Tor Tor

L. dyocheilus

Figure 18 Fisheries in Narmada river basin

Sources: https://www.wwfindia.org/, https://oralhistorynarmada.in, https://oralhistorynarmada.in, https://www.fao.org, https://indiabiodiversity.org, https://indiabiodiversity.org, https://fishbase.mnhn.fr/

4 NARMADA SEGMENT-WISE FEATURES

4.1 Upper Narmada

The Narmada River originates from a small reservoir known as the Narmada Kund, located at Amarkantak on the Amarkantak Plateau in the Anuppur District within the Shahdol zone of eastern Madhya Pradesh at coordinates 22°40′0″N 81°45′0″E, and an elevation of 1,048 m. From Sonmuda, the river descends and cascades over a cliff as the Kapildhara waterfall, then meanders through the hills, navigating a twisting path across rocks and islands up to the ruins of Ramnagar palace. Between Ramnagar and Mandla, a distance of 25 km to the southeast, the river follows a straighter course with deep, rock-free water, joined by the Banger from the left. The river then curves northwest in a narrow loop towards Jabalpur. Near this city, after a drop of about 9 m at Dhuandhara, known as the fall of mist, it flows through a deep, narrow channel carved into magnesium limestone and basalt rocks, known as the Marble Rocks. Here, the river narrows dramatically from a width of about 90 m to just 18 m. In the direction of flow, Halon, Banjar, Bargi, Shakkar, and Dudhi are the major tributaries on the left side of the main channel, and Hiran, Shahdol, Tendoni, and Barna are the major tributaries on the right side of the channel (Figure 19).

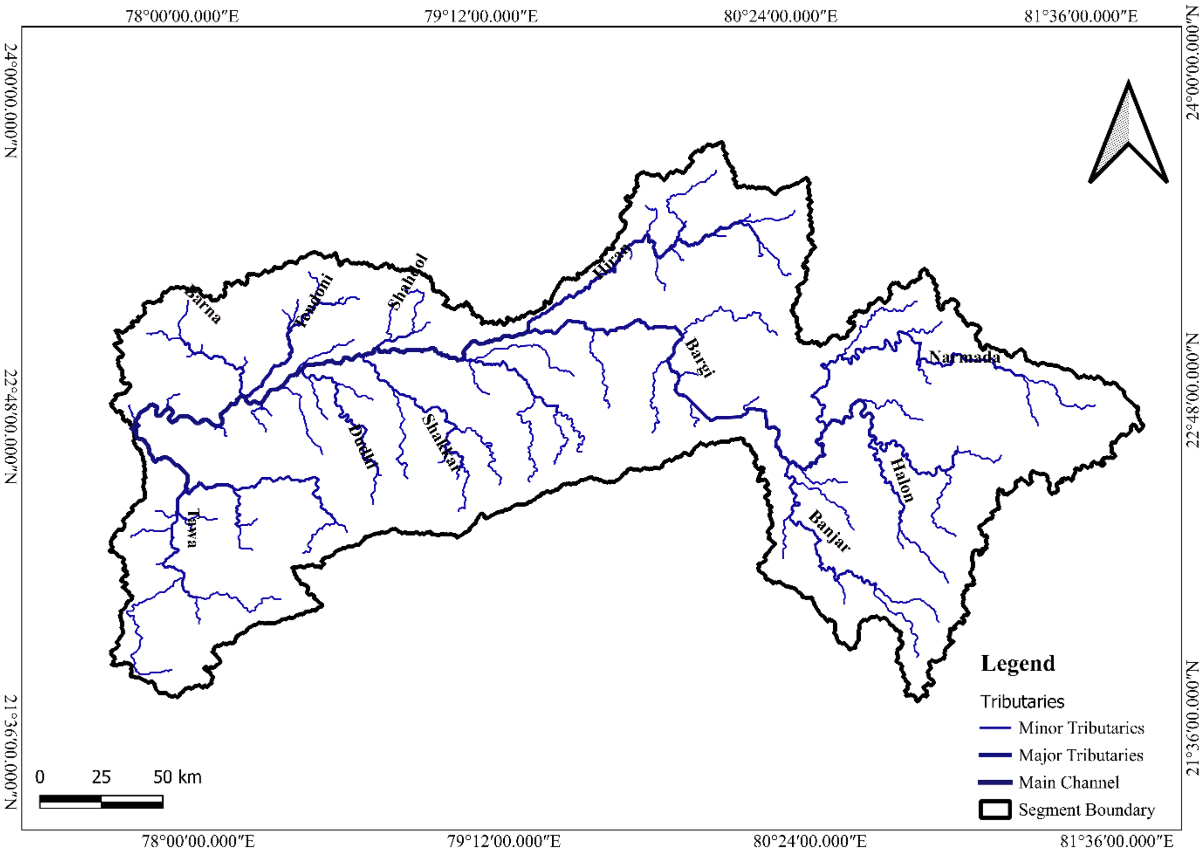


Figure 19 Tributaries of the Upper Narmada River segment

A list of major reservoirs and dams, as well as their capacity and storage, is provided in Figure. Upper Narmada Basin has several small dam structures (Figure 20) and reservoirs (Figure 21) in various tributaries of the Narmada River along with Powerhouses, i.e. Tawa powerhouse, Rani Avanti Bai (Bargi) powerhouse, Rani Avanti Bai Lodhi canal sagar powerhouse (Figure 22). Some essential irrigation projects in the upper Narmada basin segment include the Tawa Major Irrigation Project (CCA: 247 Th. ha), Bargi Diversion Major Irrigation Project (CCA: 245 Th. ha), Bargi (Rani Avanti Bai Lodhi Sagar) Major

Irrigation Project (CCA: 157 Th. ha). The population characteristics of the districts that fall under the upper Narmada basin are enumerated in Table 5.

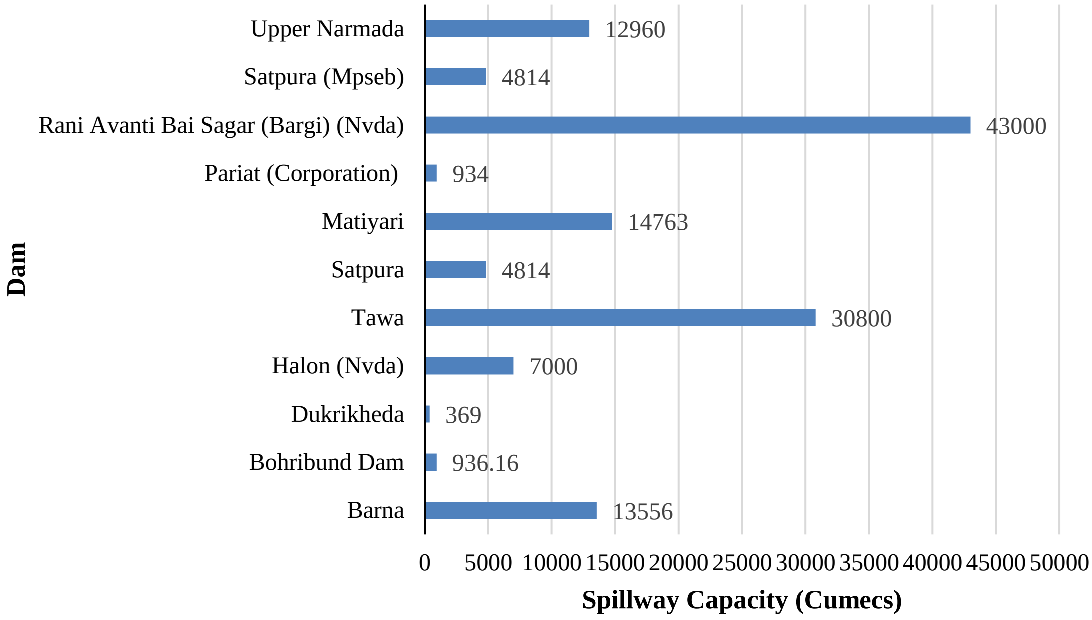


Figure 20 Dams in the Upper Narmada Basin segment

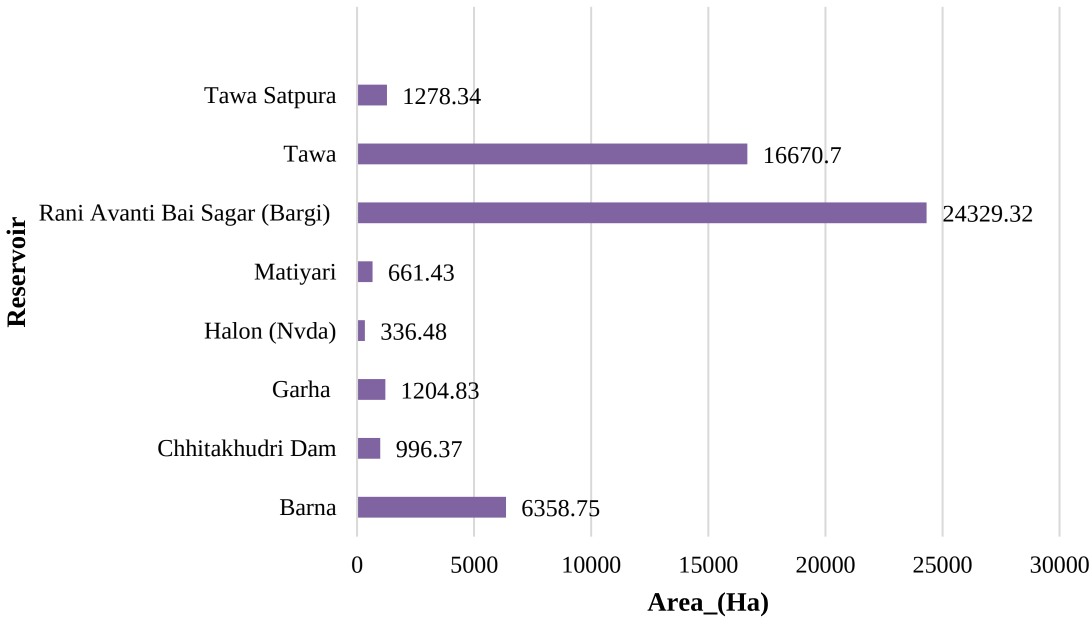


Figure 21 Reservoirs in the Upper Narmada Basin segment (Source

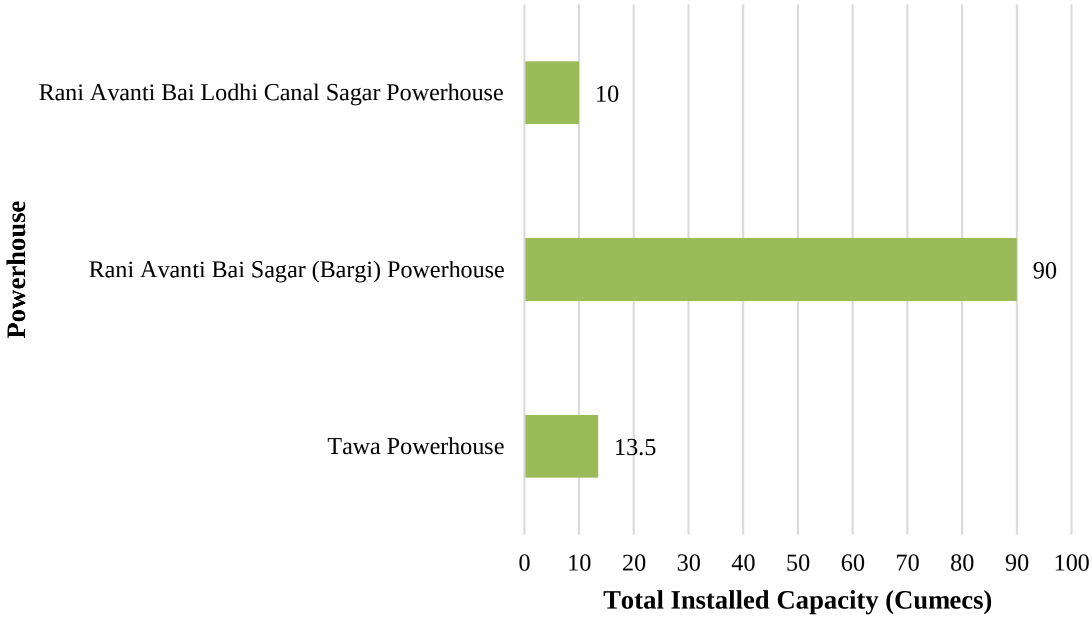


Figure 22 Powerhouses in the Upper Narmada Basin segment

Table 5: Population and % of Area in the Upper Narmada Basin

Sr No.	State	District	Population	Total District Area (Sq. km)	District Area in Basin (sq. km)	% of district area in the Basin
1	MP	Anuppur	749237	3637.4	517.37	14.22
2	MP	Balaghat	1701698	8897.36	2210.54	24.84
3	MP	Chhindwara	2090922	11361.38	3389.22	29.83
4	MP	Dewas	1563715	6700.19	3740.87	55.83
5	MP	Damoh	1264219	7068.37	417.79	5.91
6	MP	Dindori	704524	5543.2	4598.04	82.95
7	MP	Jabalpur	2463289	4911.29	4619.32	94.06
8	MP	Katni	1292042	4867.17	1093.93	22.48
9	MP	Mandla	1054905	7201.48	6371.63	88.48
10	MP	Narsimhapur	1091854	4947.28	4818.19	97.39

Sr No.	State	District	Population	Total District Area (Sq. km)	District Area in Basin (sq. km)	% of district area in the Basin
11	MP	Raisen	1331597	8172.1	4494.04	54.99
12	MP	Sagar	2378458	9858.18	371.79	3.77
13	MP	Seoni	1379131	8422.7	2153.12	25.56
14	MP	Umaria	644758	4411.61	0.47	0.01
15	MP	Bilaspur	2663629	8022.86	0.71	0.01
16	MP	Kabeerdham	822526	4061.73	596.41	14.68
17	MP	Rajnandgaon	1537133	7764.54	78.58	1.01

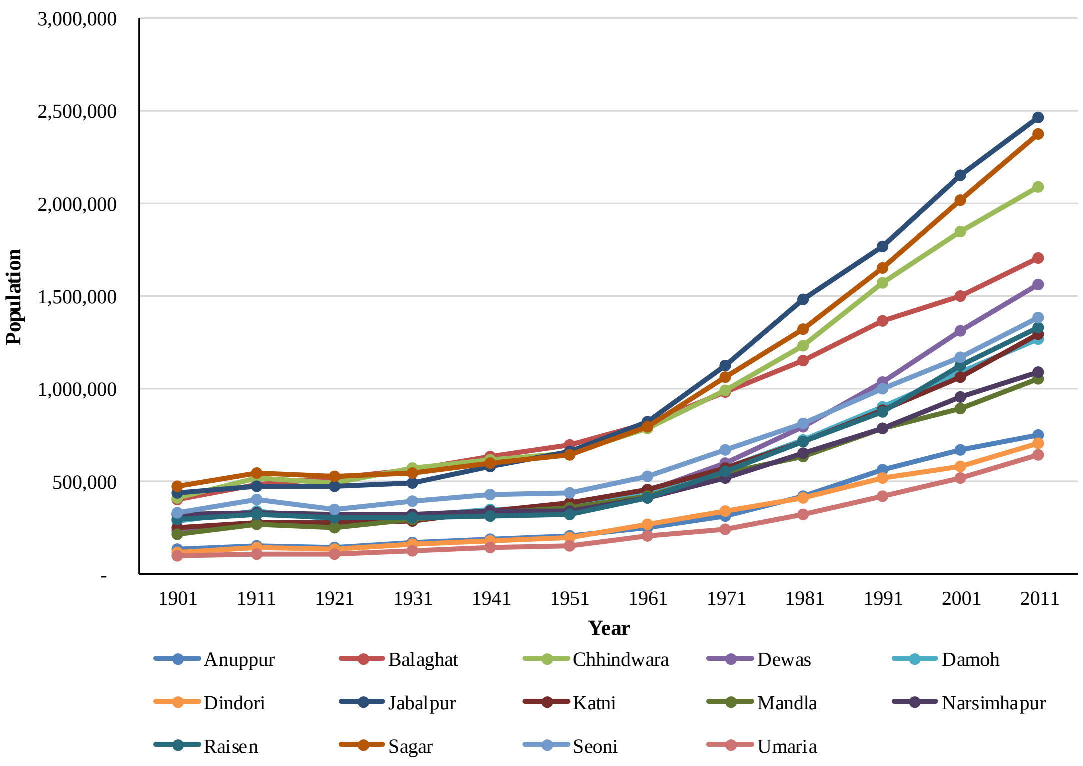


Figure 23 Population Increase in Upper Narmada Basin (1901-2021)

Source: Census India, Ministry of Home Affairs

Population variation plays a vital role in several components of river basins. Figure 23 shows population variation in past decades in districts which are part of the basin segment.

The major land use/ cover classes of Narmada Basin are water, trees, flooded vegetation, crops, built area, bare ground and the range land as shown in Figure 24. The spatial distribution of various land use classes is shown in Figure 25. Paddy is the most common crop in the upper Narmada river segment because of heavy rainfall and poor infiltration. 837.17 sq. km. area covered by land use class "Water" along with two major water bodies, Bargi dam and Tawa reservoir, in the Upper Narmada Segment.

Figure 26 shows how rainfall pattern changes in the areas of the basin segment with the help of grid-wise monthly rainfall (Source: National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) Prediction of Worldwide Energy Resource (POWER))

The majority of the soil in the upper Narmada River basin segment is shallow black soil, which has a higher water holding capacity; thus, it reduces water drainage. Mainly in hilltops and plateau regions, these soils are mixed with red soils and laterite soils from a shallow layer.

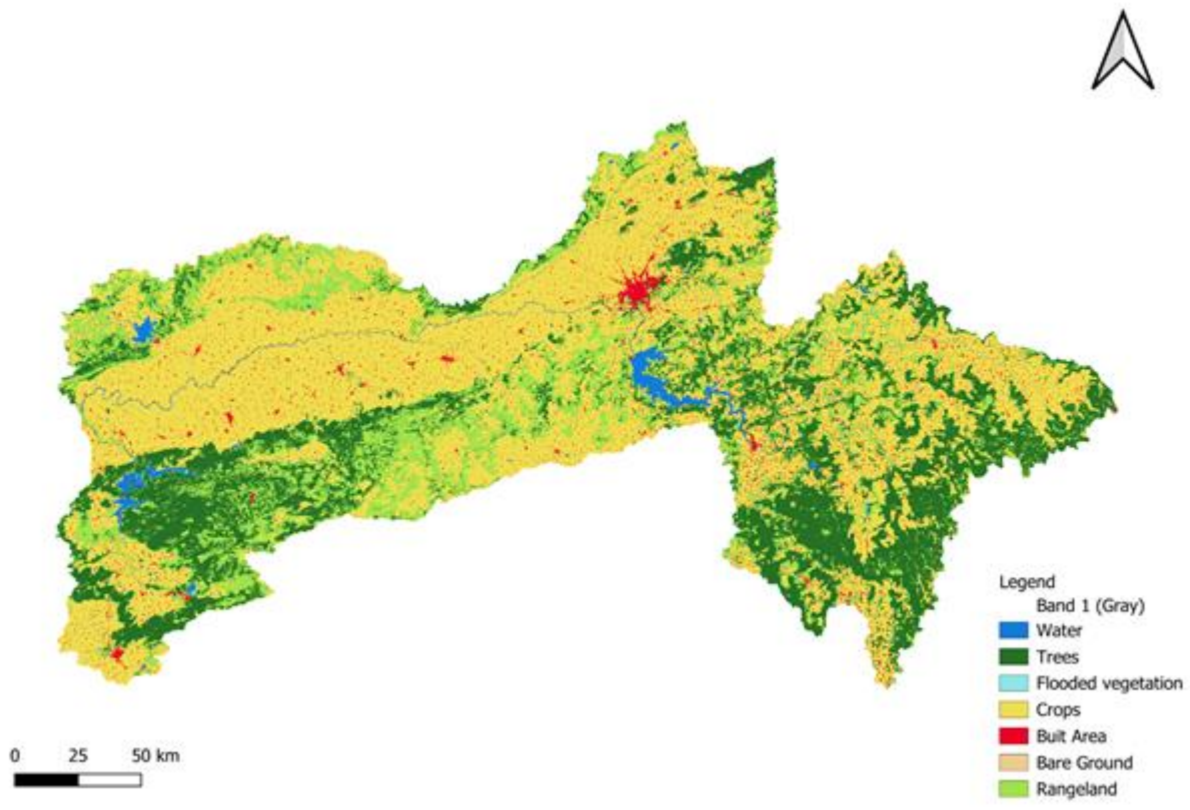


Figure 24 LULC Map of the Upper Narmada Basin

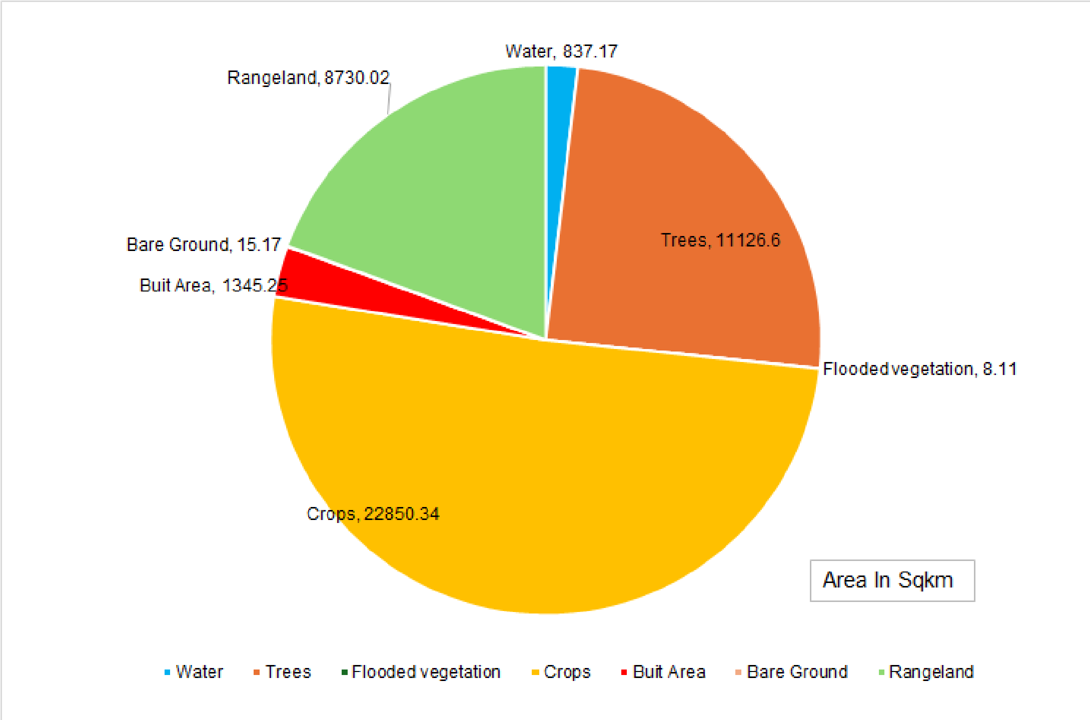


Figure 25 Land use pattern of Upper Narmada Basin

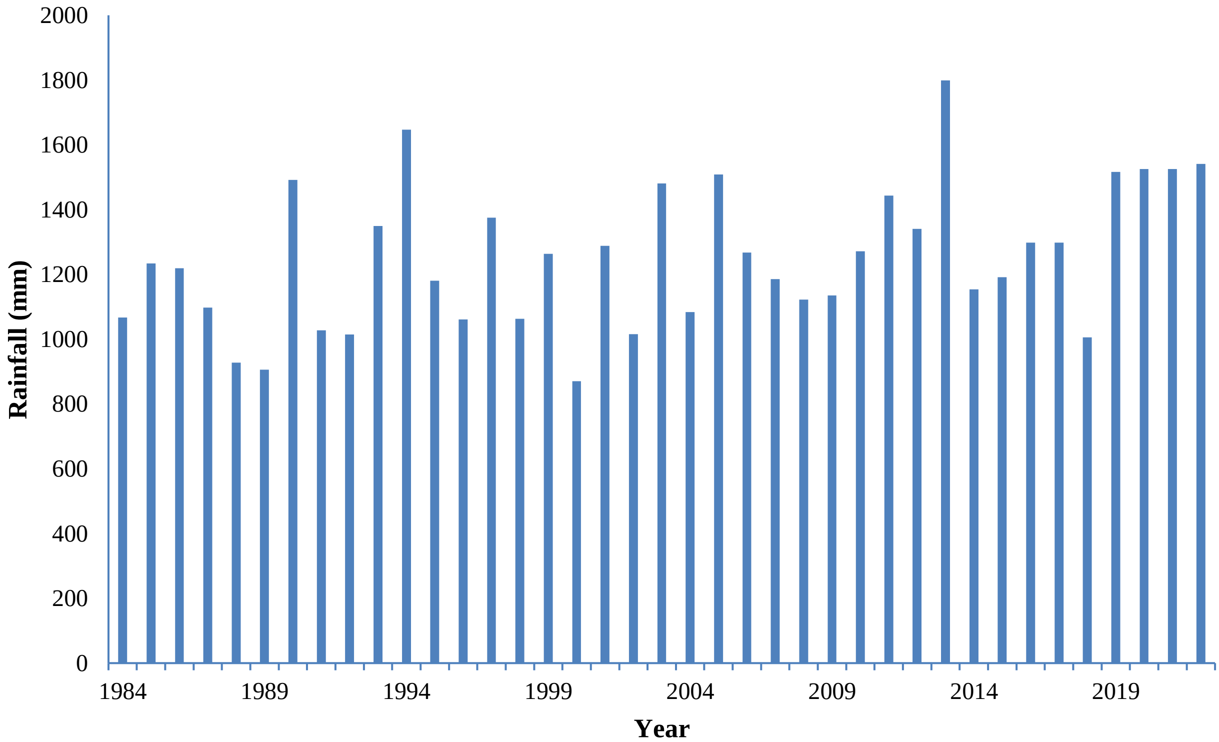


Figure 26 Variation of average annual rainfall over Upper Narmada Basin

4.1.1 Sources of Pollution

The Narmada River exhibits a significant decline in water quality as it travels from its source at Amarkantak to Hoshangabad. While the upper reaches maintain acceptable levels, pollution steadily increases downstream.
A major source of pollution is the discharge of untreated sewage from towns and cities along the riverbank. Madhya Pradesh alone discharges an estimated 51 Million Litres Daily (MLD) of untreated sewage directly into the Narmada. This lack of proper sewage treatment infrastructure leads to contamination with harmful bacteria.
Industrial activity along the Narmada contributes to pollution through the release of untreated effluents. These effluents can contain heavy metals, toxic chemicals, and organic matter. The presence of heavy metals like chromium, copper, and iron suggests potential pollution from industries like metal processing, chemical manufacturing, and paper mills.

4.1.2 Behavioural Aspects

The upper reaches of the Narmada River flow through the rugged terrain of the Vindhya and Satpura ranges. This topography influences the river's flow patterns, causing rapids and waterfalls in some stretches and relatively calmer sections in others. Here, the channel of the Narmada is mostly in bedrock, relatively narrow and winding with several hairpin turns.

4.1.3 Sensitive/ vulnerable/ undistributed areas

Table 6 and Figure 27 show identified sensitive, vulnerable, and undisturbed / protected areas in the Upper Narmada Basin segment.

Table 6 List of sensitive/ vulnerable/ undistributed areas in Upper Narmada Basin

Sensitive Areas	Vulnerable areas	Undisturbed area
• Construction of large dams (Bargi Dam, Indira Sagar Dam) impacting flow & ecology	• Areas downstream of Jabalpur (high pollution from city sewage) & Industrial zones along the river (paper mills, chemical factories) • River banks with moderate encroachment for agriculture and settlement	• Upper Kanha River & tributaries joining Narmada (minimal human intervention) • Amarkantak region with minimal human settlements • Upstream forested areas with minimal soil erosion (parts of Mandla district)

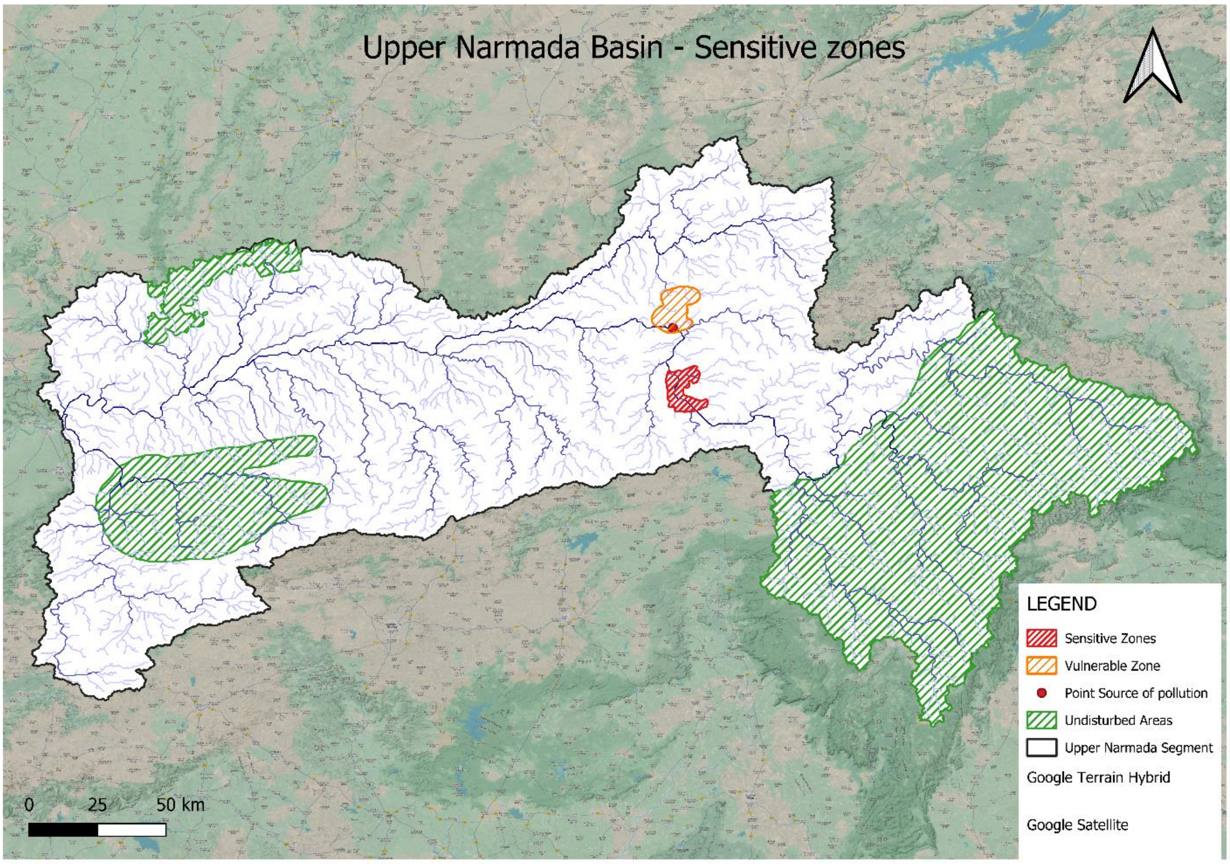


Figure 27 Sensitive, Vulnerable and Undisturbed Areas of the Upper Narmada Basin

4.2 Middle Narmada

The Middle Narmada Basin segment is comparatively flat in plain than the upper Narmada River Basin. The land becomes more open and basaltic (more visible), next 160 km from Hoshangabad. The Vindhya range comes nearer to the Narmada River (Comparatively narrow watershed) and is made of a terraced slope of hard sandstones mixed with shales. The valley has varied slopes because of its divided sections by hills in the western part of Narmada, which also has fertile land. North of the Narmada is the Dhar Upland, which is hilly and forested. The Nimar Upland stretches from east to west, north of the Satpuras. The Western Satpuras separate the Narmada and Tapi basins. In the direction of flow, Ganjal, Ajnai, Chhota Tawa, Kaveri, Kundi, Borad and Goi are the major tributaries on the left side of the main channel, and Kolar, Dahini, Sukhji, Man, Uri, Bagh and Hatni are the major tributaries in the right side of the channel (Figure 28).

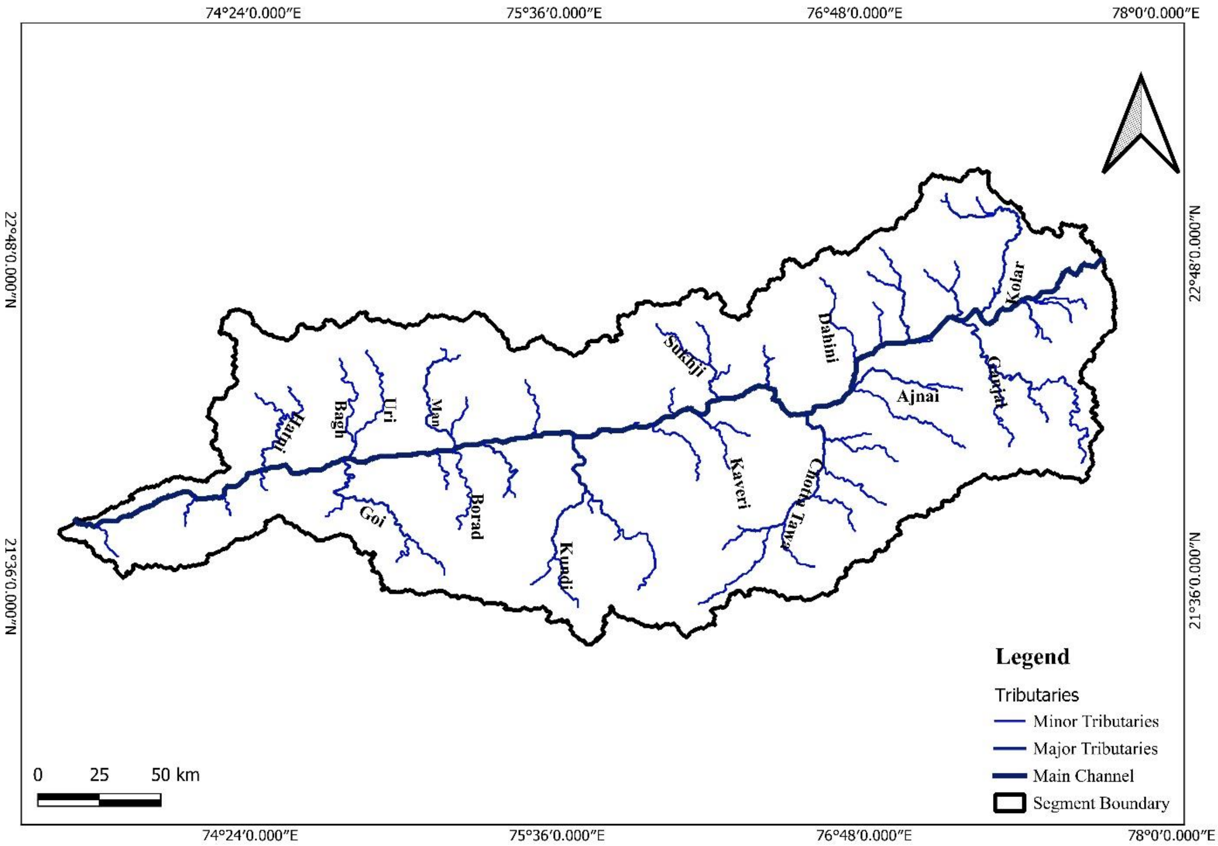


Figure 28 Tributaries of the Middle Narmada River segment

A list of essential reservoirs and Dams is given in the following charts, along with their capacity and storage. Middle Narmada Basin have several small dam structures (Figure 29) and reservoirs (Figure 30) in various tributaries of the Narmada River along with Powerhouses, i.e. Omkareshwar powerhouse, Maheshwar powerhouse, Indira Sagar powerhouse, Indira Sagar canal head powerhouse (Figure 31).

Some essential irrigation projects in the upper Narmada basin segment include the Sardar Sarovar Major Irrigation Project (CCA: 2120 Th. ha), Omkareshwar Major Irrigation Project (CCA; 146.80 Th. ha), Indira Sagar /Narmada Sagar Project Major Irrigation Project (CCA: 123 Th. ha). The population of the districts that fall under the Middle Narmada basin is shown in Table 7. A significant part of the middle Narmada basin falls in Madhya Pradesh and Maharashtra states.

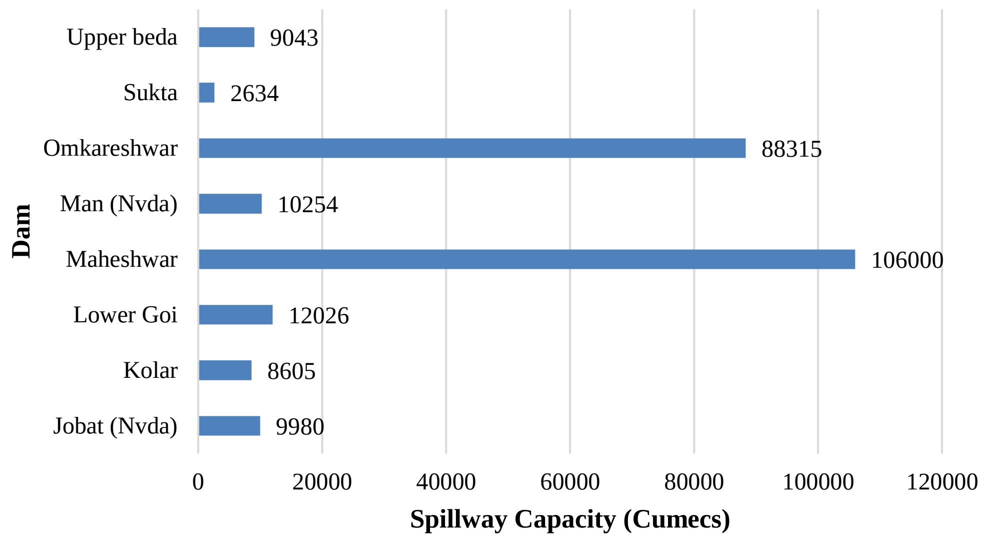


Figure 29 Dams in the Middle Narmada Basin segment

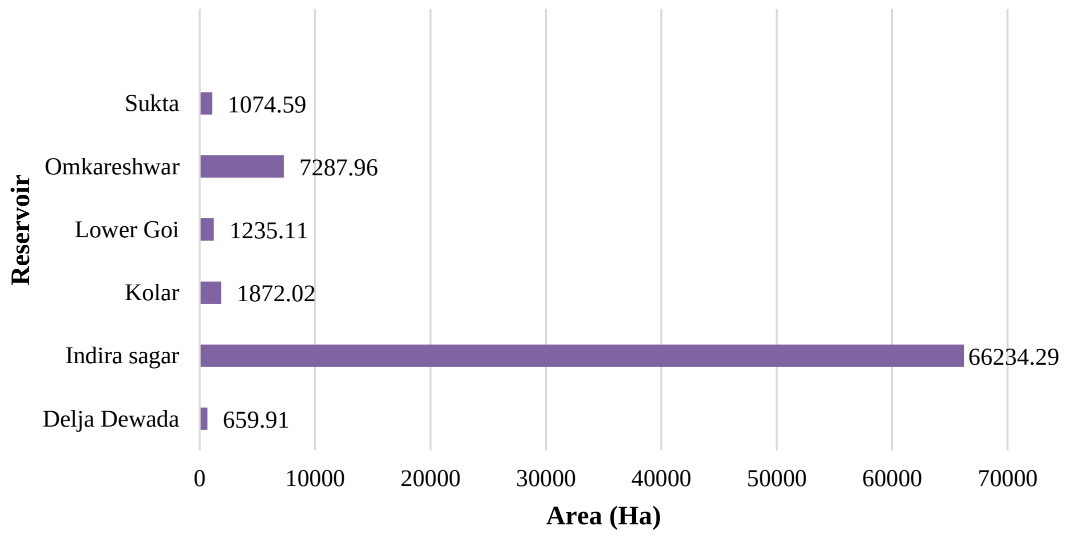


Figure 30 Reservoirs in the Middle Narmada Basin segment

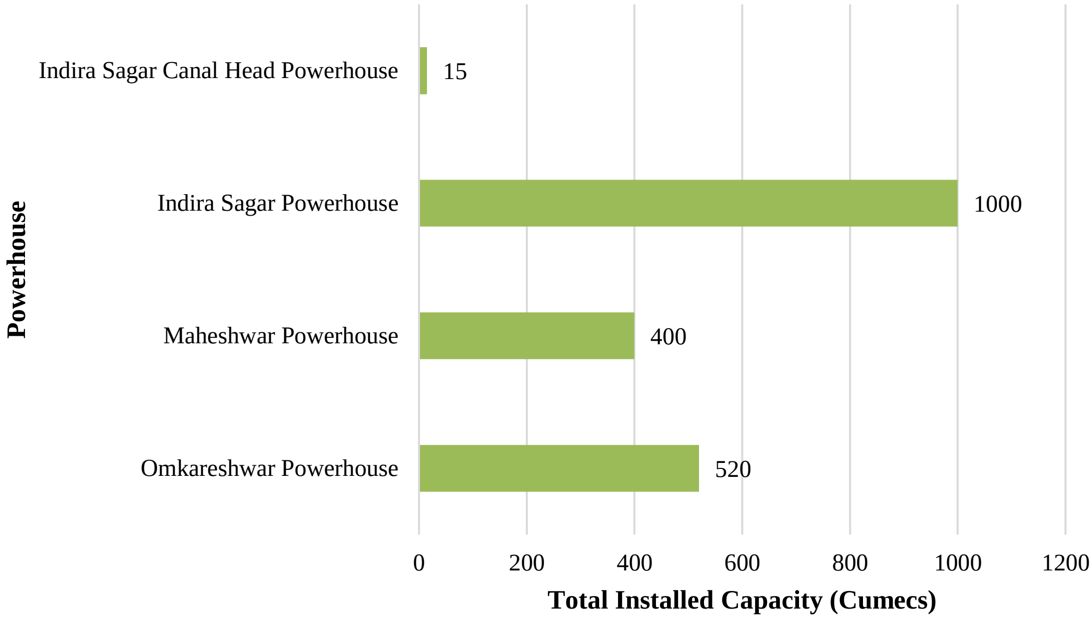


Figure 31 Powerhouses in the Upper Narmada Basin segment

Table 7: Population and % of Area in the Middle Narmada Basin

Sr No.	State	District	Population	Total District Area (Sq. km)	District Area in Basin (sq. km)	% of district area in the Basin
1	Madhya Pradesh	Alirajpur	728999	3217.78	3001.03	93.26
2	Madhya Pradesh	Bhopal	2371061	2618.98	3.33	0.13
3	Madhya Pradesh	Betul	1575362	9690.38	3712.61	38.31
4	Madhya Pradesh	Burhanpur	757847	3084.12	368.6	11.95
5	Madhya Pradesh	Dhar	2185793	7842.3	4756.36	60.65
6	Madhya Pradesh	Indore	3276697	3765.95	1013.68	26.92
7	Madhya Pradesh	Khargone (West Nimar)	1873046	7757.16	7397.29	95.36
8	Madhya Pradesh	Khandwa (East Nimar)	1310061	7169.74	6469.19	90.23
9	Madhya Pradesh	Hoshangabad	1241350	6456.42	6456.42	100
10	Madhya Pradesh	Harda	570465	3192.55	3127.44	97.96
11	Madhya Pradesh	Jhabua	1025048	3302.18	7.92	0.24
12	Madhya Pradesh	Sehore	1311332	6317.41	3143.66	49.76
13	Maharashtra	Dhule	2050862	6925.51	7.95	0.11

Source: Narmada Basin Document, India-WRIS, Ministry of Water Resources

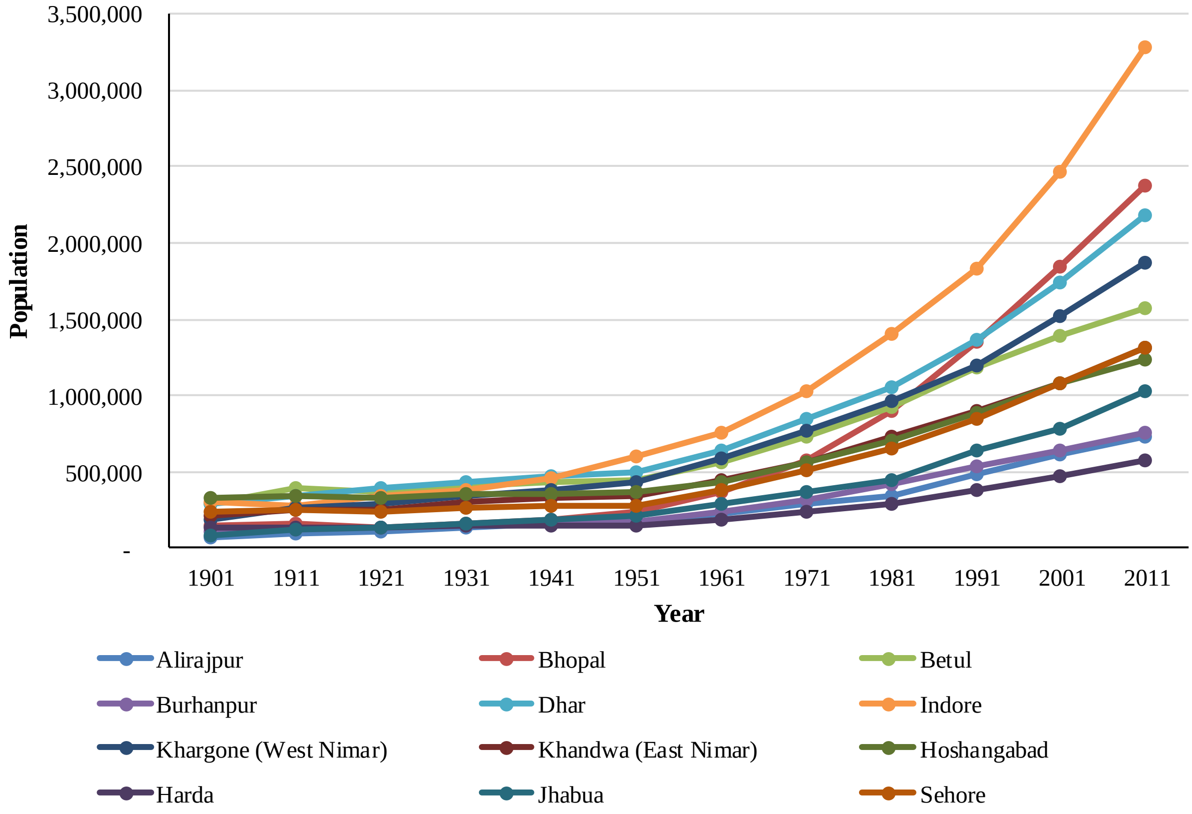


Figure 32 Population Increase in Middle Narmada Basin (1901-2021) Source: Census India, Ministry of Home Affairs

Population variation plays a vital role in several components of river basins. Figure 32 shows population variation in past decades in districts which are part of the basin segment.

The major land use/ cover classes of Narmada Basin are water, trees, Flooded vegetation, crops, built area, bare ground and the range land as shown in Figure 33. The spatial distribution of various land use classes is shown in Figure 34. Wheat is a more popular crop than paddy in the middle Narmada basin segment. Other crops like Jowar, Maize, Barley, and Bajra are also cultivated in some districts here. Approximately 1484.83 sq. km. area is covered by LULC class “water”, including the Indira Sagar reservoir and Sardar Sarovar dam reservoir.

Figure 35 shows how rainfall pattern changes in the areas of the basin segment with the help of grid-wise monthly rainfall (Source: National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) Prediction of Worldwide Energy Resource (POWER))

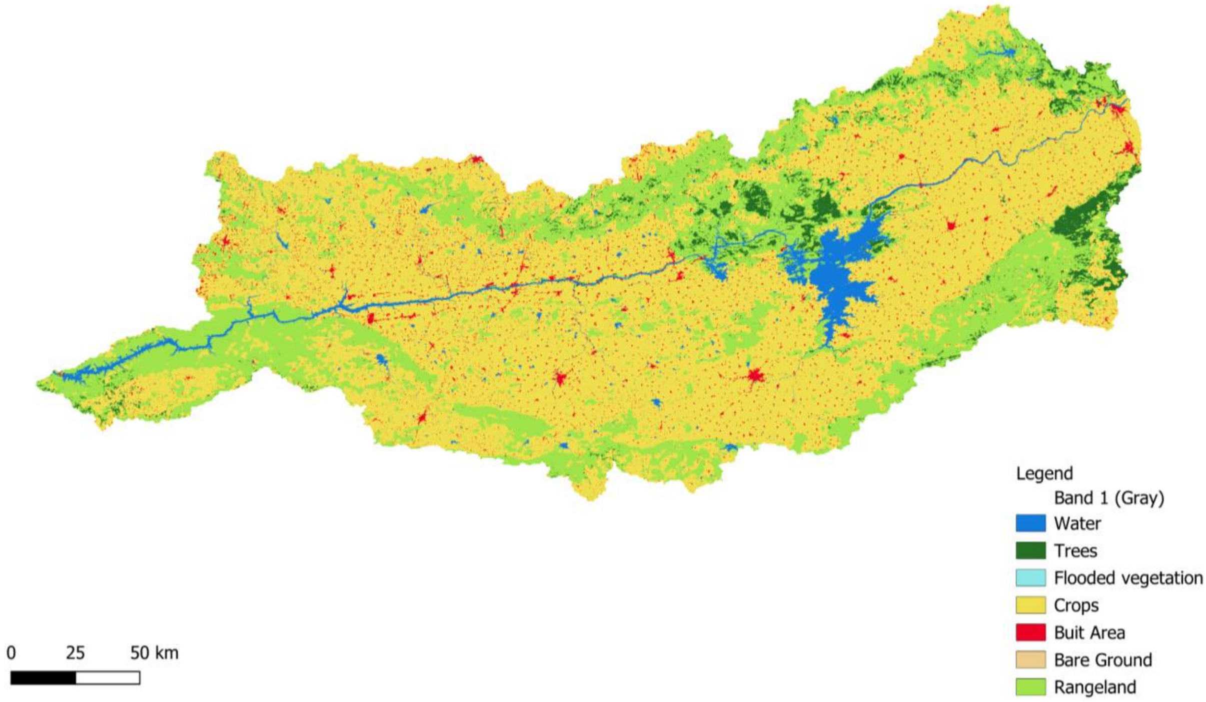


Figure 33 LULC Map of the Middle Narmada Basin

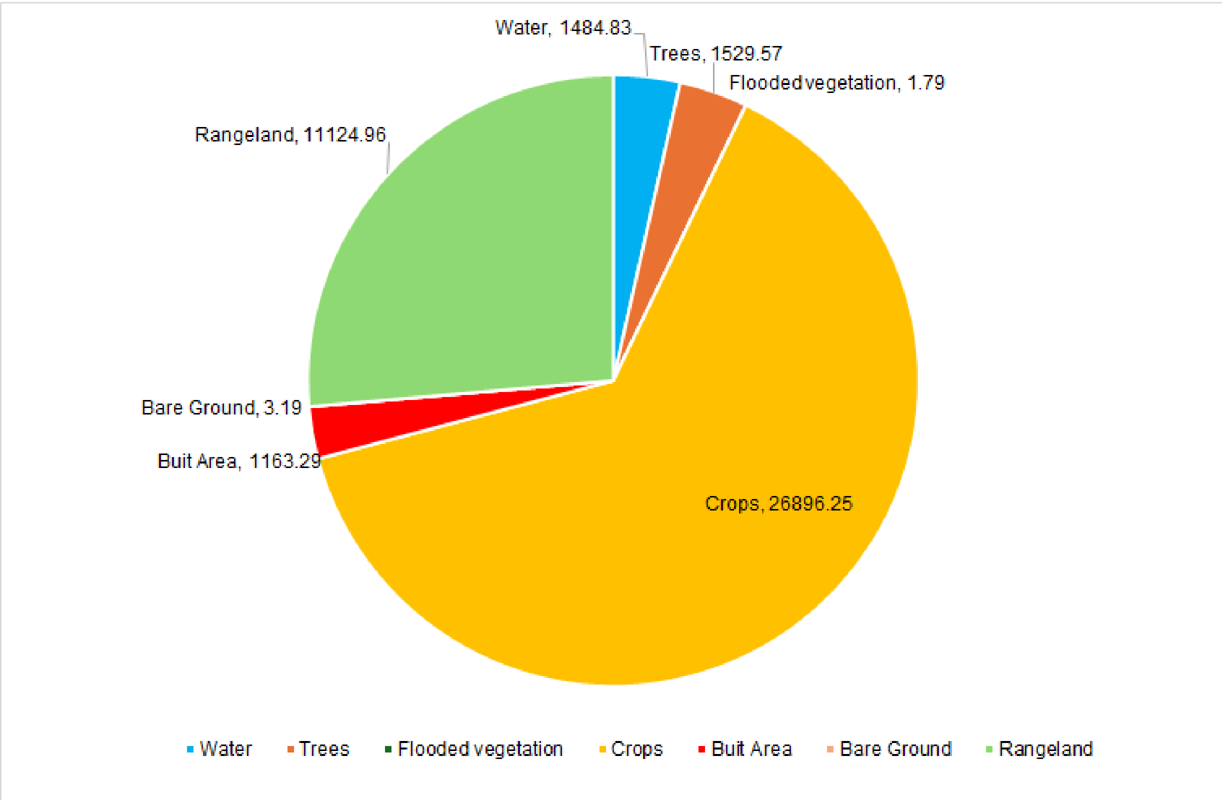


Figure 34 Land use pattern of the Middle Narmada Basin

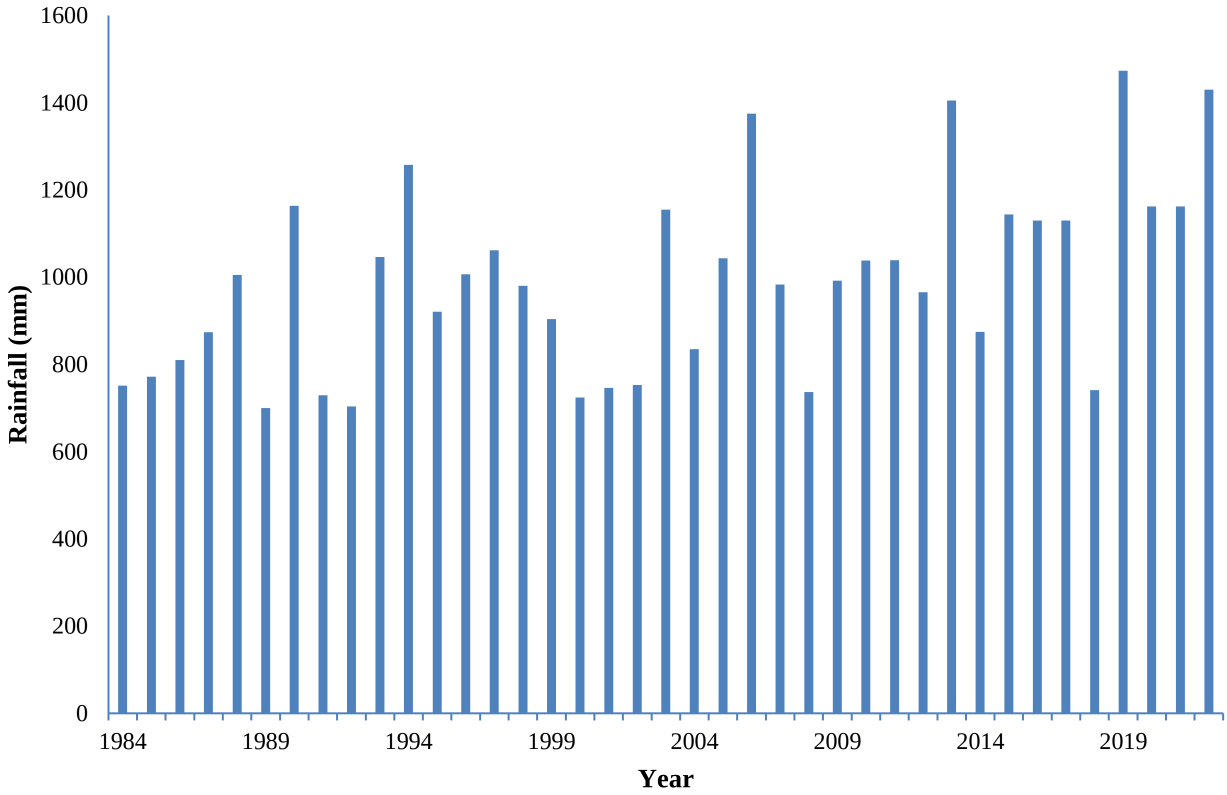


Figure 35 Variation of average annual rainfall over the Middle Narmada Basin

4.2.1 Sources of Pollution

Untreated Sewage: The discharge of untreated sewage from towns and cities continues to be a significant source of pollution. Narmadapuram itself contributes around 1.3 Million Litres Per Day (MLD) of untreated sewage into the river. This sewage, laden with harmful bacteria and pathogens, poses severe health risks to those who use the river water.

Industrial activities along the riverbank contribute to pollution through the release of untreated effluents. Industries like paper mills, chemical manufacturing plants, and textile mills release wastewater containing heavy metals, toxic chemicals, and organic matter. These pollutants can have long-lasting detrimental effects on the river's ecosystem and the health of those who depend on it.

Excessive use of fertilisers and pesticides in agricultural practices along the riverbank leads to the runoff of these chemicals into the Narmada. This disrupts the natural balance of nutrients in the water, causing algal blooms and oxygen depletion, harming aquatic life and reducing the water's quality for human use.

4.2.2 Behavioural Aspects

In the middle reaches, the Narmada River flows through a relatively broader valley compared to the upper reaches. This results in a more stable flow regime characterised by moderate velocities and sediment transport. The middle Narmada's channel morphology is influenced by the geological features of the region, including alluvial plains and occasional rocky stretches. These features affect the river's behaviour in terms of sediment deposition, erosion, and channel stability.

4.2.3 Sensitive/ vulnerable/ undistributed areas

Table 8 and Figure 36 show identified sensitive, vulnerable, and undisturbed/protected areas in the Middle Narmada Basin segment.

Table 8 List of sensitive/ vulnerable/ undistributed areas in Middle Narmada Basin

Sensitive Areas	Vulnerable areas	Undisturbed area
• Industrial corridors along the river (e.g. paper mills near Itarsi, chemical factories near Barwani and Hoshangabad) impacting water quality. • High siltation due to deforestation and agricultural activities in the upper catchment areas (e.g., Satpura Range)	• Areas downstream of Hoshangabad (increased pollution from municipal sewage) & Handia (agricultural runoff) • Encroachment for agriculture and settlements along the riverbanks near the Madhya Pradesh-Gujarat border (e.g., near the Dhar River confluence)	• Areas with minimal human intervention around the Bori Sanctuary.

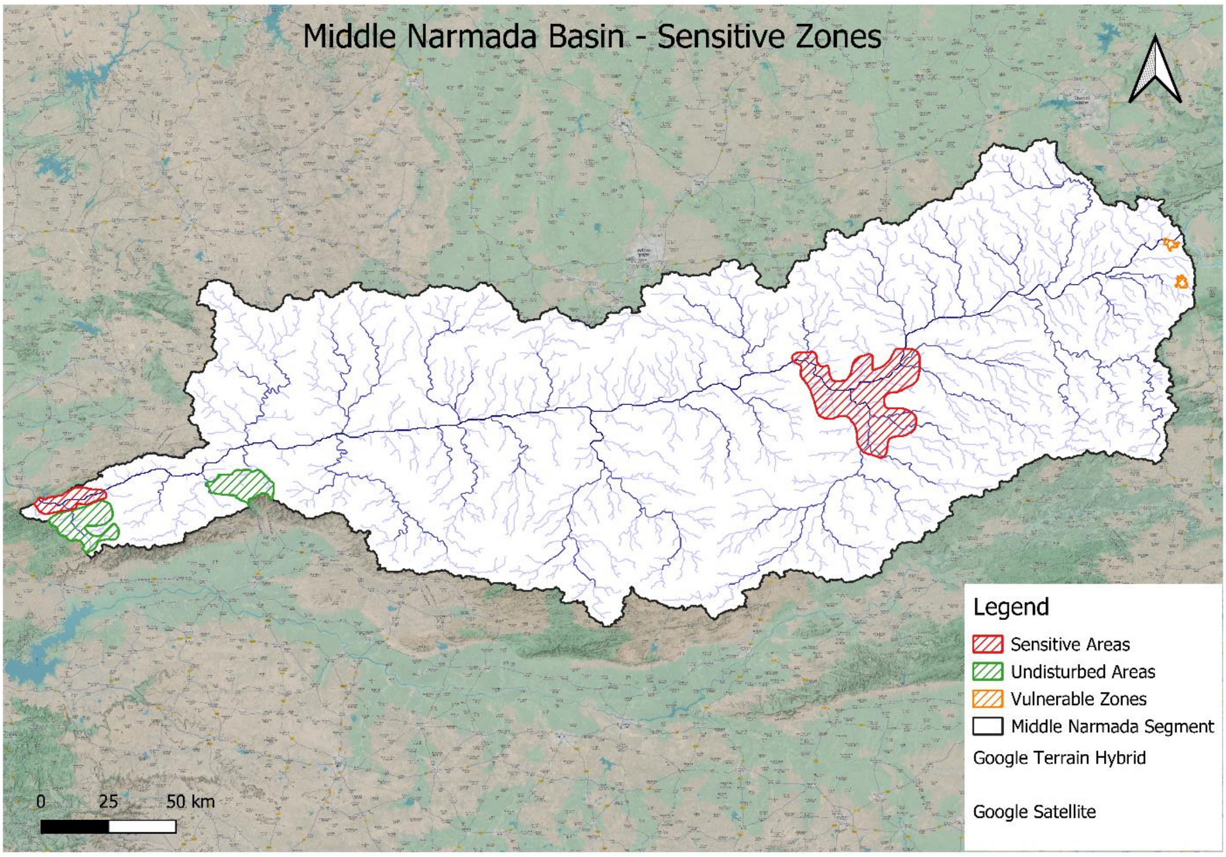


Figure 36 Sensitive, Vulnerable and Undisturbed Areas of the Middle Narmada Basin

4.3 Lower Narmada

The Narmada River meets the Arabian Sea in the Gulf of Khambhat in the Bharuch District of Gujarat. The Narmada passes through three narrow valleys between the Vindhya scarps to the north and the Satpura range to the south, with the southern extension of the valley being wider in most places.

The number of large tributaries in the lower segment of the Narmada River is smaller than that in the upper and middle segments. However, contributions from rivers like the Orsang, Heran, Karjan, and numerous smaller streams are crucial (Figure 37). The Orsang River, originating in southeastern Gujarat, joins the Narmada near Chandod village, significantly boosting its flow during the monsoon season. The Heran River, rising in Gujarat's Panchmahal district, merges with the Narmada in Vadodara district, enhancing the river's volume in its lower segment. Flowing through the Narmada district, the Karjan River joins the Narmada downstream of the Karjan Dam, adding to its flow. The Dudhi River, originating in the Satpura Range's western part, merges with the Narmada near Rajpipla in Gujarat, further increasing the water volume. The Tawa River, originating in Madhya Pradesh's Mahadeo Hills, joins the Narmada near Hoshangabad, and its effects are felt downstream into the lower basin. Additionally, a local stream contributes to the Narmada near Ankleshwar, an industrial town. Numerous smaller streams and seasonal rivers also feed into the Narmada in its lower segment, especially during the monsoon, bringing in sediments that impact the river's morphology and the fertility of its floodplains, supporting diverse ecosystems in the lower Narmada basin.

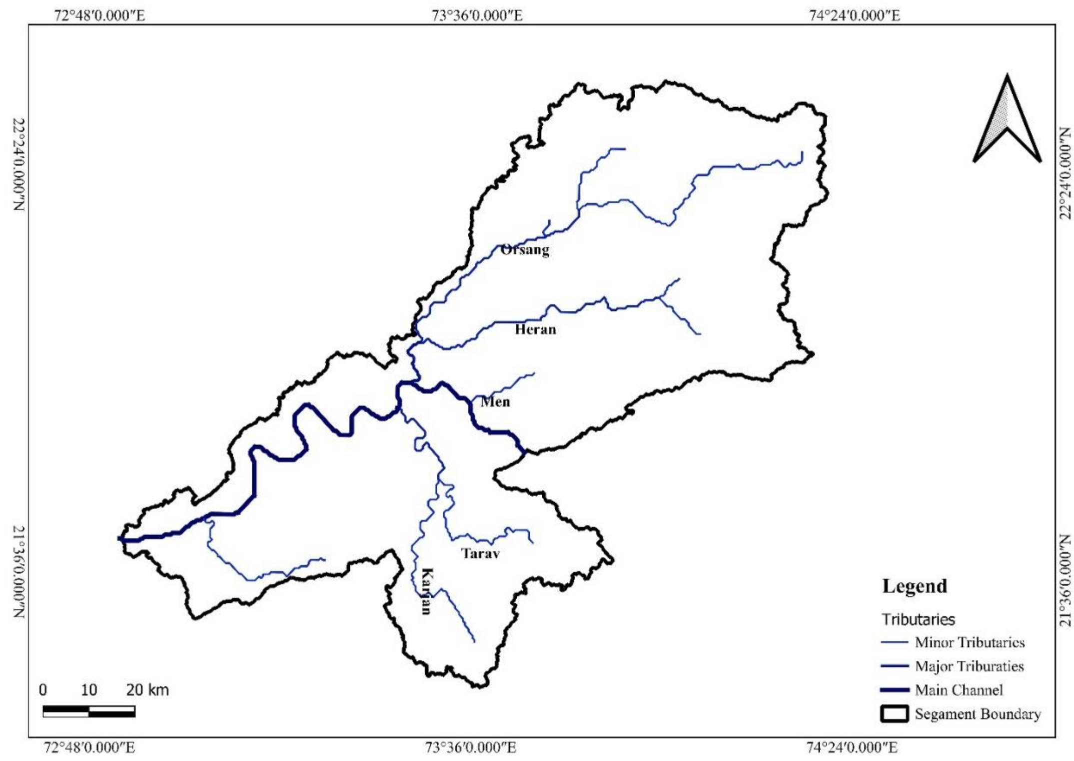


Figure 37 Tributaries of the Lower Narmada River segment

The Sardar Sarovar Dam, one of the largest on the river, regulates the downstream water flow and helps mitigate monsoon floods by storing excess water, but it affects the river's natural flood cycles, which are essential for the ecological health of the river basin. Other upstream dams, such as the Bargi Dam and the Indira Sagar Dam, also alter flow patterns by changing the timing and amount of water released downstream. These dams trap significant sediment amounts that would naturally flow downstream, leading to riverbank erosion and changes in riverbed composition. Reduced sediment supply impacts delta formation and can cause coastal erosion near the river's mouth in the Gulf of Khambhat.

Industrial areas along the river, particularly in the basins like Bharuch and Ankleshwar, discharge pollutants, including heavy metals, chemicals, and untreated effluents, into the river, contaminating the water and affecting aquatic life, making it unsafe for human consumption and agriculture. Agricultural runoff carries fertilisers, pesticides, and chemicals into the river, causing nutrient loading and eutrophication, harming aquatic ecosystems and reducing biodiversity. Urban areas along the river, especially in the middle and lower segments, contribute significant amounts of untreated or partially treated sewage, increasing pathogen and organic pollutant levels, posing health risks, and degrading water quality. Sand mining is another major environmental concern in the lower Narmada basin. Excessive sand extraction from the riverbed disrupts the river's ecology, affects fishermen's livelihoods, and causes increased siltation, reducing water storage capacity. The Narmada basin has numerous wetlands, including marshes, swamps, and bogs, playing a vital role in water purification, flood control, and providing habitat for diverse aquatic plants and animals. Reservoirs built on the river provide habitat for fish and other aquatic organisms but can also disrupt the natural flow and have negative ecological impacts.

A list of important reservoirs and Dams is given in the following charts, along with their capacity and storage. Lower Narmada Basin has several small dam structures (Figure 38) and reservoirs (Figure 39) in various tributaries of the Narmada River along with Powerhouses, i.e. Sardar Sarovar powerhouse, Sardar Sarovar Canal Head powerhouse (Figure 40). Karjan Major Irrigation Project (CCA: 51 Th. ha), Omkareshwar Major Irrigation Project (CCA: 146.80 Th. ha), Indira Sagar /Narmada Sagar Project Major Irrigation Project (CCA: 123 Th. ha) are some important irrigation projects in the upper Narmada basin segment. The population characteristics of the districts that fall under the Lower Narmada basin are enumerated in Table 9. The increase in population in districts of Gujarat, the Narmada River, is shown in Figure 41. Population density in the basin varies from 100 to 1000 persons/Sq.km.

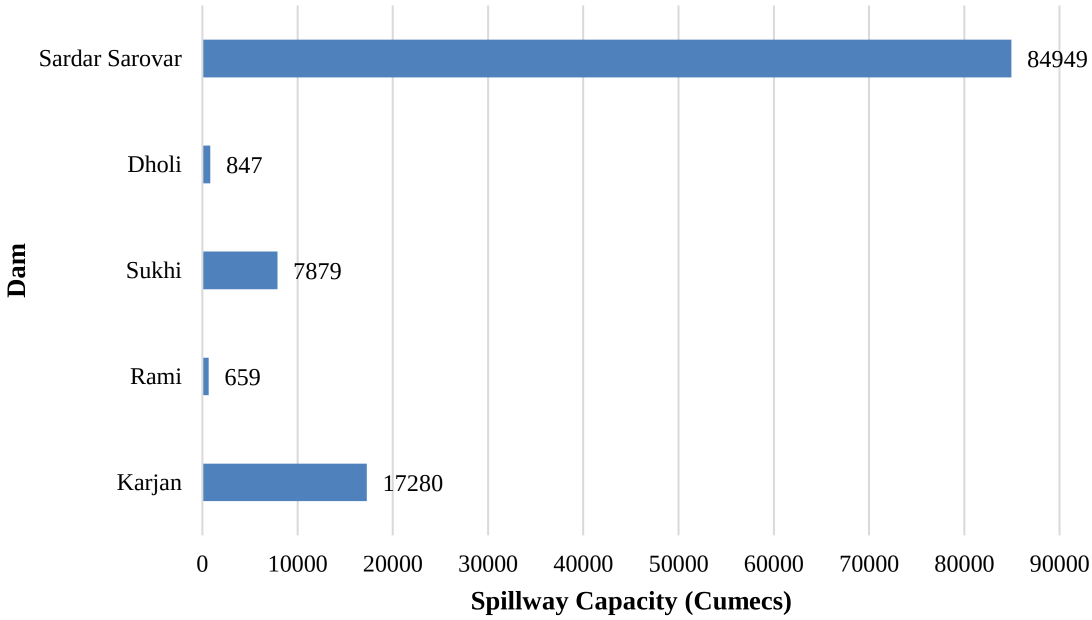


Figure 38 Dams in the Lower Narmada Basin segment

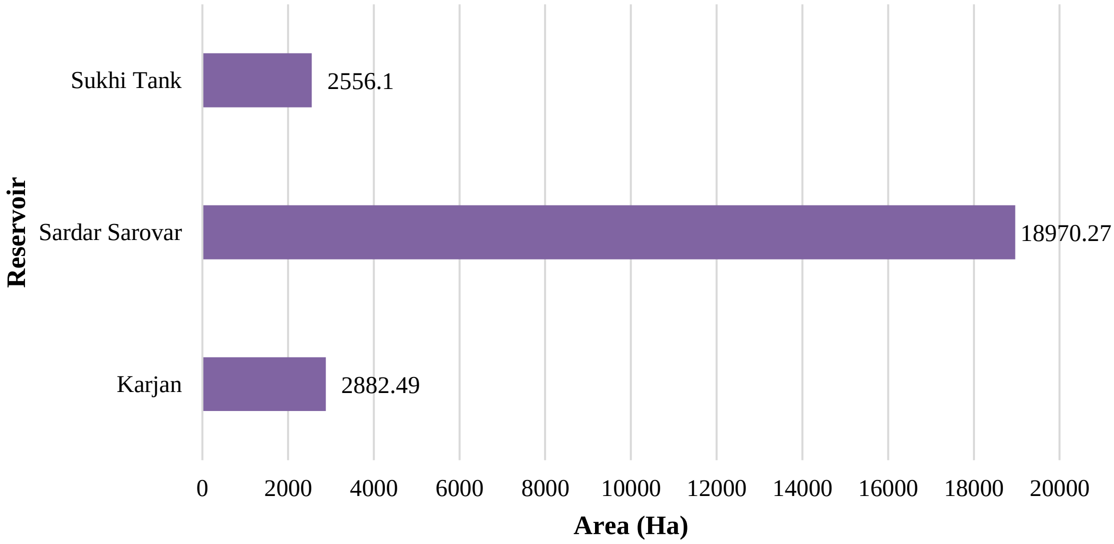


Figure 39 Reservoirs in the Lower Narmada Basin segment

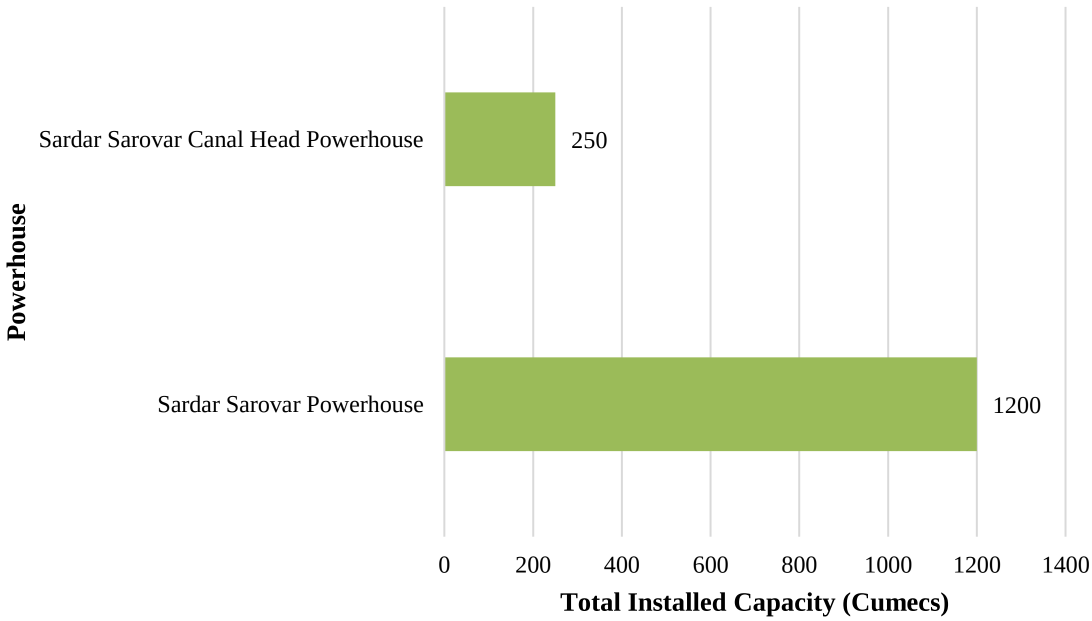


Figure 40 Powerhouses in the Lower Narmada Basin segment

Table 9: Population and % of Area in the Lower Narmada Basin

Sr No.	State	District	Population	Total District Area (Sq. km)	District Area in Basin (sq. km)	% of district area in the Basin
1	Gujarat	Bharuch	1551019.00	5083.67	1849.91	36.39
2	Gujarat	Dahod	2127086.00	3458.35	60.36	1.75
3	Gujarat	Narmada	590297.00	2719.36	2321.2	85.36
4	Gujarat	Panchmahal	2390776.00	5095.62	137.56	2.7
5	Gujarat	Tapi	6081322.00	4174.64	168.82	4.04
6	Gujarat	Vadodara	4165626.00	7234.95	3788.5	52.36

Source: Narmada Basin Document, India-WRIS, Ministry of Water Resources

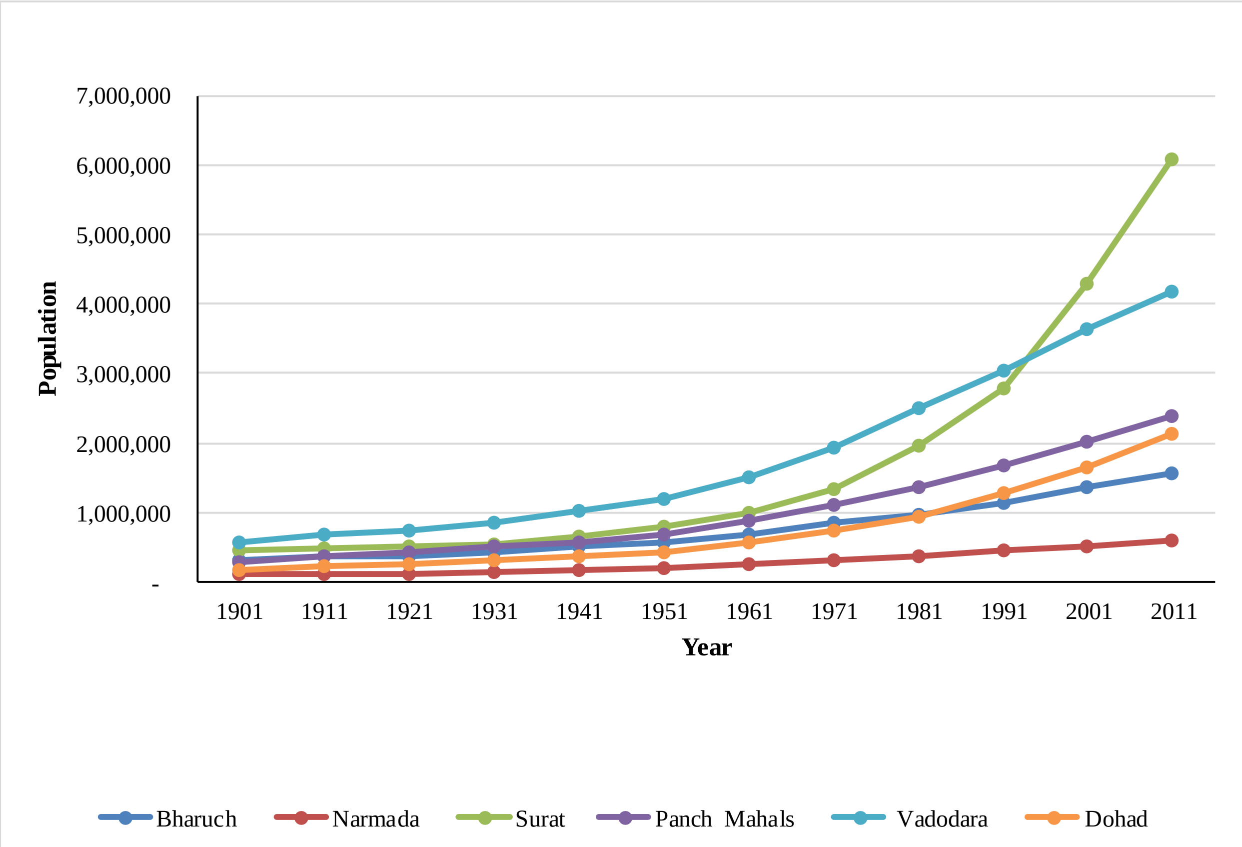


Figure 41 Population Increase in Lower Narmada Basin (1901-2021) Source: Census India, Ministry of Home Affairs

The major land use/ cover classes of Narmada Basin are water, trees, Flooded vegetation, crops, built area, bare ground and the range land as shown in Figure 42. The spatial distribution of various land use classes is shown in Figure 43. Wheat is a more popular crop than paddy in the middle Narmada basin segment. The lower Narmada segment has a smaller water storage structure than the upper and middle Narmada basin segments.

Figure 44 shows how rainfall pattern changes in the areas of the basin segment with the help of grid-wise monthly rainfall (Source: National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) Prediction of Worldwide Energy Resource (POWER))

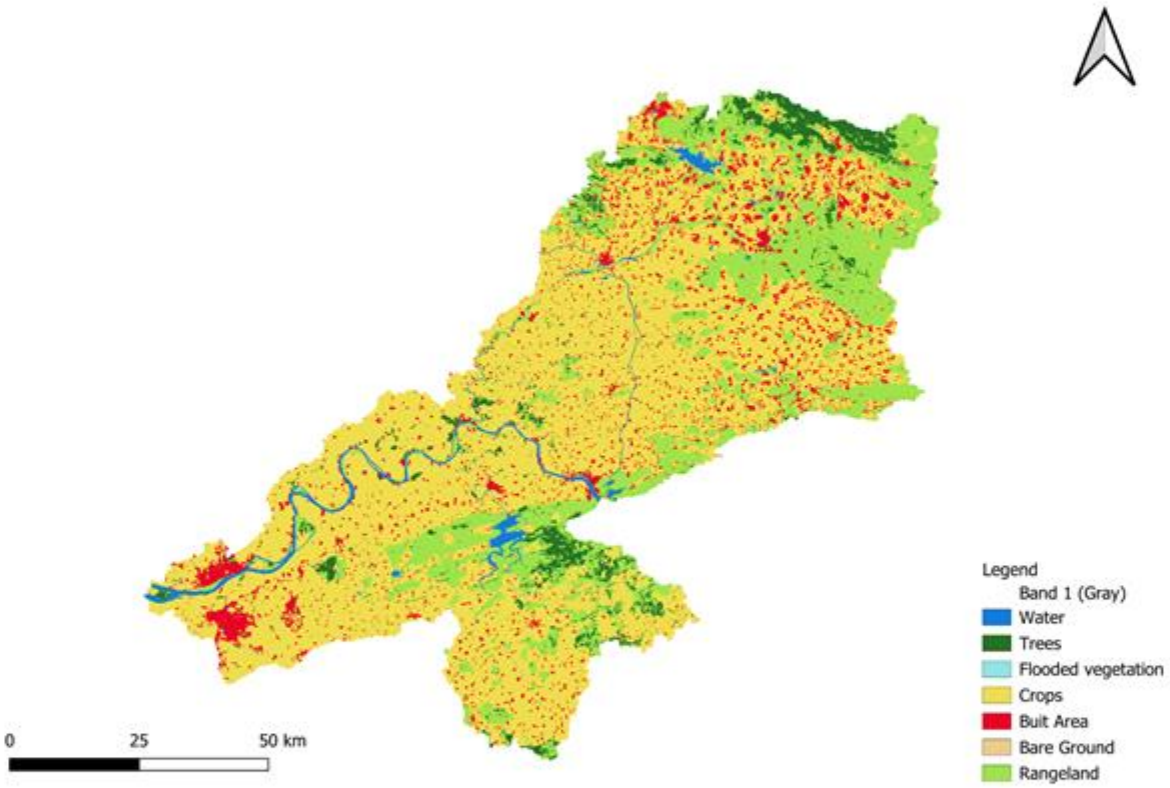


Figure 42 LULC Map of Lower Narmada Basin

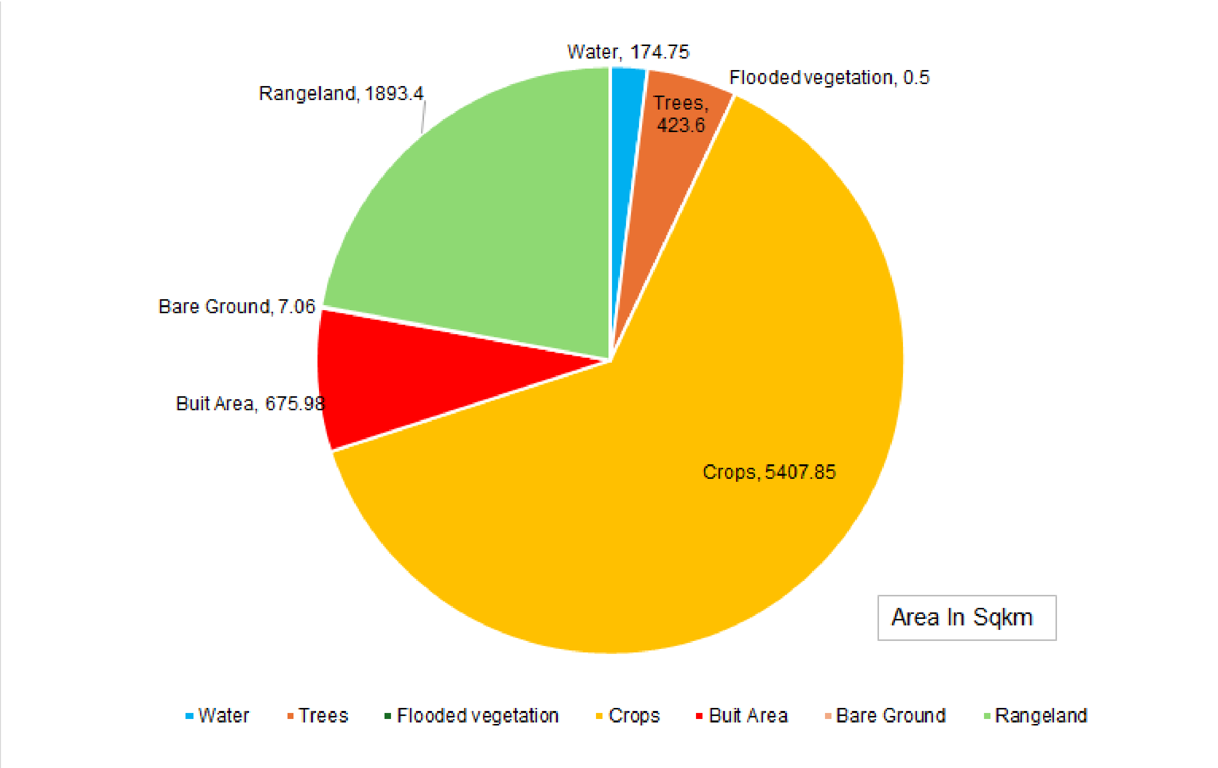


Figure 43 Land use pattern of Lower Narmada Basin

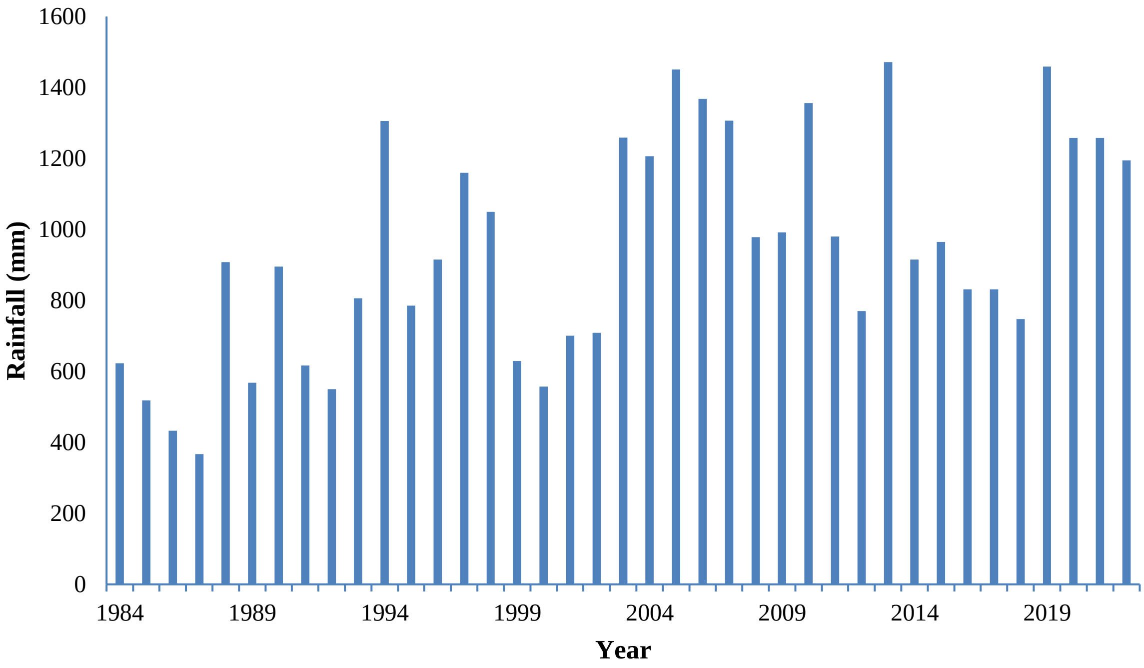


Figure 44 Variation of average annual rainfall over the Lower Narmada Basin

4.3.1 Sources of Pollution

The construction of the Sardar Sarovar Dam has significantly altered the natural flow of the Narmada. Downstream, the river often experiences reduced water volume, impacting its ability to dilute pollutants. This stagnant water becomes a breeding ground for harmful bacteria and creates ideal conditions for pollution to concentrate.

Industrial activity along the riverbank continues to be a major source of pollution. Untreated effluents from industries like chemical plants, textile mills, and paper mills release heavy metals, toxic chemicals, and organic matter into the river. These pollutants pose a serious threat to the river's ecosystem and public health.

The lack of proper sewage treatment infrastructure in towns and cities along the riverbank leads to the direct discharge of untreated sewage. This sewage contaminates the water with harmful bacteria and pathogens, posing a significant health risk.

Reduced freshwater flow from the dam, coupled with rising sea levels, allows seawater to intrude further upstream. This salinisation of the river further disrupts the ecosystem and renders the water unsuitable for most traditional uses.

4.3.2 Behavioural Aspects

The lower reaches of the Narmada River exhibit distinctive hydraulic behavior influenced by its journey through the plains, delta formation, tidal effects near the estuary, and human interventions. As the Narmada River approaches its mouth near the Gulf of Khambhat (Cambay), it forms a deltaic region characterised by sediment deposition. The river carries a significant sediment load from upstream, which contributes to the formation and maintenance of the delta. Near its estuarine region, the lower Narmada experiences tidal effects from the Arabian Sea. Tides influence water levels, flow direction, and sediment transport in the lower reaches, impacting the river's hydraulic behaviour.

4.3.3 Sensitive/ vulnerable/ undistributed areas

Table 10 and Figure 45 show identified sensitive zones, vulnerable zones and undisturbed/protected areas in the Lower Narmada Basin segment.

Table 10 List of sensitive/ vulnerable/ undistributed areas in Lower Narmada Basin

Sensitive Areas	Vulnerable areas	Undisturbed area
• Downstream of the Sardar Sarovar Dam (impacts on natural flow regime and ecology • Industrial zones along the river (chemical plants near Ankleshwar) affecting water quality	• Areas with agricultural runoff and potential for increased salinity intrusion near Bharuch city • River mouth (Gulf of Khambhat) with significant ecological changes due to reduced freshwater flow • Areas with moderate encroachment for settlements and some industrial activity near Ankleshwar and Vadodara	• Shoolpaneshwar Wildlife Sanctuary, particularly on the eastern bank (closer to the Rajpipla Hills)

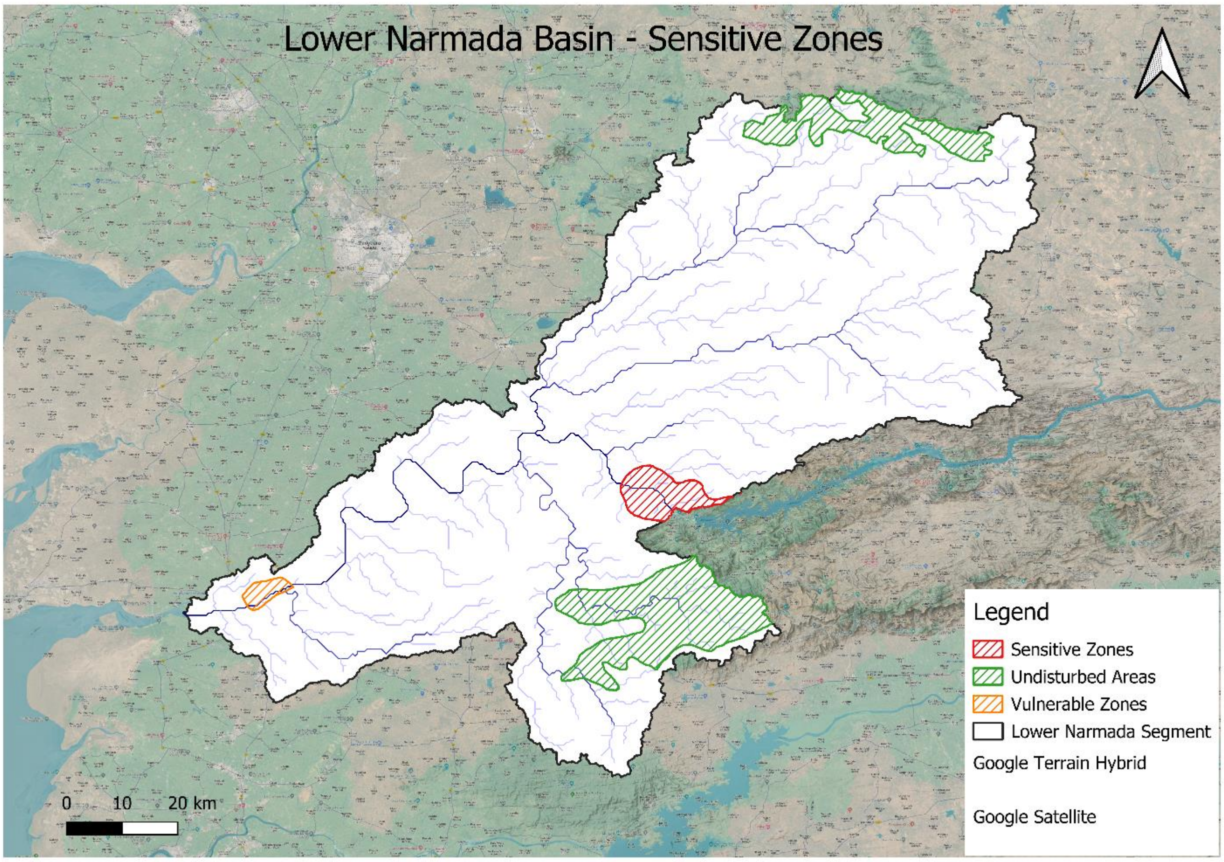


Figure 44 Sensitive, Vulnerable and Undisturbed Areas of the lower Narmada basin

5 CHALLENGES FACED BY RIVER NARMADA

The Narmada River has several challenges that threaten its ecological health and the well-being of communities dependent on it. These multifaceted challenges require a holistic approach that integrates environmental conservation, equitable water resource management, sustainable development practices, and robust governance frameworks.

5.1 Challenges

5.1.1 Dam Construction and Resettlement

The construction of dams along the Narmada, such as the Sardar Sarovar Dam, has led to significant environmental and social impacts. Large-scale displacement of communities and loss of agricultural land due to submergence have been contentious issues. Resettlement and rehabilitation efforts have often been inadequate, leading to prolonged hardships for affected populations.

5.1.2 Water Scarcity and Pollution

Increasing water demand for agriculture, industry, and urban consumption has led to the depletion of water levels in the river, especially during dry seasons. Pollution from industrial effluents, agricultural runoff, and untreated sewage further degrades water quality, impacting aquatic life and the health of downstream communities.

5.1.3 Deforestation and Erosion

Deforestation in the river basin contributes to soil erosion, leading to sedimentation and siltation of the riverbed. This reduces water storage capacity and affects aquatic biodiversity. Erosion also threatens agricultural productivity and increases vulnerability to floods during monsoon seasons.

5.1.4 Climate Change Impacts

The Narmada River basin is increasingly vulnerable to climate change impacts such as erratic rainfall patterns, prolonged droughts, and extreme weather events. These factors exacerbate water scarcity, affect agricultural productivity, and challenge the sustainability of water resource management practices.

5.1.5 Biodiversity Loss

Habitat destruction, pollution, and altered flow regimes due to dam constructions have severely impacted the river's biodiversity. Endangered species such as the Ganges river dolphin and various migratory birds are threatened, disrupting the ecological balance of the river ecosystem.

5.1.6 Governance and Management Issues

Challenges in governance, including inadequate coordination between states sharing the river, inefficient water resource allocation, and the lack of comprehensive river basin management plans, contribute to the unsustainable use of Narmada's resources.

5.2 Conservation and Protection

Consumptive uses of Narmada River water are increasing rapidly and cannot be replaced unless suitable alternative sources are found. Thus, it is imperative to develop and implement effective measures for the conservation of available riverine resources, as well as the river's productivity and production functions.

5.2.1 Conservation of the resources

There is a need to improve and conserve the river water resources for the protection of the natural flora and fauna through the restoration of their habitats. Natural basin characteristics should not be altered, in view of their important role in providing necessary breeding and feeding habitats for a number of commercial species, particularly the foothill Carps. Deep pools play an important role in sheltering fish stocks, especially large-sized fish, during fair-weather periods. An extensive survey of deep pools in all river sections of stakeholder states is needed, with mapping of the hydro-ecological status of pools as a basis for regular monitoring of their status. There is a need to declare the deep pools and gorges as sanctuaries or non-fishing areas. Conservation of these deeper areas of the river would help protect the brood stocks of the fish and aid in the recovery of their depleted stocks.

5.2.2 Conservation of fish stocks

Overfishing causes of the depletion of the fish stocks and the composition of the catches. Free fishing in the concerned states is an unstated right of fishers, and until ad libitum fishing is controlled, little progress can be made towards the conservation and development of fisheries. Measures such as non-fishing seasons and areas, sanctuaries, and size limits for commercial species should be enforced.

5.2.3 Environmental protection

The use of river waters for waste removal is commonly practiced throughout the Narmada River region. Both non-point and point sources have contributed to degrading water quality and habitats for aquatic flora and fauna. Discharges from cities and industrial areas in Madhya Pradesh, Gujarat and Maharashtra are gradually increasing the pollution loads, which are either untreated or semi-treated. To overcome the problem of pollution and related hazards for the ecosystem and fisheries, positive measures like agglomeration of like industries, adoption of common treatment facilities, execution of zero-effluent measures, and safe disposal of different harmful industrial elements must be adopted.

The Narmada is a rain-fed system, and the annual run-off is dependent on the rate of water flow in the catchment areas. Therefore, to restore desired and optimum habitat conditions in the dam-affected river stretches, a suitable flow regime needs to be maintained. Research in this regard is needed and the recommended rate of discharge may be maintained, if not throughout the year then at least for the crisis periods of the flora and fauna.

6 ECONOMIC

The Narmada River plays a significant role in the economic development of the regions it traverses i.e. 14 districts of Madhya Pradesh, 5 districts of Gujrat and one district of Maharashtra. Following are the key areas of its economic impact:

6.1 Agriculture

Irrigation: The Narmada River supports extensive irrigation systems, providing water to millions of hectares of agricultural land. This irrigation is crucial for the cultivation of crops such as wheat, rice, cotton, and pulses, contributing significantly to the agrarian economy.
***Agricultural Productivity*:** The fertile plains along the Narmada River enhance agricultural productivity, leading to higher yields and supporting the livelihoods of numerous farming communities.

6.2 Hydroelectric Power

Narmada Valley Development Project: A series of dams and hydroelectric projects like the Sardar Sarovar Dam and the Indira Sagar Dam generate substantial hydroelectric power, contributing to the energy needs of Madhya Pradesh, Maharashtra, and Gujarat.
Renewable Energy: The hydroelectric power generated from the Narmada River is a crucial component of the region's renewable energy mix, reducing dependency on fossil fuels and promoting sustainable development.

6.3 Water Supply

Domestic and Industrial Use: The Narmada provides essential water supply for domestic use in urban and rural areas and also supports industrial activities, particularly in regions like Gujarat, which are heavily reliant on Narmada water for manufacturing processes.
Drinking Water: Projects like the Sardar Sarovar Dam supply drinking water to drought-prone areas in Gujarat and Rajasthan, significantly improving the quality of life and health outcomes for millions of people.

6.4 Fisheries

Fishing Industry: The Narmada River supports a thriving fishing industry. The river and its reservoirs are home to a variety of fish species, providing livelihoods for local fishing communities and contributing to the local economy.
Aquaculture: The development of aquaculture in the Narmada basin has further boosted the fishery sector, providing additional income sources and employment opportunities.

6.5 Tourism

Cultural and Religious Tourism: The Narmada River is a site of immense cultural and religious significance. Pilgrimages to temples and ghats along the river, particularly in cities like Omkareshwar and Maheshwar, attract millions of tourists annually, supporting local businesses and hospitality sectors. Some notable tourism sites are depicted in Figure 46.
Ecotourism: The scenic beauty of the Narmada Valley, with its lush landscapes and diverse wildlife, promotes ecotourism. Activities such as boating, trekking, and wildlife tours generate revenue and foster conservation efforts.

Panchmarhi Hill station

Zarwani waterfall

Maheshwar Ghat

Marble rocks Jabalpur

Statue of Unity

Dhuandhar Fall, Bhedaghat

Figure 45 Tourism sites in the Narmada river basin

Sources: https://www.penchnationalparkonline.in/ , https://narmada.nic.in/gallery/ , https://narmada.nic.in/ , https://www.incredibleindia.org, https://timesofindia.indiatimes.com/

6.6 Industrial Development

Riverine Ports and Transport: The development of riverine ports and improved transportation along the Narmada facilitates trade and commerce. Efficient movement of goods via waterways reduces transportation costs and boosts economic activities in the region.
Industrial Corridors: The availability of water from the Narmada has spurred the development of industrial corridors, attracting investments and promoting industrial growth in states like Gujarat and Madhya Pradesh.

6.7 Flood Control and Management

Flood Mitigation: The construction of dams and reservoirs along the Narmada helps in flood control and management, protecting agricultural lands and settlements from flood-related damages. This stability fosters a conducive environment for sustained economic activities.

6.8 Upper Narmada

The Narmada River significantly boosts the economy of districts Jabalpur, Narsinghpur, Mandla, Anuppur, and Dindori in upper Narmada through enhanced agricultural productivity and reliable irrigation infrastructure. Reliable irrigation via canals, lift irrigation projects, reservoirs, and tube wells supports multiple cropping cycles, producing high yields of wheat, rice, pulses, soybeans, oilseeds, and horticultural crops like guava and mango.

6.9 Middle Narmada

The Narmada River significantly benefits several districts in Madhya Pradesh, like Alirajpur, Hoshangabad (Narmadapuram) , Dewas , Khargone , and Sehore, fostering robust agricultural economies through reliable irrigation infrastructure: These districts rely on canals, wells and tube wells for irrigation, enabling diverse crop cultivation like wheat, rice, pulses, cotton, soybeans, oilseeds, and fruits, stabilizing farmer incomes and supporting agro-industries. The Narmada River's irrigation systems across these districts reduce dependency on rainfall, stabilize agricultural incomes, create employment in farming and related industries, and support sustainable practices, ensuring long-term socio-economic prosperity.

6.10 Lower Narmada

The three district in lower Narmada i.e. Narmada, Bharuch and Vadodara benefits significantly from the Narmada River, supporting a thriving agricultural economy through efficient irrigation from the Sardar Sarovar Dam. These districts have irrigation support for year-round cultivation of wheat, rice, pulses, and oilseeds. Horticulture thrives with fruits and vegetables due to reliable water supply, increasing farmer incomes and stabilizing economic conditions through reduced reliance on monsoons. Agriculture is a major employer, creating jobs in farming, agro-processing, transportation, and retail, while surplus output supports food processing and dairy industries, enhancing economic resilience.

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