Narmada River: Basin-scale features

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About Narmada

- 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).

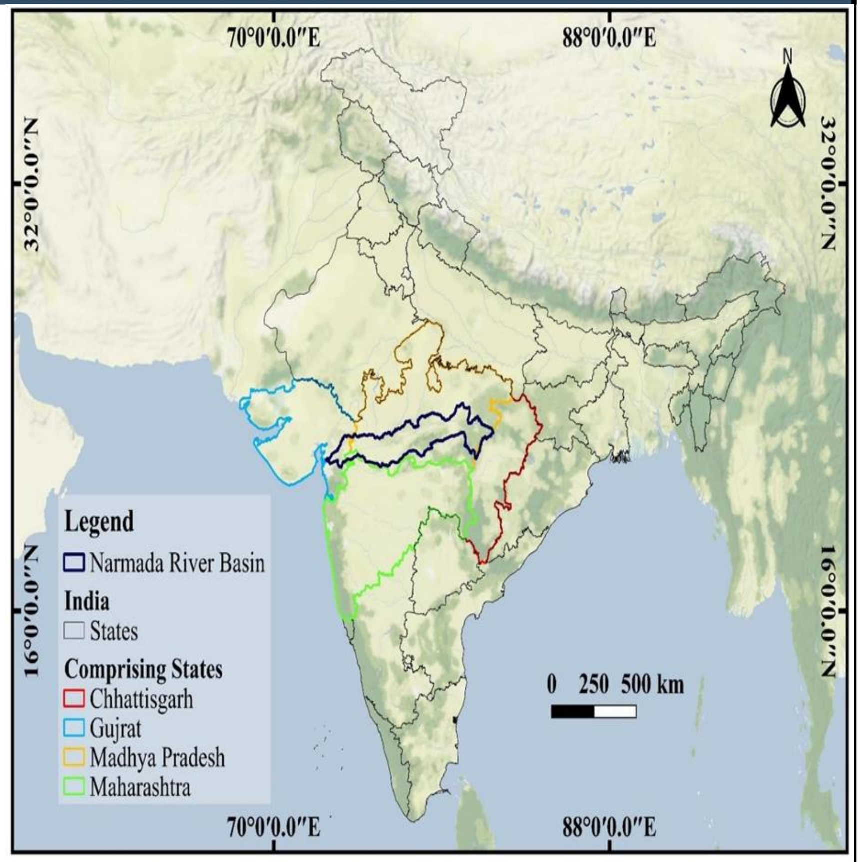

Fig.1 Geographical location map

Basin Demography

- **Geographic Spread:** The Narmada River basin spans four Indian states: Chhattisgarh, Maharashtra, Gujarat, and Madhya Pradesh, each with diverse demographic characteristics.
- **Chhattisgarh:**
  - Raj Nandgaon: Covers 86.61 sq. km, with a population exceeding 1.5 million and a growth rate of 17.79%, indicating high population density.
  - Kabirdham: Spans 627.25 sq. km, showing a significant population growth of 40.71%, reflecting rapid development and increasing density.
- **Madhya Pradesh:**
  - Harda: Features a population growth rate of 32.88% and a high density of 833.15 people per sq. km, highlighting rapid urbanization and resource pressure.
  - Mandla: Covers a larger area of 4,628.55 sq. km, with a lower population density of 156.86, indicating less demographic pressure.
  - Hoshangabad and East Nimar: Mostly within the basin, these districts are geographically significant and heavily reliant on basin resources.
- **Demographic Insights:** The analysis reveals varying levels of dependence on the Narmada River across districts, substantial urban population growth, and notable demographic shifts. These insights are crucial for effective planning and sustainable development of the basin.

Fig.2 Drainage area of the Narmada River with its three segments

The entire stretch of River Narmada can be primarily divided into three sub-basins/segments based on their geomorphology, ecology and rheology:

- 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 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.

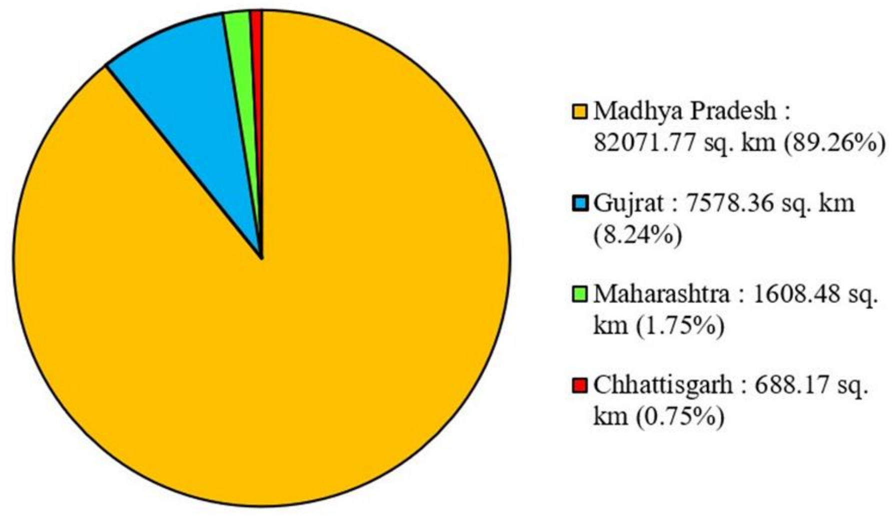

Fig.3 State-wise basin area

Drainage Map

The drainage network of the Narmada River consists of 19 major tributaries (a total of 41 tributaries)
(Banjar, Barna, Beda, Burhner, Chota, Tawa, Dudhi, Ganjal, Goi, Hiran, Karjan, Man, Orsang, Shakkar, Sher, Tawa, Tendoni, Hatni, Kolar, Uri)

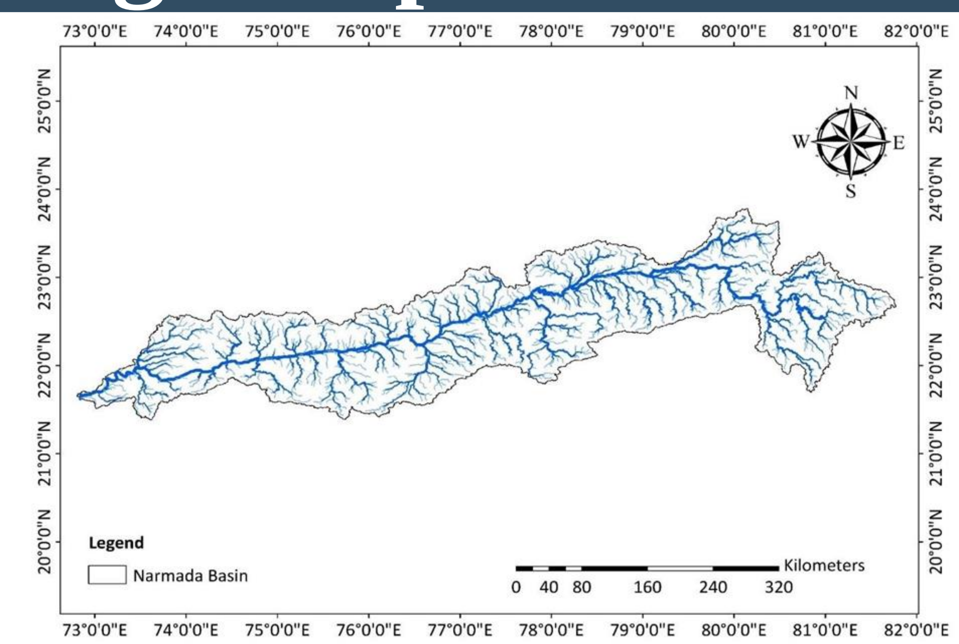

Fig.4 Narmada basin drainage map

Topography:

- The Narmada basin comprises five well-defined physiographic zones:
  - The Upper Hilly Areas
  - The Upper Plains
  - The Middle Plains
  - The Lower Hilly Areas
  - The Lower Plains.
- The highest elevation within the basin is observed to be 1231 m (CartoDEM), as given in Table.

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		

Table 1: Elevation zones of the Narmada basin

- The spatial distribution of elevation in the basin is depicted in Figure
- 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

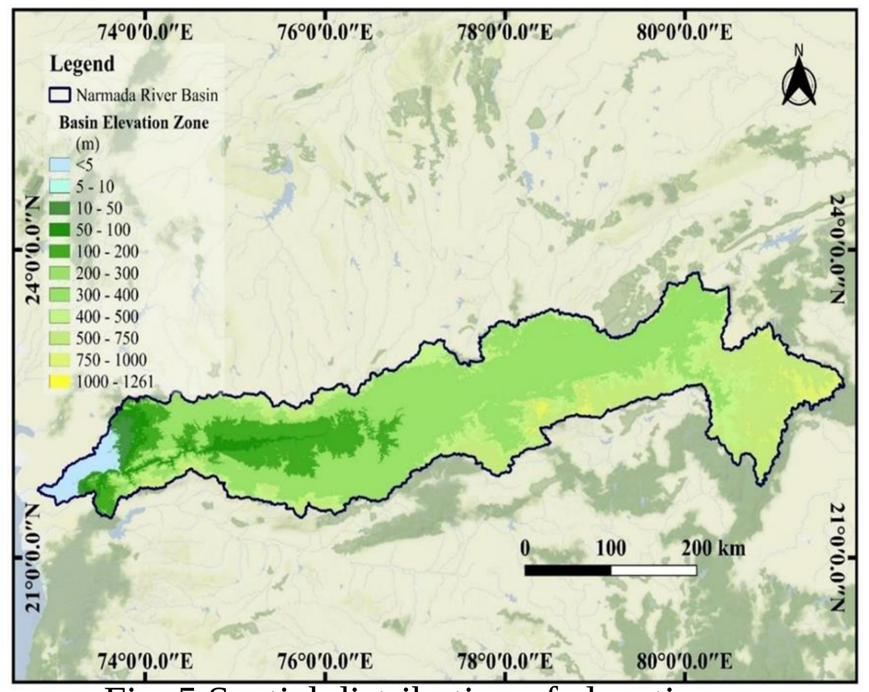

Fig. 5 Spatial distribution of elevation zones

Sediment

- 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).

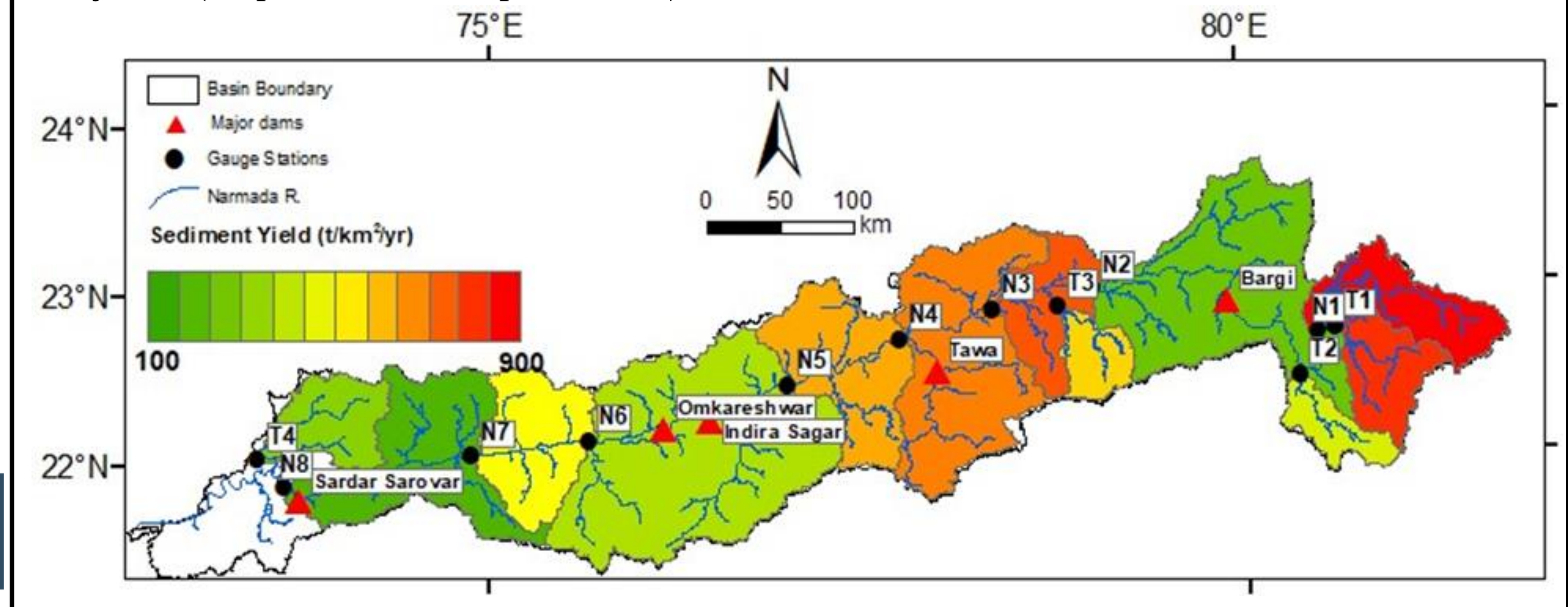

Fig. 6 Sediment yield in the Narmada basin

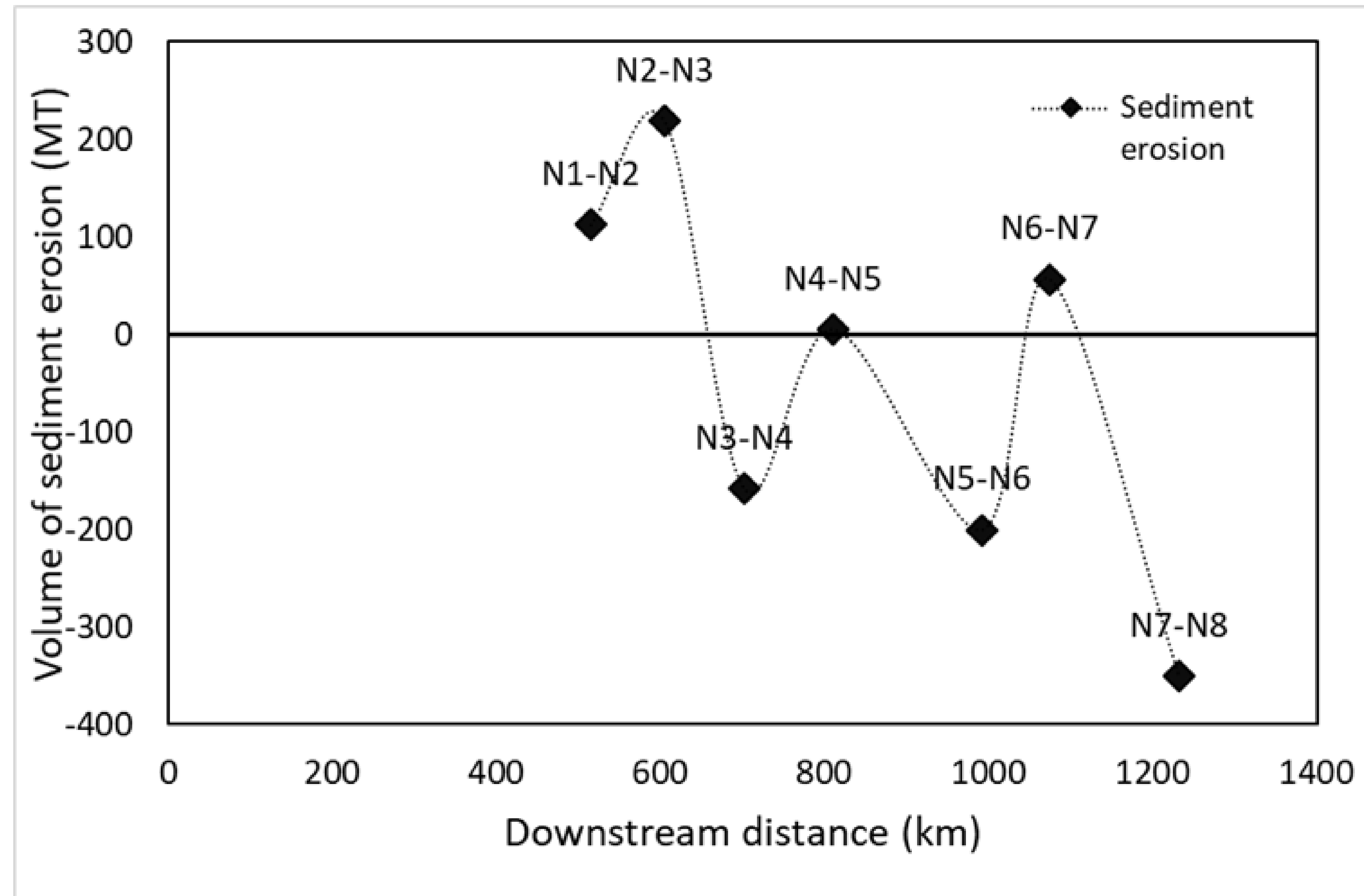

Fig. 7 Volume of sediment erosion in Narmada River stretches,

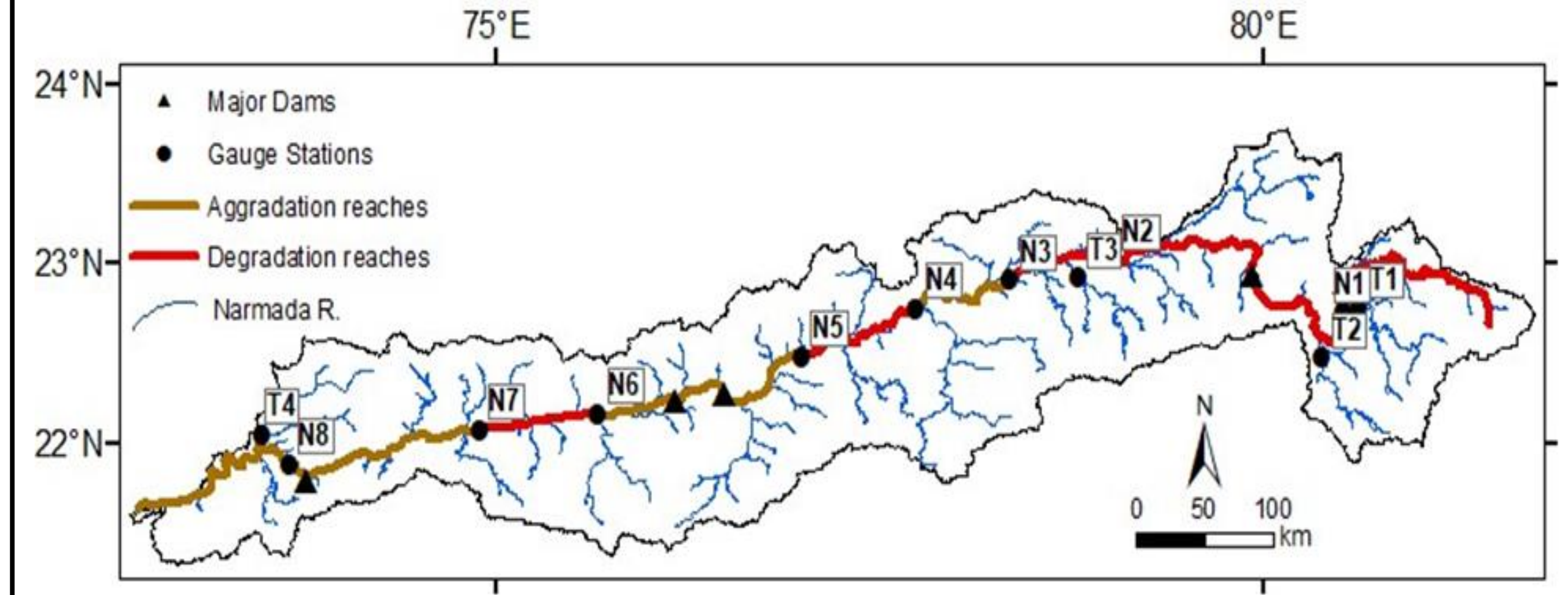

Fig. 8 Gradation characteristics in Narmada River stretches

- The upstream reaches show degradation
- The mid-stream and downstream reaches are deposition-dominated.
- These downstream deposition sites could provide possible sediment mining sites.

Narmada River Basin: A Comprehensive Sub-Basin Analysis

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Upper Narmada River segment

- The Narmada River originates from the Narmada Kund, a small reservoir in Amarkantak, located on the Amarkantak Plateau in Anuppur District, Madhya Pradesh, at coordinates 22°40′0″N 81°45′0″E and an elevation of 1,048 m.
- Tributarie:
  - Left Side: Major tributaries include Halon, Banjar, Bargi, Shakkar, and Dudhi.
  - Right Side: Major tributaries include Hiran, Shahdol, Tendoni, and Barna.

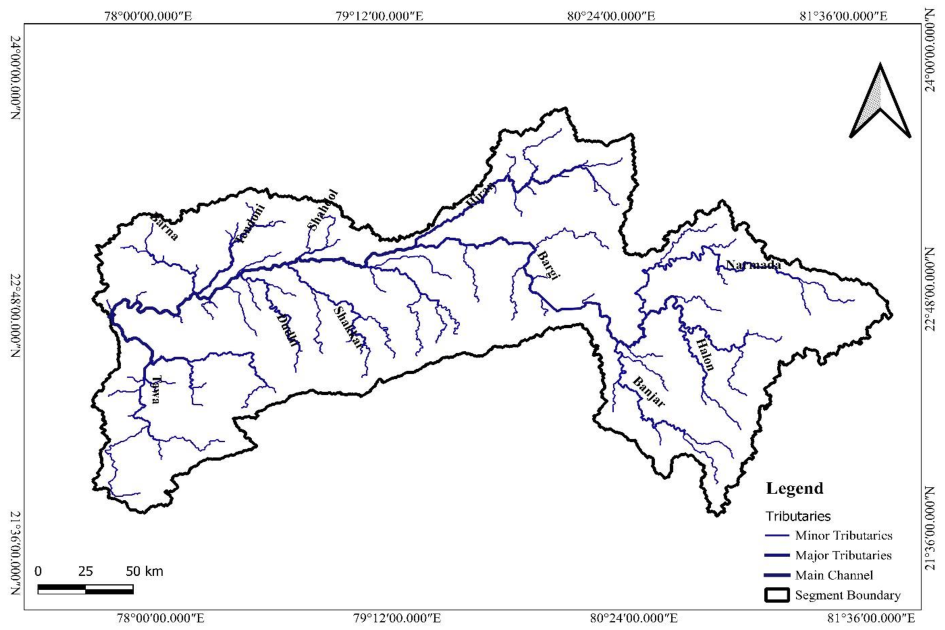

Fig.1 Tributaries

- Major Land Use/Cover Classes: The Narmada Basin includes water, trees, flooded vegetation, crops, built areas, bare ground, and rangeland (Figure 2).
- Paddy Cultivation: Paddy is the dominant crop in the upper Narmada River segment due to heavy rainfall and poor infiltration.
- Water Bodies: The "Water" land use class covers 837.17 sq. km, including major water bodies like Bargi Dam and Tawa Reservoir in the Upper Narmada Segment.
- Soil Composition: The upper Narmada River basin has shallow black soil with high water-holding capacity, reducing drainage. In hilltops and plateau regions, these soils are mixed with red and laterite soils.

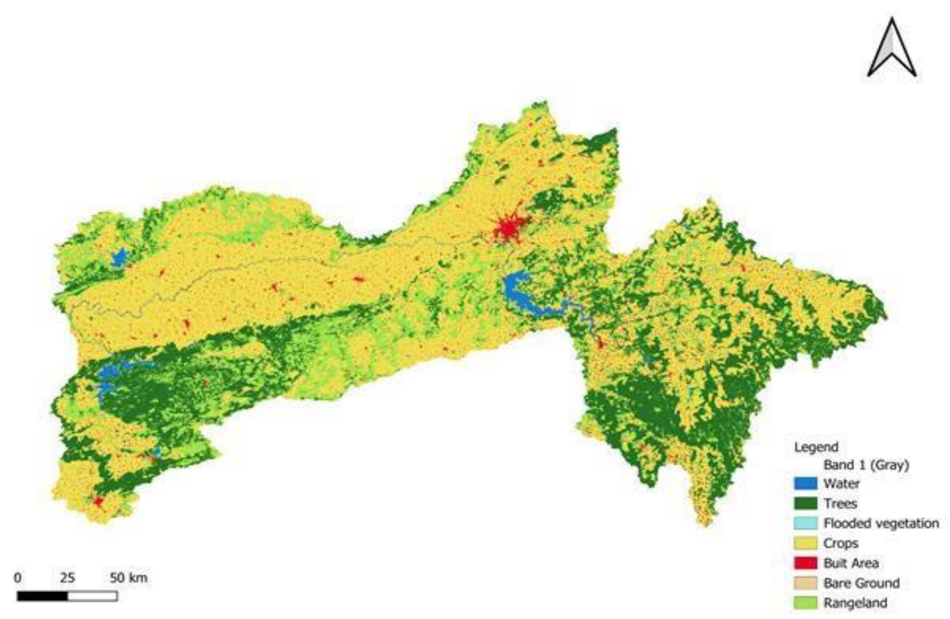

Fig.2 LULC Map

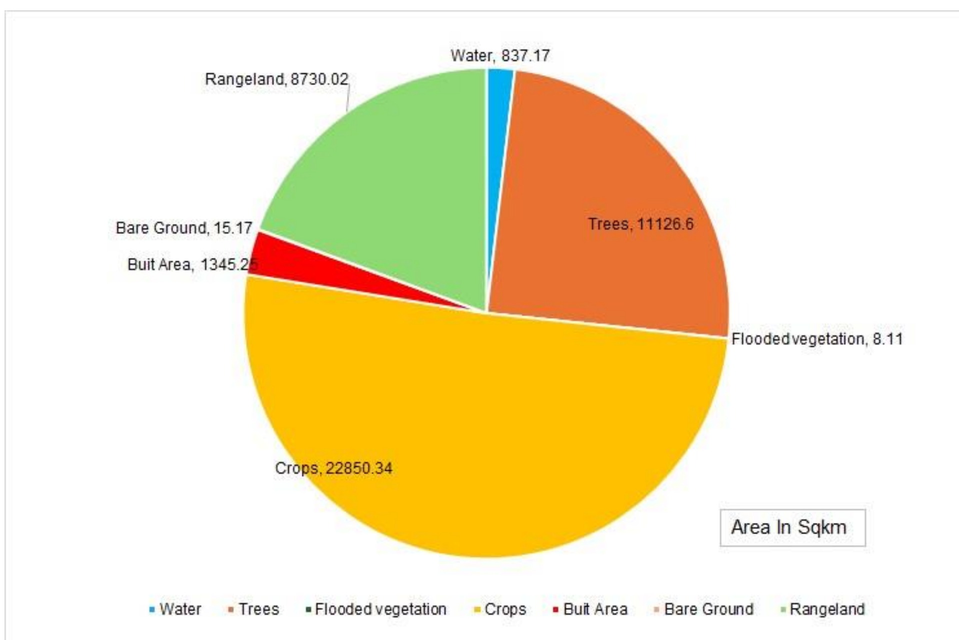

Fig.3 Land use pattern

- Sensitive/ vulnerable/ undistributed areas in Upper Narmada Basin :

1) Sensitive Areas: Construction of large dams (Bargi Dam, Indira Sagar Dam) impacting flow & ecology.
2) Vulnerable areas : Areas downstream of Jabalpur (high pollution from city sewage) & Industrial zones along the river (paper mills, chemical factories),
3) Undisturbed area : Upper Kanha River & tributaries joining Narmada (minimal human intervention), Amarkantak region with minimal human settlements.

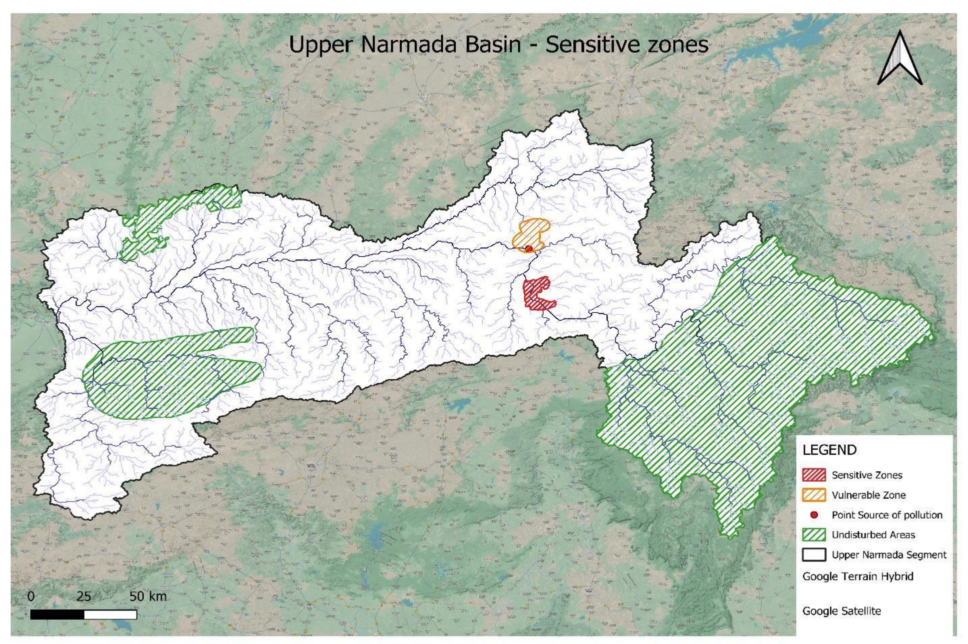

Fig.4 Sensitive, Vulnerable, and Undisturbed Areas

Middle Narmada River segment

- The Middle Narmada Basin segment is flatter compared to the upper basin, with more open and visible basaltic land, especially over the 160 km stretch from Hoshangabad.
- The valley in the western part of the Narmada Basin has varied slopes due to hill divisions, contributing to fertile land.
- Major Tributaries:
  - Left Side: Ganjal, Ajnai, Chhota Tawa, Kaveri, Kundi, Borad, and Goi.
  - Right Side: Kolar, Dahini, Sukhji, Man, Uri, Bagh, and Hatni.

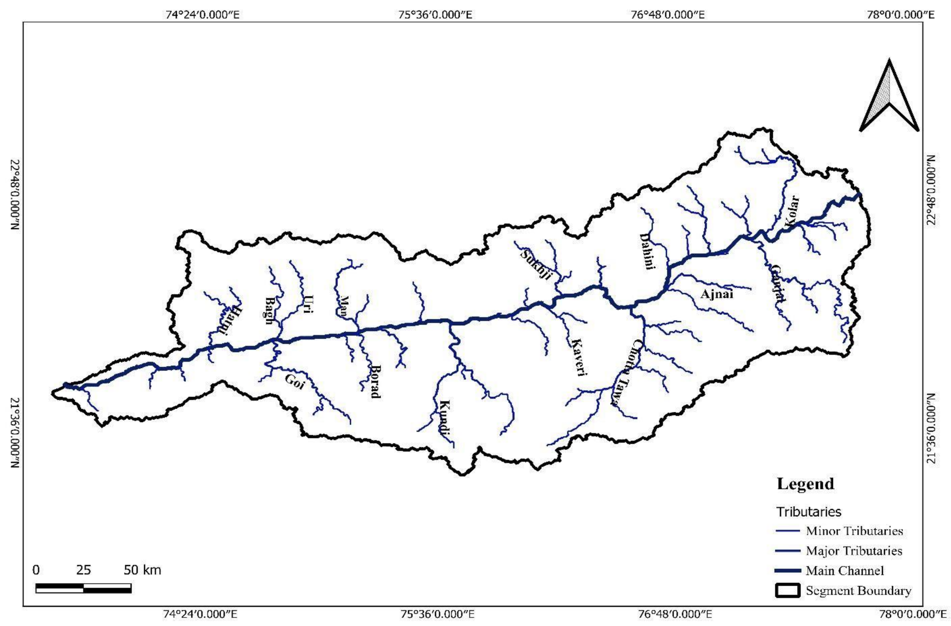

Fig.5 Tributaries

- Land Use/Cover Classes: The major land use/cover types in the Narmada Basin include water, trees, flooded vegetation, crops, built areas, bare ground, and rangeland (Figure 6).
- Agriculture: Wheat is more widely cultivated than paddy in the middle Narmada basin segment, with other crops like Jowar, Maize, Barley, and Bajra also grown.
- Water Bodies: The "Water" LULC class covers approximately 1,484.83 sq. km, including major reservoirs like Indira Sagar and Sardar Sarovar.

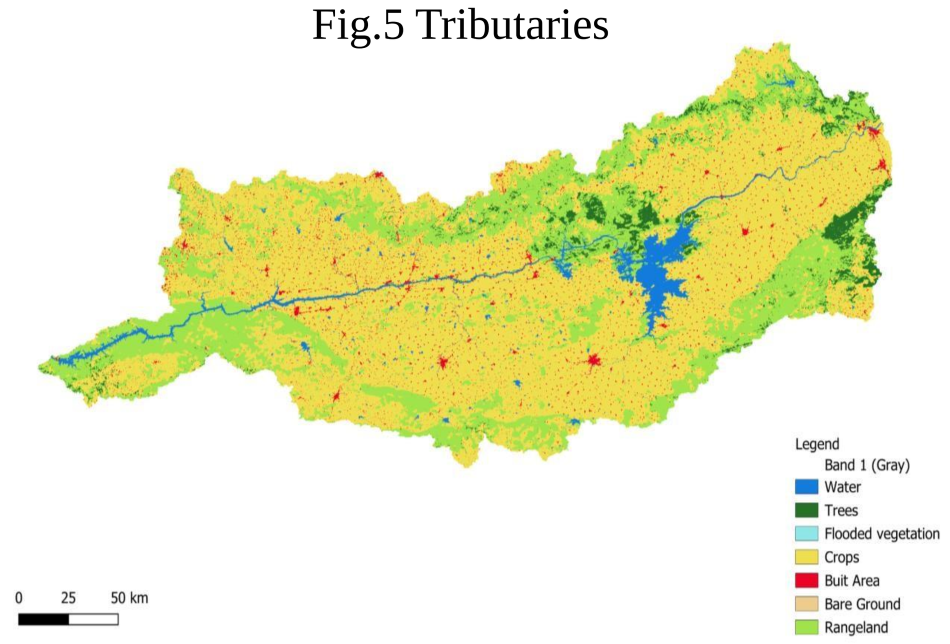

Fig.6 LULC Map

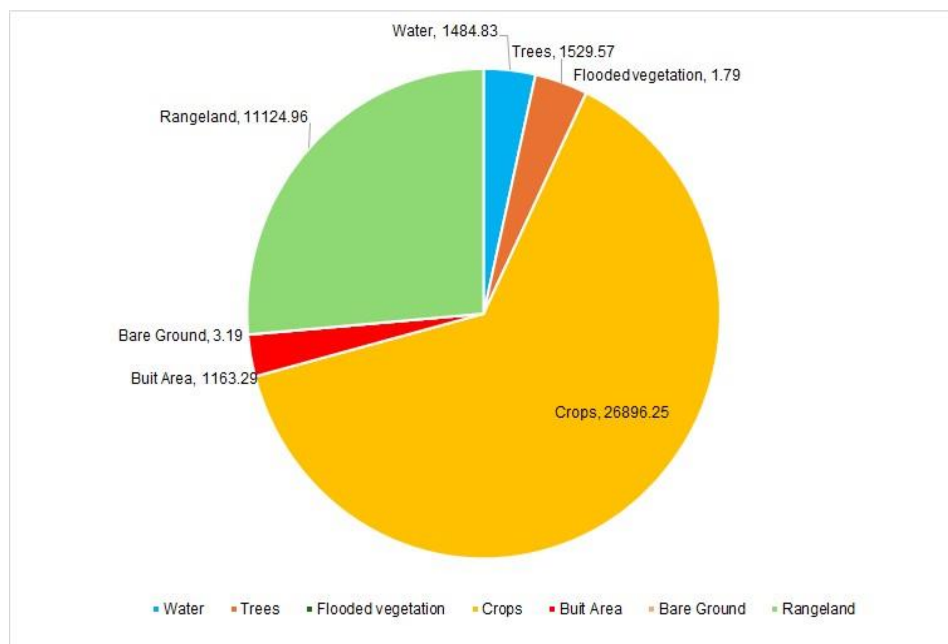

Fig.7 Land use pattern

- Sensitive/ vulnerable/ undistributed areas in Upper Narmada Basin :

1.Sensitive Areas: 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)
2.Vulnerable areas : 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)
3.Undisturbed area: Areas with minimal human intervention around the Bori Sanctuary.

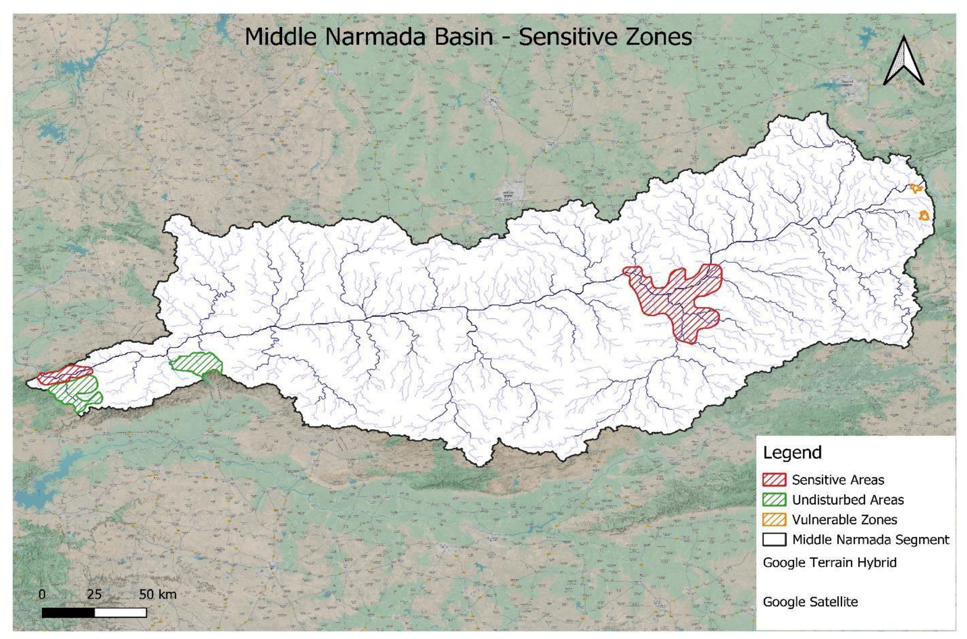

Fig.8 Sensitive, Vulnerable, and Undisturbed Areas

Lower Narmada River segment

- The Narmada River meets into the Arabian Sea in the Gulf of Khambhat, Bharuch District, Gujarat.
- The river passes through three narrow valleys between the Vindhya scarps (north) and the Satpura range (south), with the southern part of the valley being generally wider.
- Major Tributaries:
  - Orsang, Heran, Karjan, Tawa and Dudhi rivers

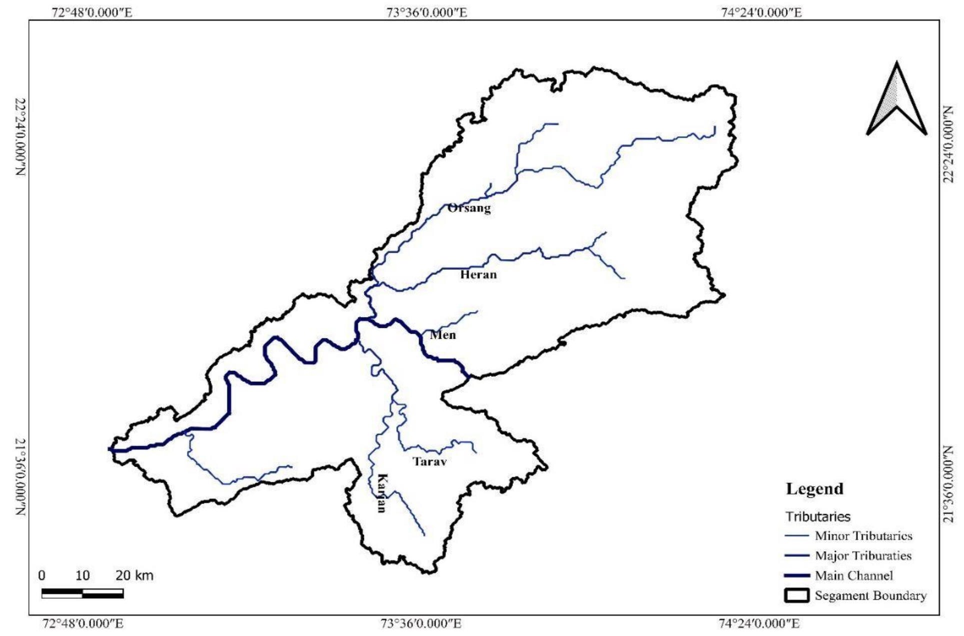

Fig.9 Tributaries

- Land Use/Cover Classes: The Narmada Basin includes water, trees, flooded vegetation, crops, built areas, bare ground, and rangeland (Figure 10).
- Agriculture in Middle Segment: Wheat is more widely cultivated than paddy in the middle Narmada basin segment.
- Water Storage: The lower Narmada segment has smaller water storage structures compared to the upper and middle segments.

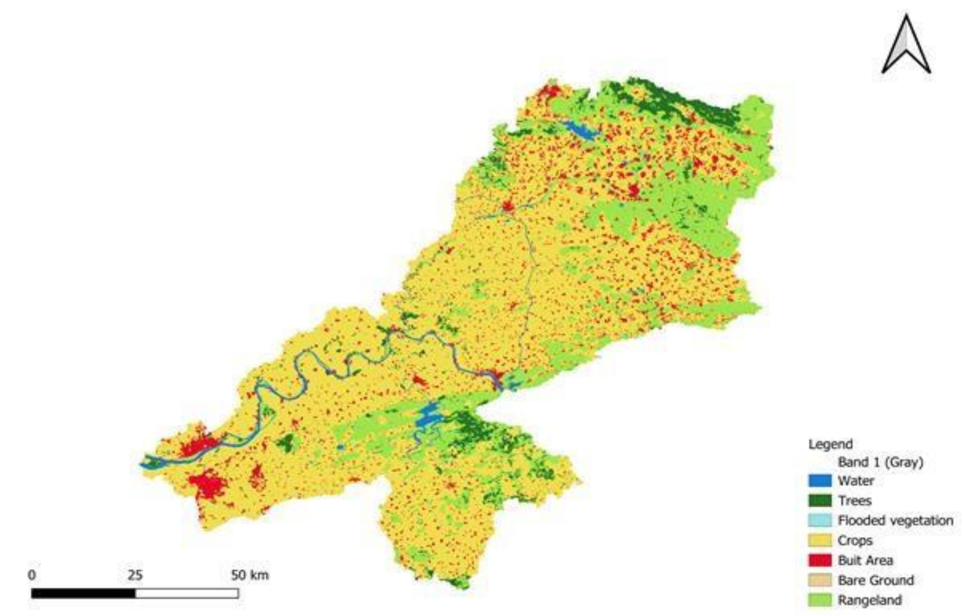

Fig.10 LULC Map

- Sensitive/vulnerable/ undistributed areas in Upper Narmada Basin :

1.Sensitive Areas: 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.
2.Vulnerable areas :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.
3.Undisturbed area: Shoolpaneshwar Wildlife Sanctuary, particularly on the eastern bank (closer to the Rajpipla Hills).

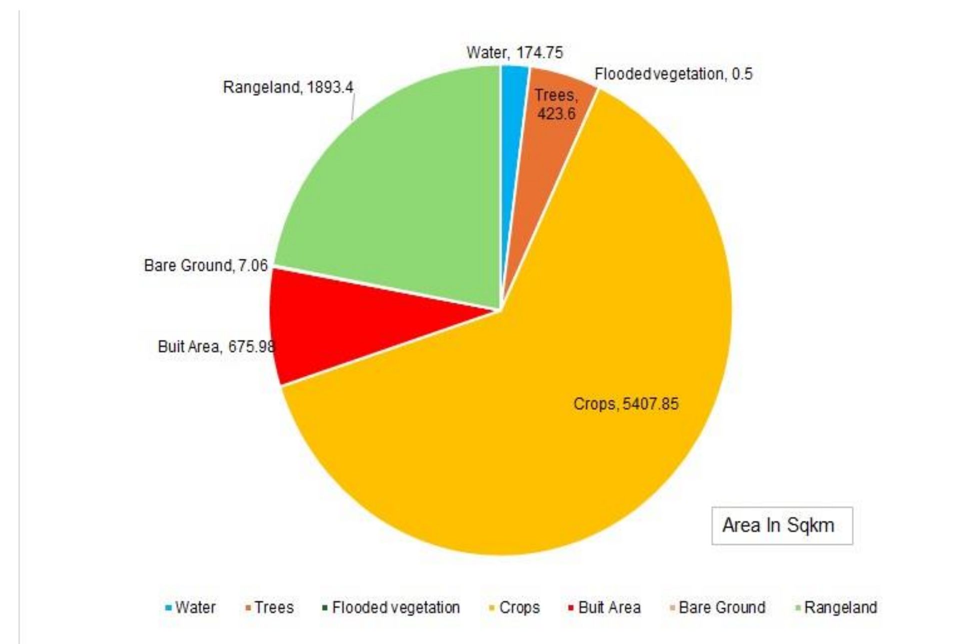

Fig.11 Land use pattern

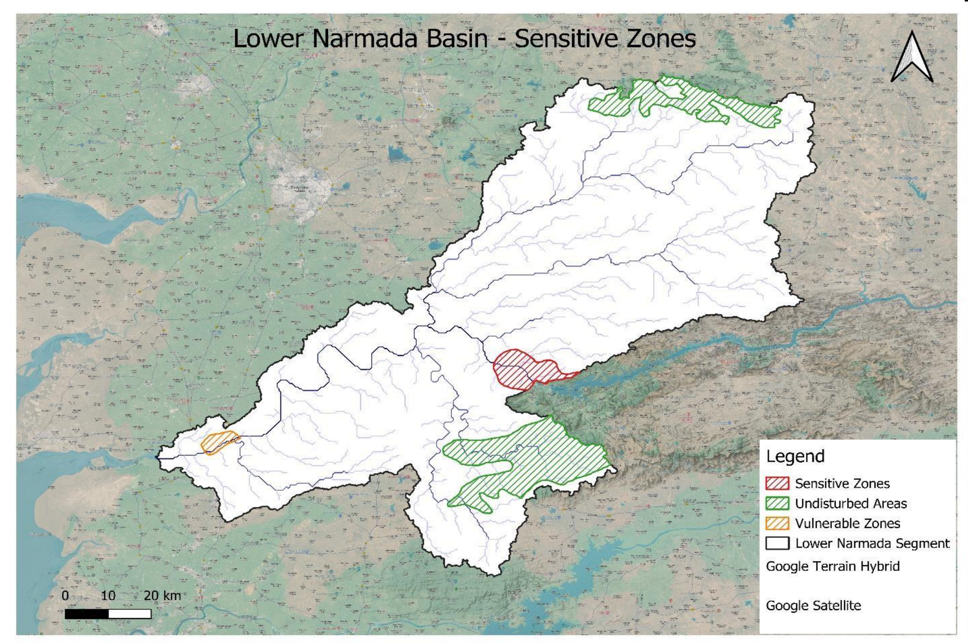

Fig.12 Sensitive, Vulnerable, and Undisturbed Areas

Climate, Land And Soil Of Narmada River Basin

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Introduction

- The Narmada River basin experiences four distinct seasons: i) Cold weather, ii) Hot weather, iii) South-west monsoon, and iv) post-monsoon.
- The cold season with light precipitation runs from November to February. The hot, dry season begins in March, peaking in May, and lasts until mid-June.
- The rainy season, driven by the southwest monsoon, occurs from mid-June to September. Post-monsoon, a few thunderstorms may occur in October before the weather turns dry and pleasant for the rest of the year.

Rainfall

- Rainfall is heaviest in the upper hilly and northeastern plains of the Narmada basin, gradually decreasing towards the lower plains in the west, with some coastal and southwestern areas receiving higher precipitation.
- Understanding these rainfall patterns is crucial for effective water resource management and agricultural planning in the basin.

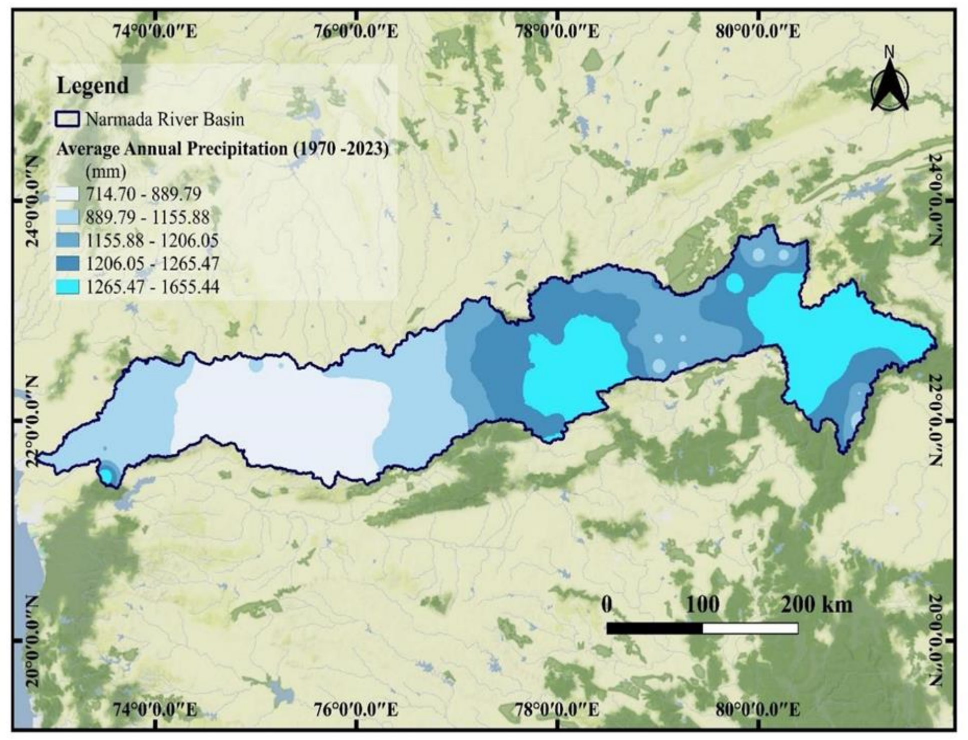

Figure 1. Spatial distribution of precipitation (1970 – 2023) Source: IMD gridded data (0.25° X 0.25°)

Temperature

- The Narmada basin experiences significant temperature variations, with mean annual temperatures ranging from 24.92°C to 27.39°C.
- Higher temperatures are mainly found in the western parts of the basin, influencing the local climate and agricultural practices.
- These temperature differences are important to consider in resource management strategies.

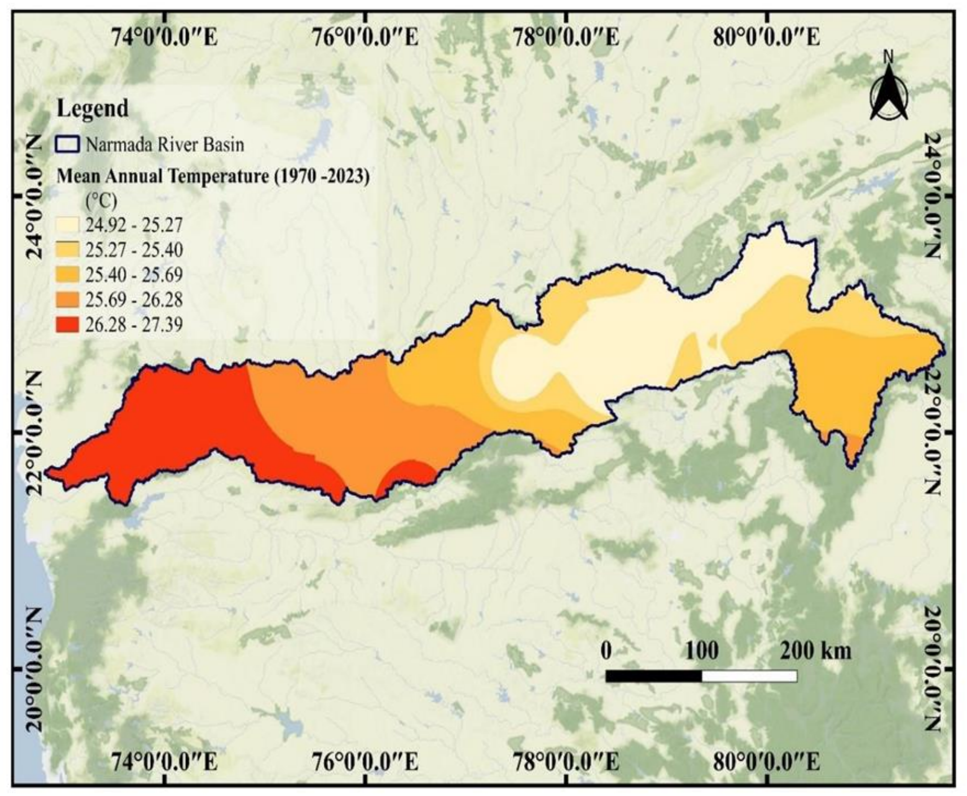

Fig. 2 Spatial distribution of temperature (1970 – 2023)

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

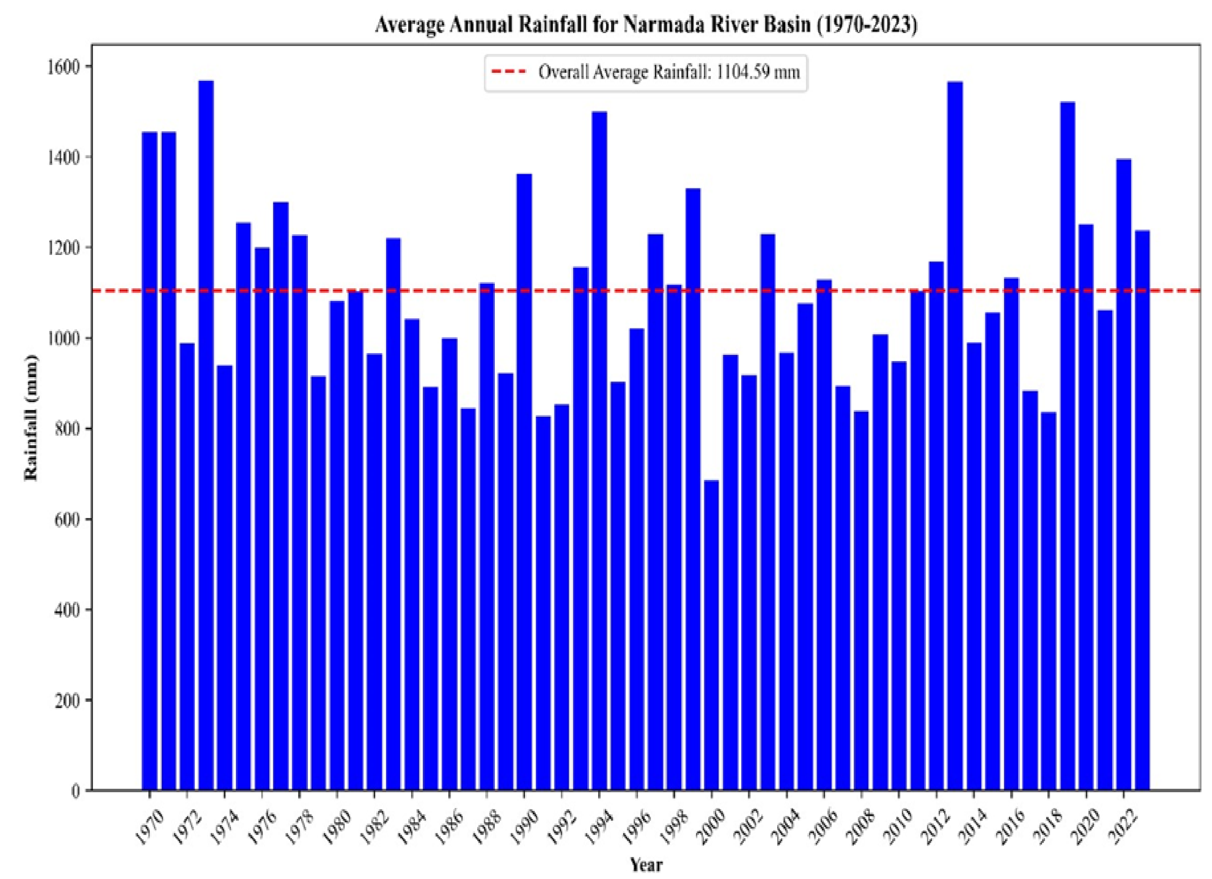

Fig.3 Annual Rainfall for Narmada River Basin

- Figure 3. 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. The overall average annual rainfall (1104.59 mm) provides a benchmark for assessing individual years.
- 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.

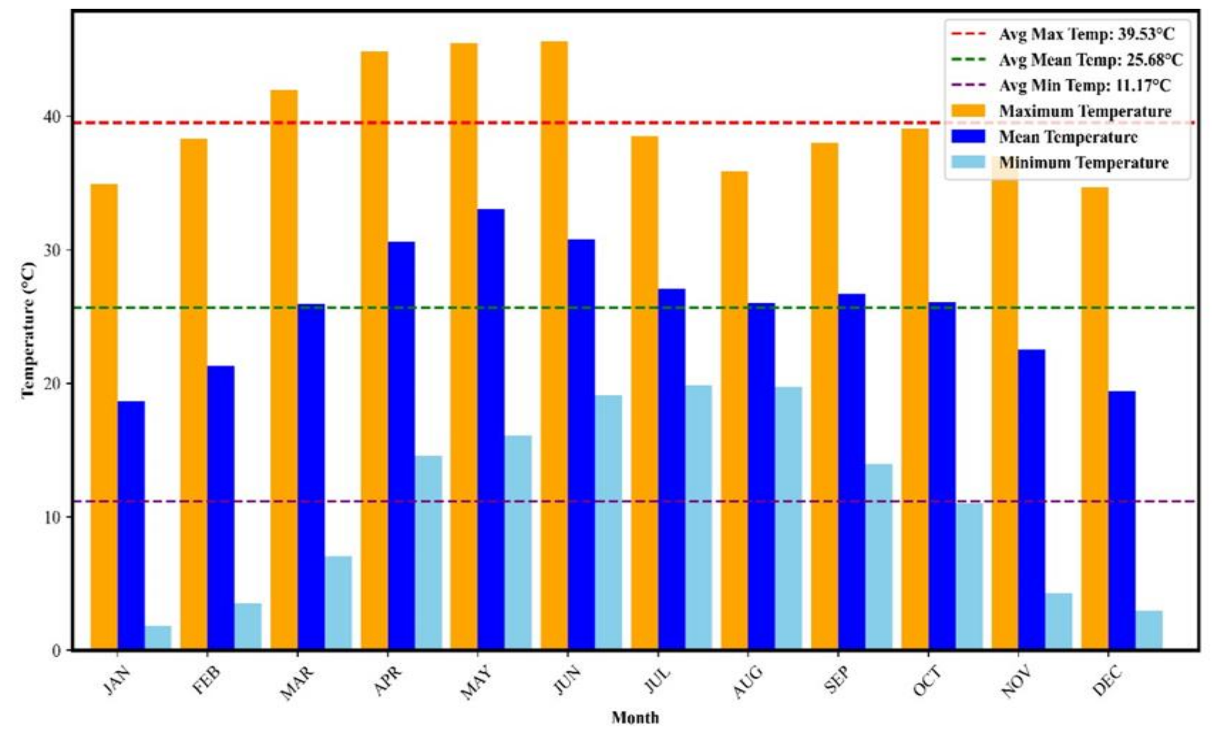

Fig. 4 Monthly Average Temperature of Narmada River Basin (1970-2023)

- Figure 4. represents 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).
- 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. Temperatures begin to decrease, with maximum temperatures falling below 30°C by November and minimum temperatures dropping to around 15°C.

Land and Soil of Narmada River Basin

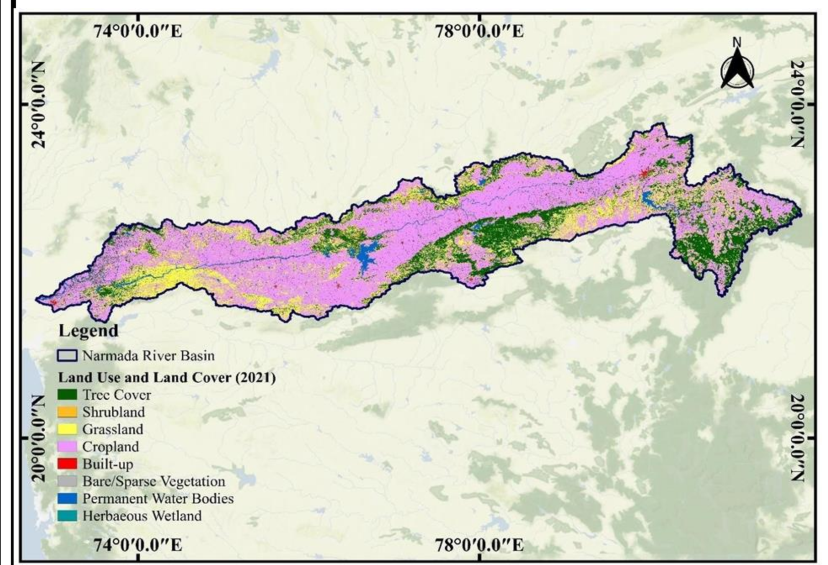

Fig.5 Land use and Land cover of Narmada river basin

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

Table 1

- The 2021 land use and land cover analysis of the Narmada River basin shows a predominantly agricultural landscape, with cropland covering 57.47% of the area. Tree cover is the second largest, occupying 17.01%, followed by grasslands at 16.30%. Shrubland covers 2.17%, while built-up areas and bare/sparse vegetation account for 0.95% and 3.77%, respectively. Permanent water bodies cover 2.33%, and herbaceous wetlands are minimal, occupying just 0.002% of the basin.

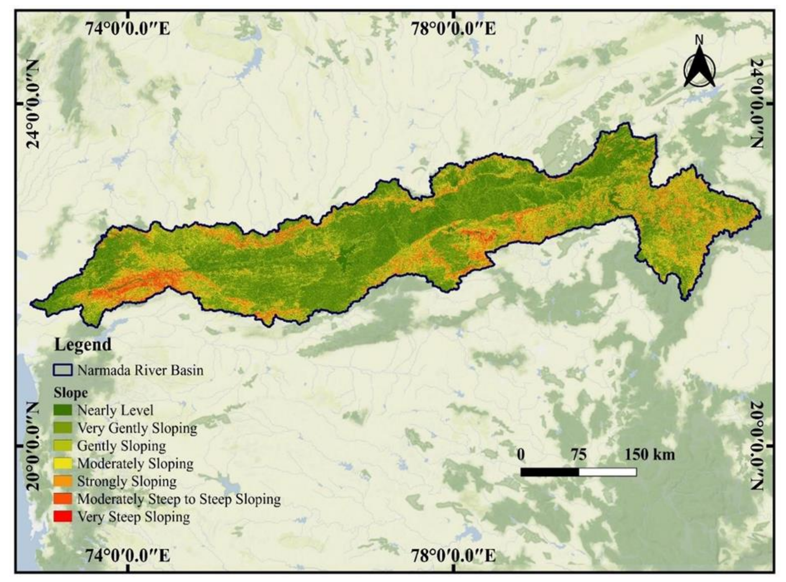

Fig. 6 Spatial distribution of soil type

- The central parts of the Narmada basin are predominantly covered by clay loam soils, ideal for agriculture due to their fertility.
- Loam soils, found in the eastern and southeastern regions, also support productive farming with good drainage.
- The northeastern and southwestern extremities have clay soils, suitable for moisture-loving crops, while the northwestern and some northeastern fringes contain sandy clay loam soils, offering a mix of properties for specific crops.
- This diverse soil distribution underscores the basin's agricultural potential.

- The Narmada River basin mainly features nearly level to very gently sloping areas in the central and northern regions, ideal for agriculture.
- In contrast, the southern and eastern edges have moderately steep to steep slopes, suitable for plantation agriculture and hydroelectric projects, with very steep zones requiring erosion control.

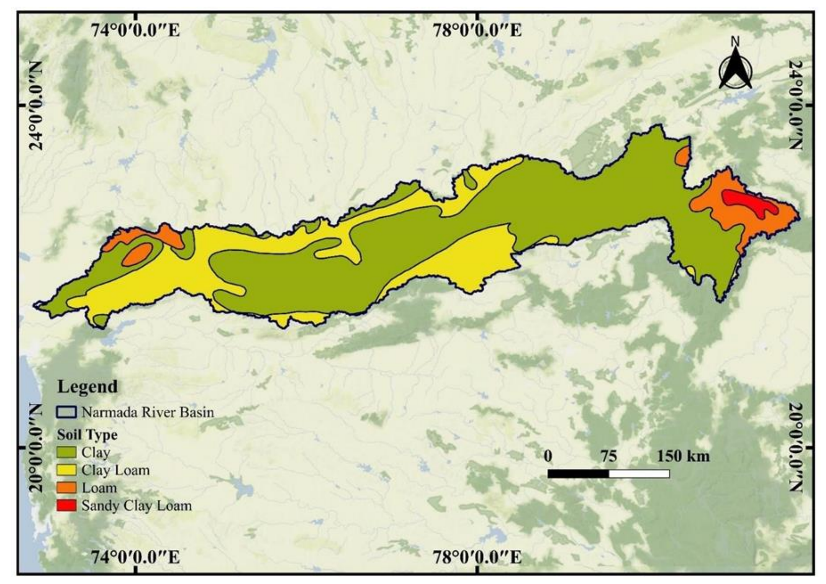

Fig. 7 Spatial distribution of slope

- Negative NDVI Values: Indicate the presence of water bodies, such as reservoirs, and other non-vegetative features.
- Low NDVI Values: Indicate the barren lands with minimal vegetation cover.
- High NDVI Values: Indicate the richer vegetation, including deciduous forests, shrubs, grasslands, or agricultural crops.

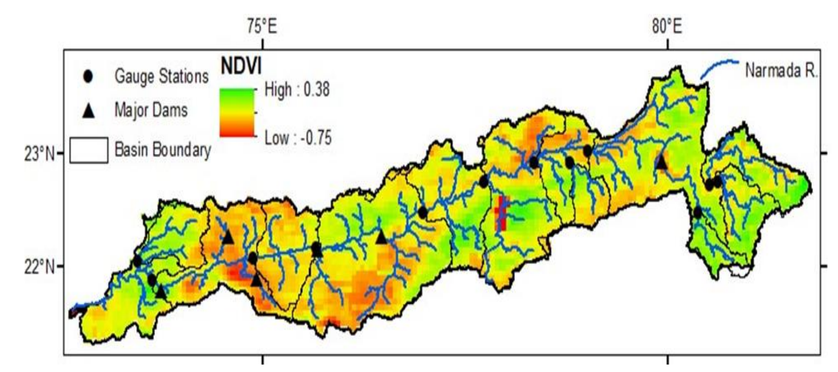

Fig.8 Spatial distribution of slope

Significance Of Narmada River Basin And Tourism

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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.
- 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. 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.
- 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.

Socio-cultural

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.

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 , which draw devotees from across India.

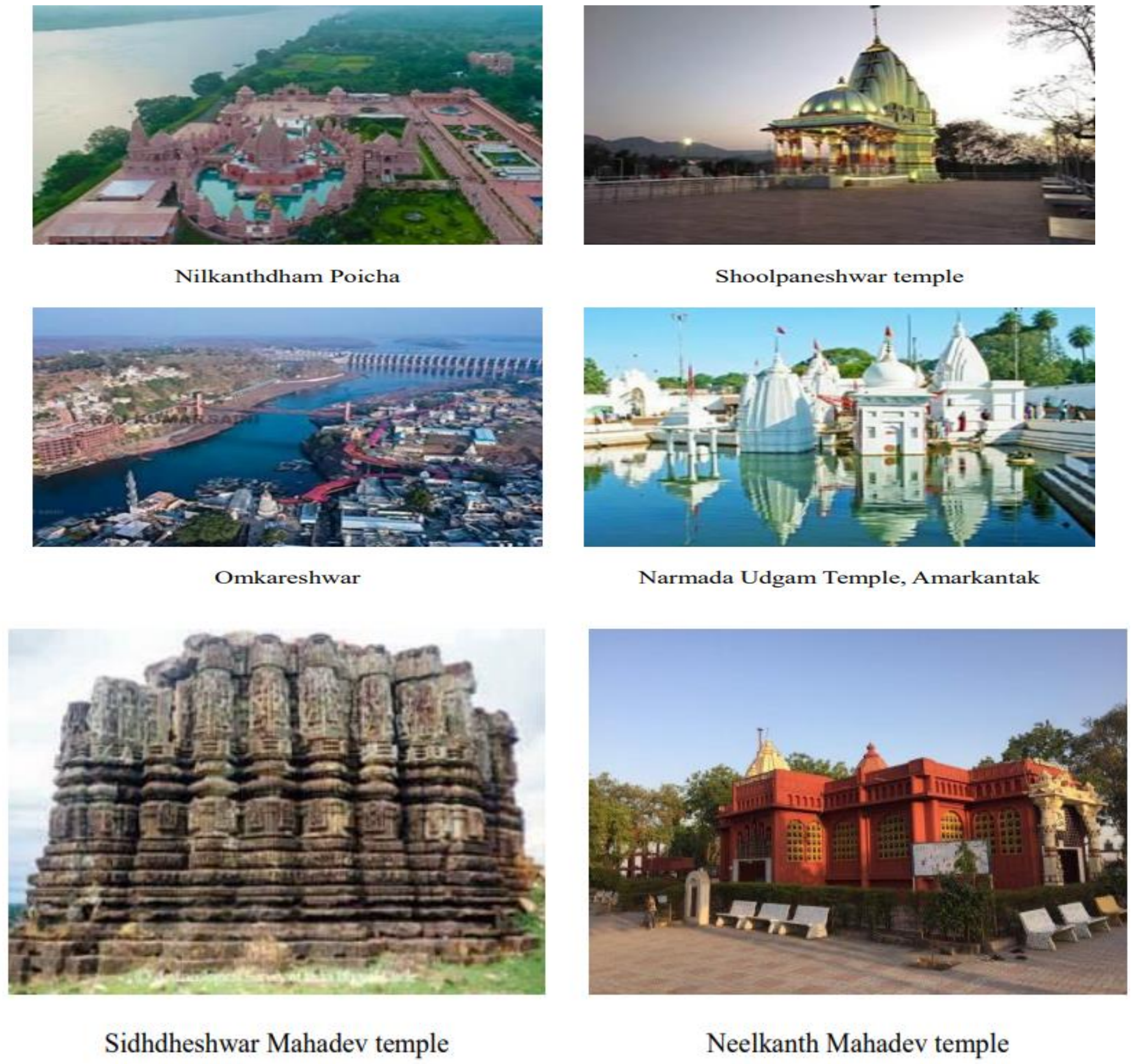

Fig. 1 Religious sites in the Narmada River Basin

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.
- Reserve and Shoolpaneshwar Sanctuary Covers, supporting a wide range of plant, birds and animal species typical of the central highland region

Tourism

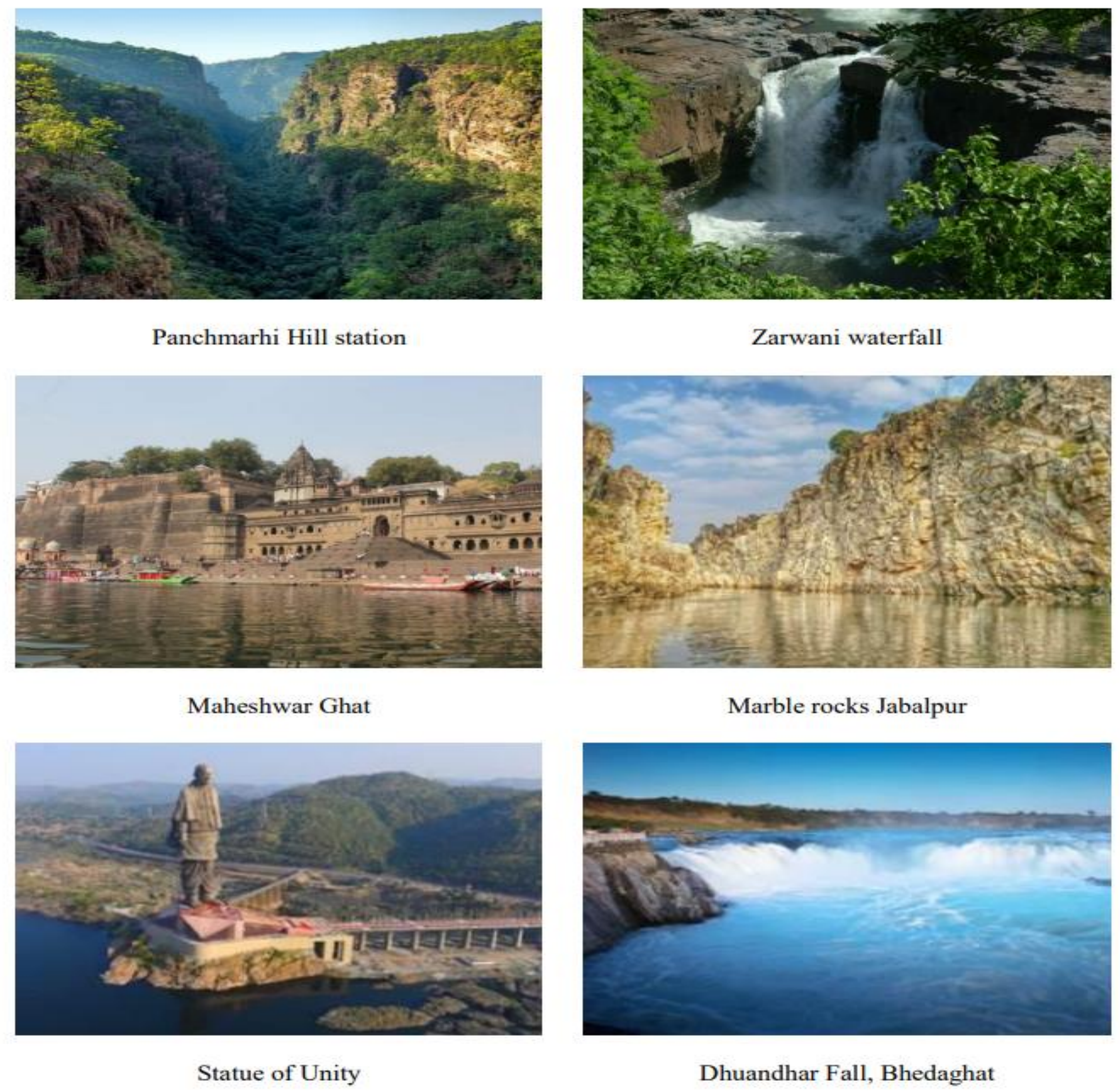

Fig. 2 Numerous Tourism Sites

- **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, Some notable tourism sites are depicted in Figure 2.
- **Ecotourism:** The scenic beauty of the Narmada Valley, with its lush landscapes and diverse wildlife, promotes ecotourism.

Narmada River: Biodiversity

Hydraulics and Water Management Lab
Department of Civil Engineering, Indian Institute of Technology, Gandhinagar, India

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Animals

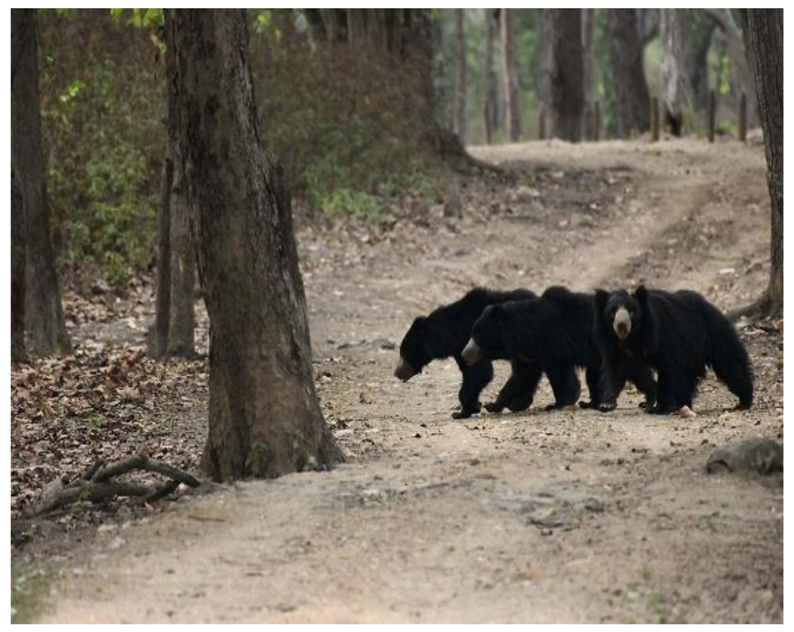

Indian Gaur Bison Bison (Bos gaurus)


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)

Notable animal in the Narmada basin

Birds Species


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)

Birds species in the Narmada basin

Fisheries


Mahseer


Catfish


Hilsa


Labeo fimbriatus


Macrobrachium rosenbergii


Tenualosa ilisha


Tor Tor


L. dyocheilus

Fisheries in Narmada river basin

Designing Resilient Multipurpose Reservoir Operation Policies for Sardar Sarovar Dam in Presence of Internal Climate Variability

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[2]Department of Computer Science and Engineering, Indian Institute of Technology, Gandhinagar, India

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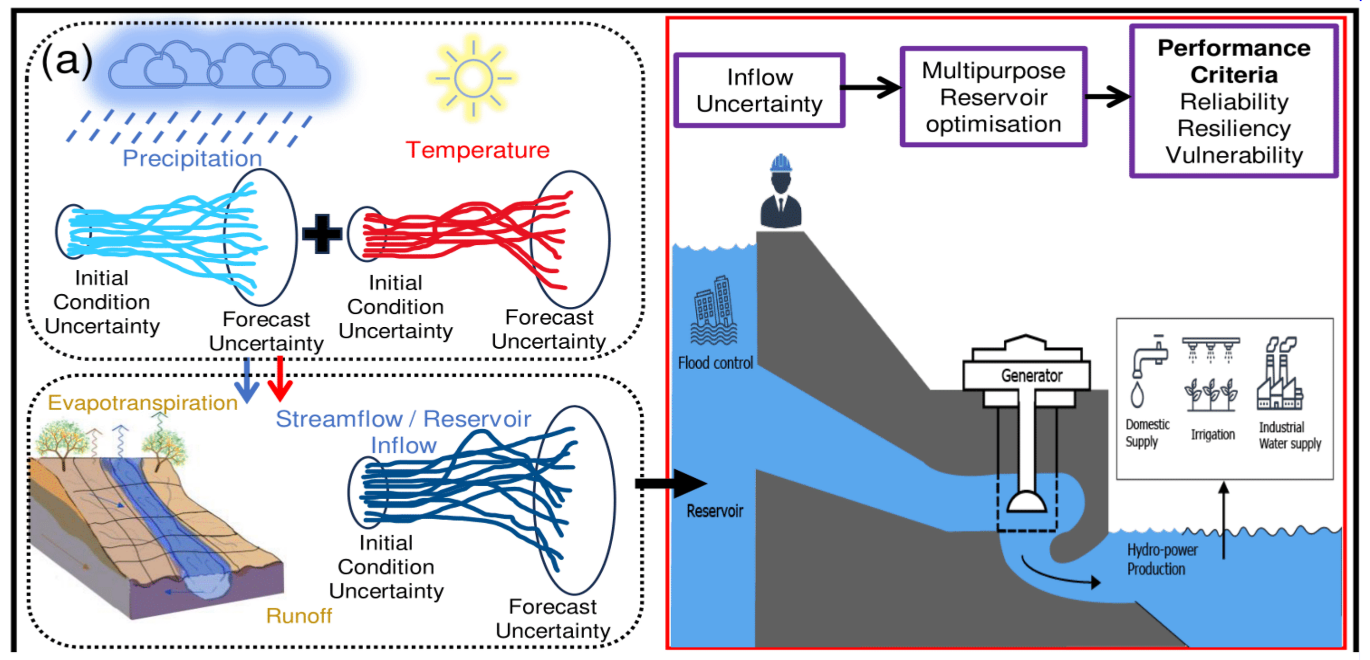
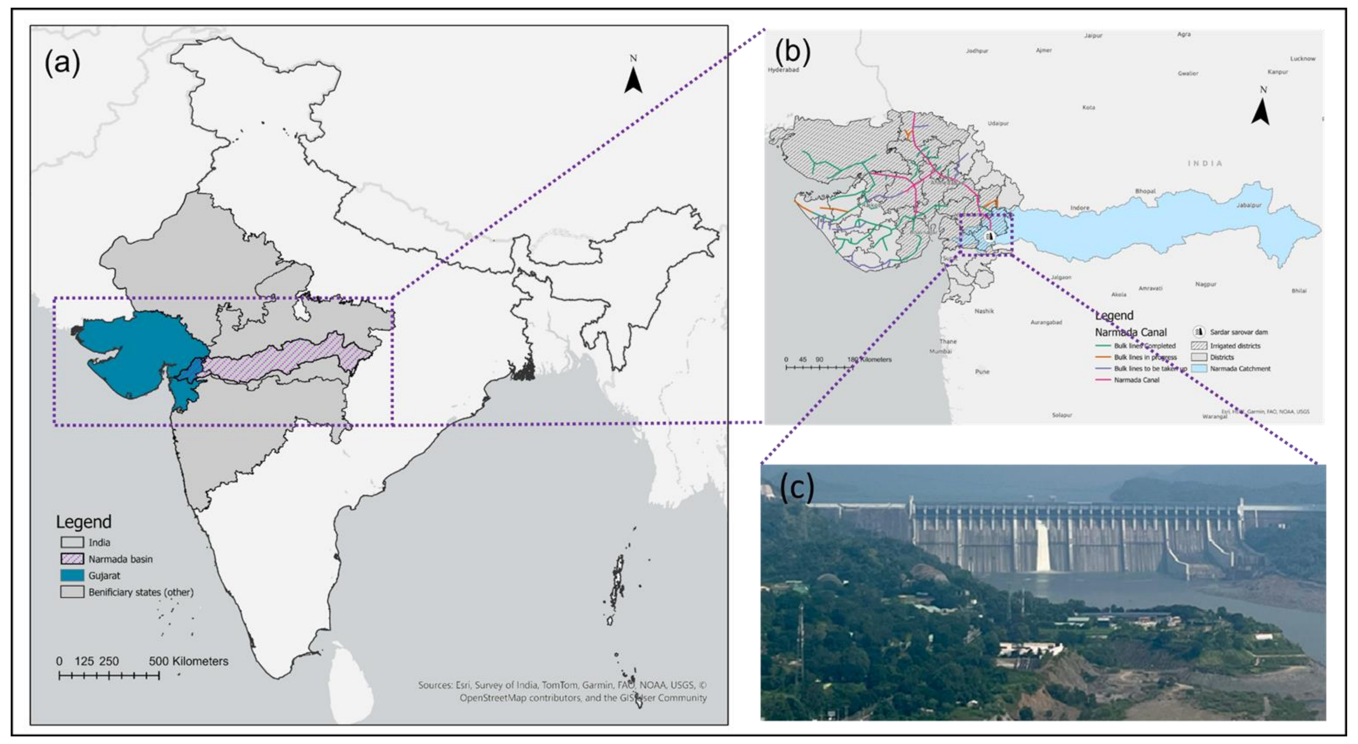
1. Introduction



2. Objectives

- To develop end-to-end framework to understand the implications of ICV on optimal reservoir policies and its impact on the various utilities of a multipurpose reservoir.

3. Study Area

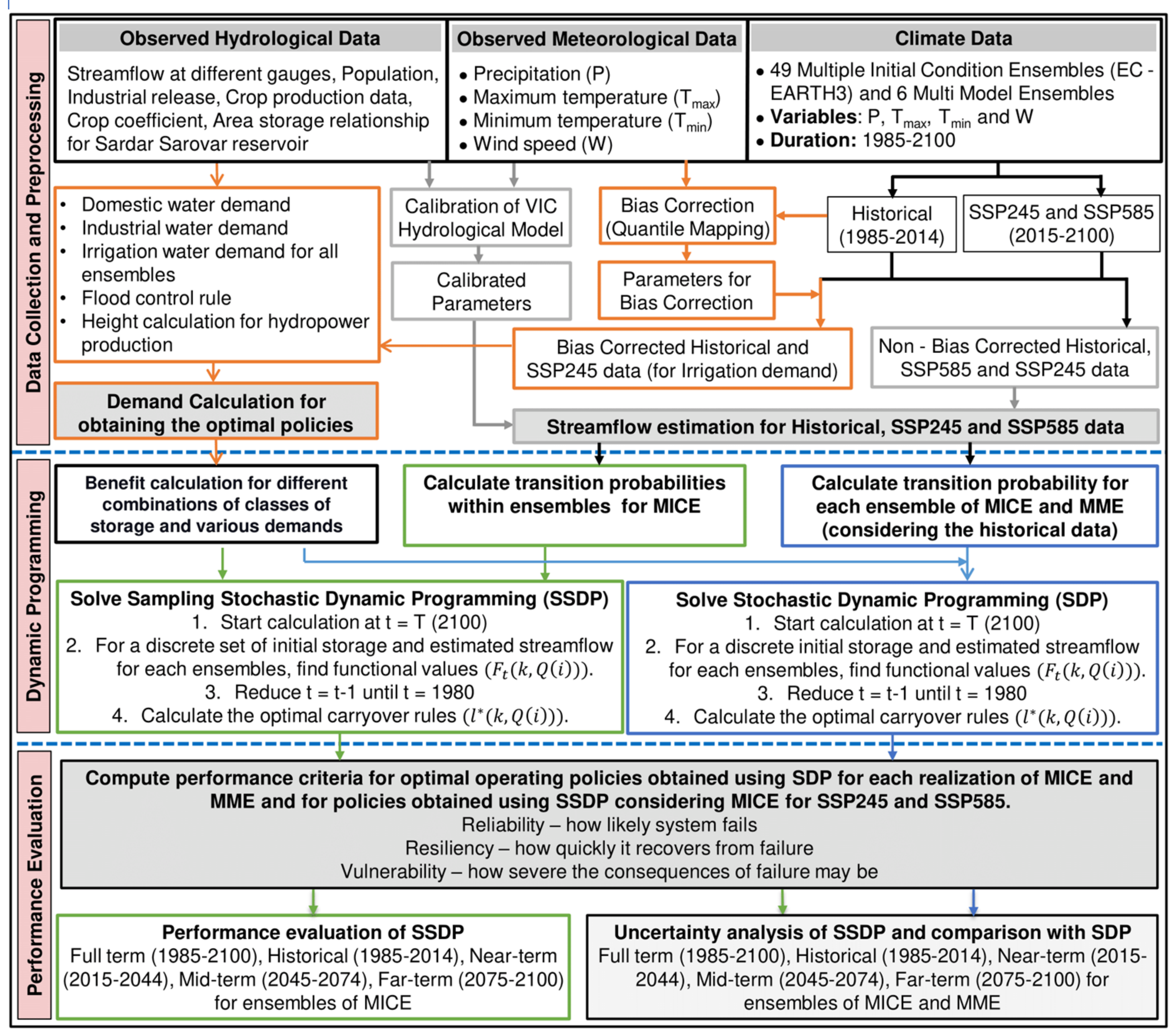


Objective Function

$(S_{t+1} - T_s)^2 + (R_{t1} - T_{r1})^2 + (R_{t2} - T_{r2})^2 + (R_{t3} - T_{r3})^2 + (HP - T_p)^2$

T_s- Target storage (flood control)
R_{t1}- Drinking water release,
T_{r1} Drinking water demand
R_{t2} - Irrigation water release.
T_{r2} - Irrigation water demand
R_{t3} - Industrial water release,
T_{r2} - Industrial water demand
HP - Hydropower production
T_p- Target power (installed capacity is 1450 MW)

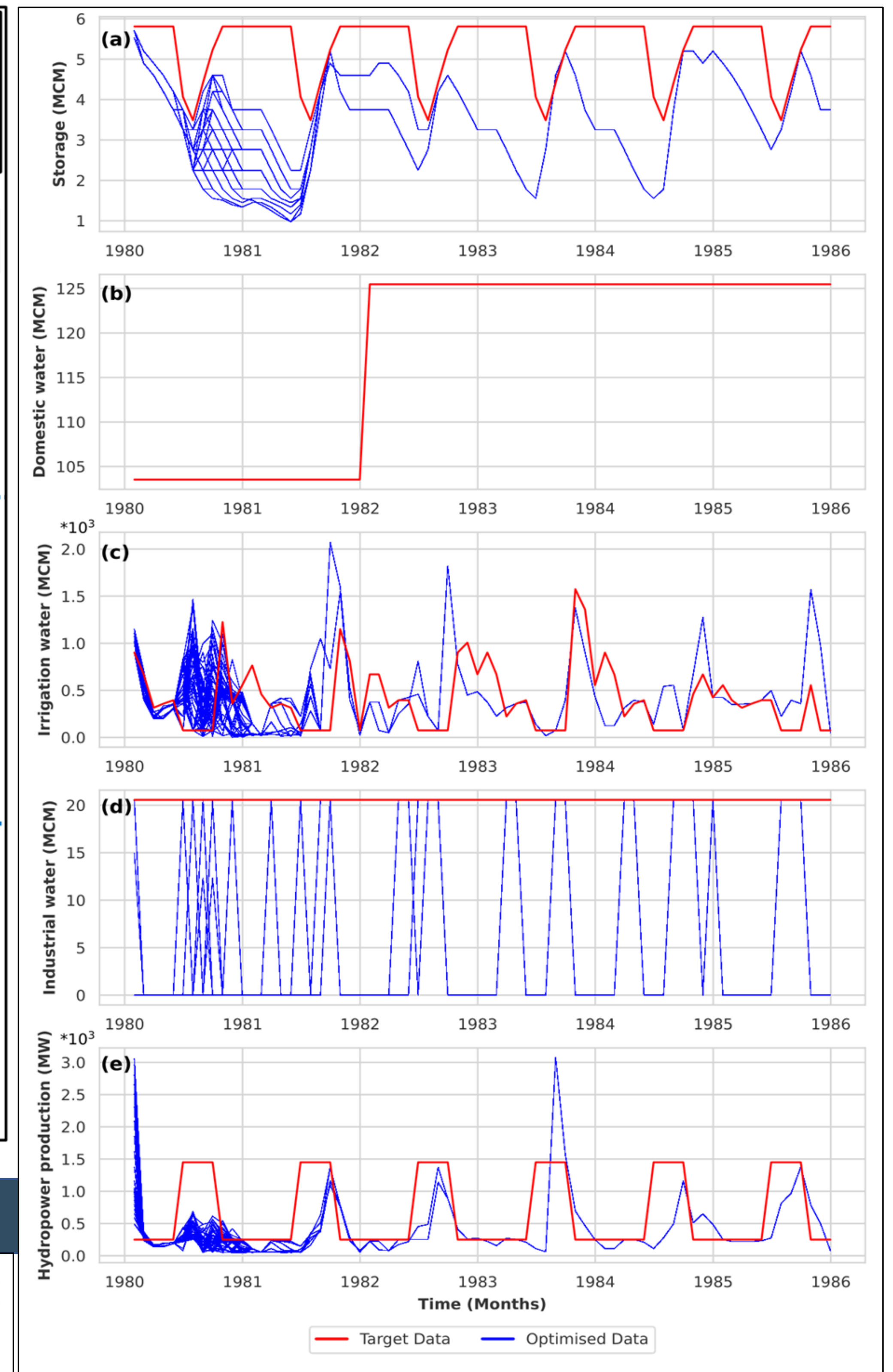
4. Methodology



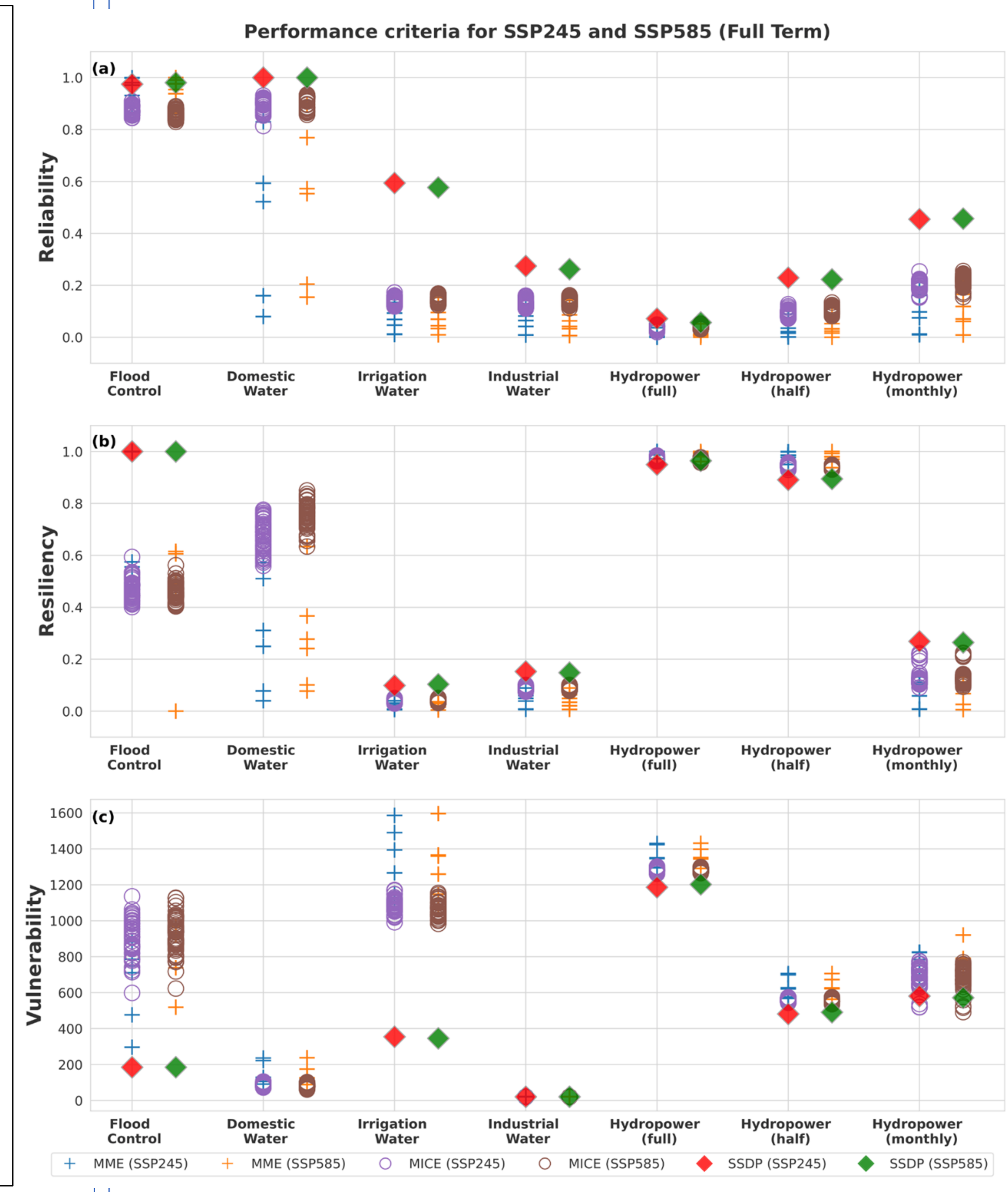
6. Summary

- Adaptation planning for water resource systems is fraught with significant challenges, arising from uncertainties associated with diverse climate change scenarios, varying model structures, and Internal Climate Variability (ICV).
- We develop an end-to-end framework to understand the implications of ICV on optimal reservoir policies of a multipurpose reservoir.
- We implemented for the Sardar Sarovar Dam, the lifeline of the state of Gujarat (also contributing to the other three states of India), which is crucial for flood control, hydroelectric generation and water supply.
- We consider the uncertainty in irrigation water demand to derive optimal reservoir operation policies.
- Assess and improve the dam's reliability, resilience, and vulnerability in managing flood control, hydropower generation, and various water demands under future climate scenarios.
- Our results demonstrate that incorporating a wide range of climate projections can enhance the effectiveness of reservoir policies despite inherent uncertainties.

5. Results



Timeseries: Target and optimized storage levels, releases for domestic, irrigation, and industrial water demands and for hydropower production.



Performance of optimal policies (reliability, (b) resiliency, and (c) vulnerability) for flood control, drinking water, irrigation, industrial water demand, and hydropower production

7. References

- Upadhyay, D., Mohapatra, P., & Bhatia, U. (2021). Depth-duration-frequency of extreme precipitation events under internal climate variability: Indian summer monsoon. Journal of Geophysical Research: Atmospheres, 126 (8), e2020JD034193.
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Acknowledgment

This work is supported by Pandya Shivpuri chair endowment funds and the DST-SCCC-NMSKCC project, work for Establishing/Strengthening the State Climate Change Centre/Cell under NMSKCC (SCCC-NMSKCC) in the State of Gujarat, India. The authors would also like to thank Prof. Pranab Mohapatra, IIT Gandhinagar, India, for refining our objective function for reservoir operating policies and sharing his expert and practical knowledge of reservoir operation.

Translating the Internal Climate Variability from climate variables to Hydropower Production for Sardar Sarovar Dam

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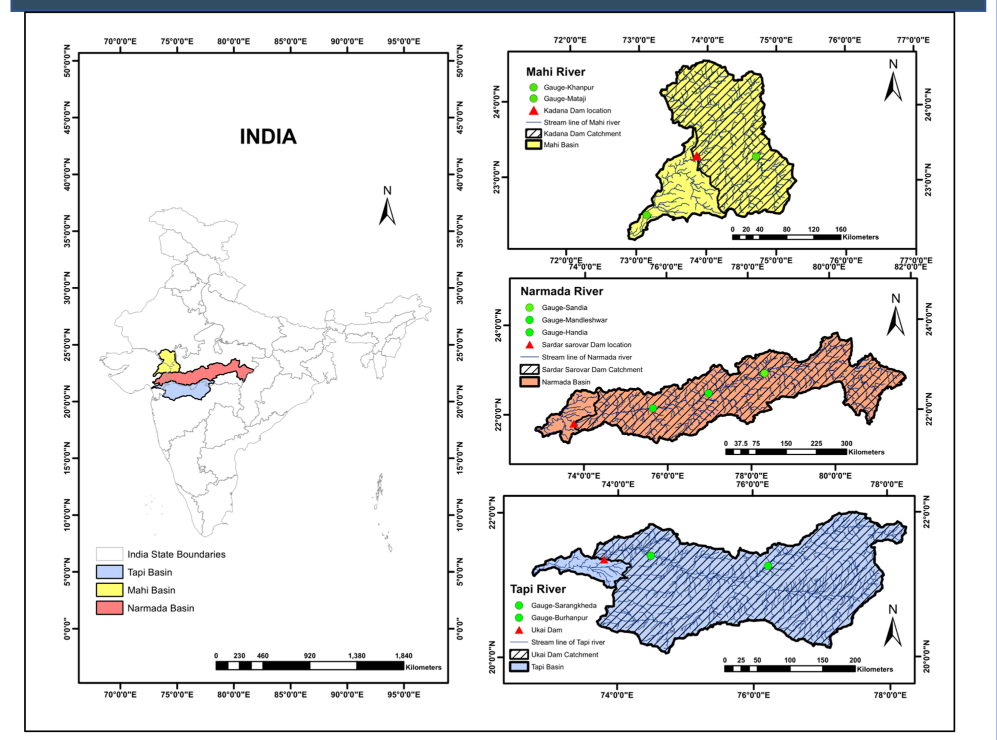
1. Introduction

- Uncertainties and variabilities associated with hydroclimatic variables pose a challenge for the planning, operation and management of water resources.
- **Internal Climate Variability (ICV)** - Natural variability of the climate system - arises from non-linear dynamical processes intrinsic to the atmosphere.
- Variable Infiltration Capacity (VIC) Hydrological model for estimation of streamflow (Liang et.al. 1994) using the meteorological data such as precipitation, minimum and maximum temperature and wind speed.

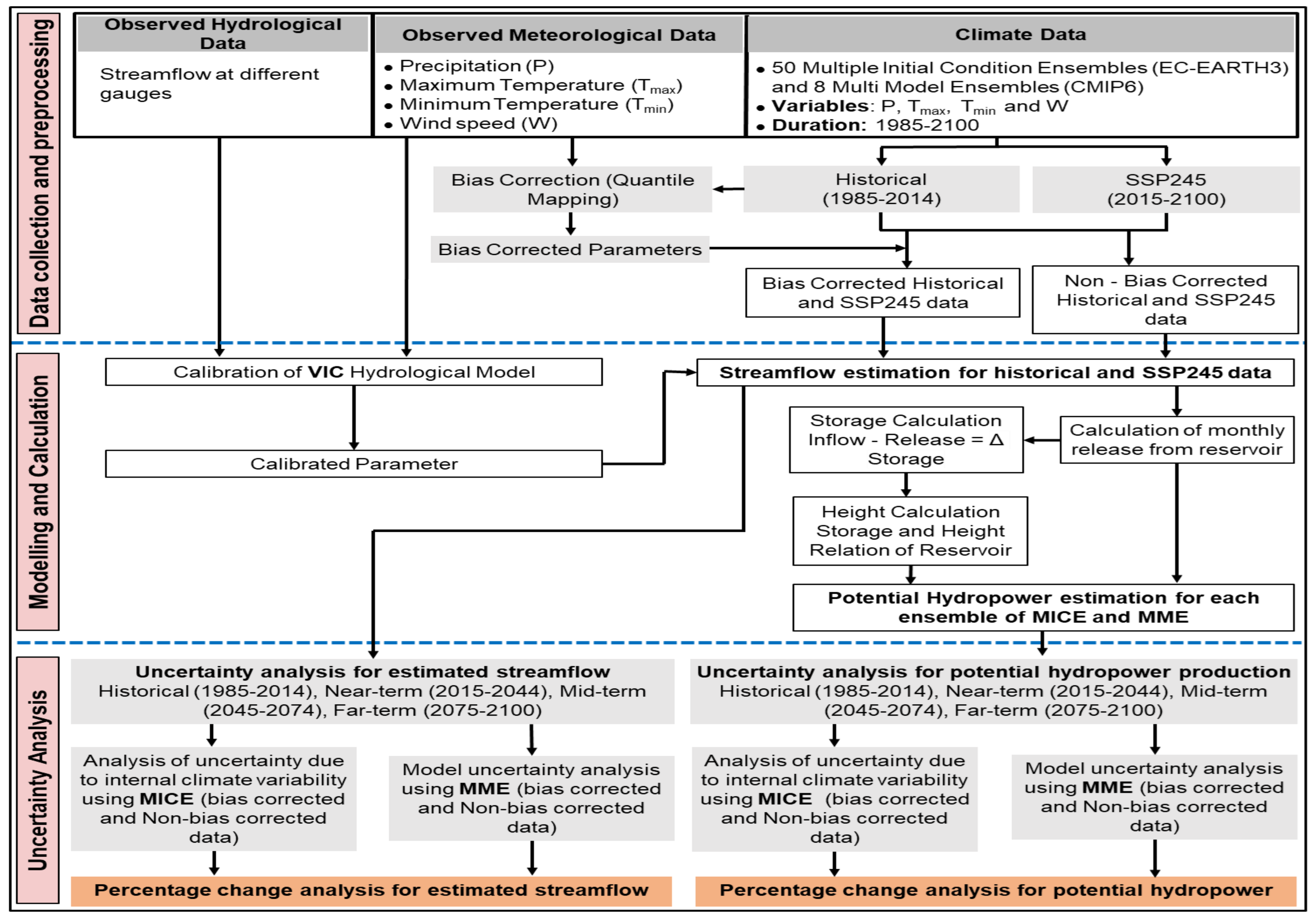
2. Objectives

- To analyze the role of internal variability and model uncertainty in estimating the potential hydropower production.
- To analyze the effect of bias correction on meteorological data and its impact on streamflow estimation.
- To analyze how these uncertainties translate to hydropower estimation.

3. Study Area



4. Methodology



Monthly release (Hanasaki et al.2006, Ali et. al. 2018)

$$R_m = \begin{cases} k_y i_a & c \geq 0.5 \\ i_m \left[1 - \left(\frac{c}{0.5}\right)^2\right] + \left(\frac{c}{0.5}\right)^2 k_y i_a & 0 < c < 0.5 \end{cases}$$

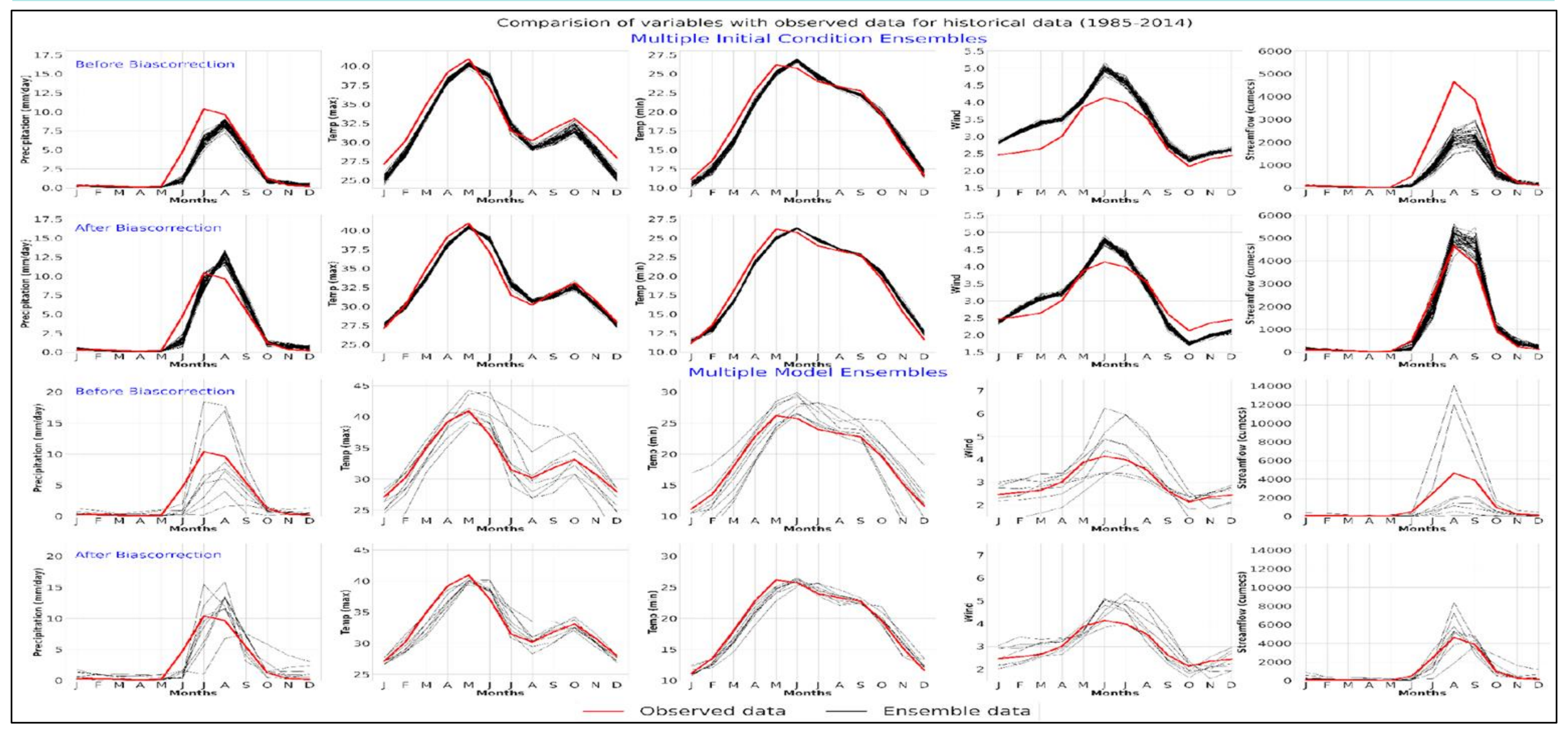
i_m is monthly inflow (m^3 /s), i_a is mean annual inflow (m^3 /s), $k_y = S_{beg}/\alpha C$ and $c = C/I_a$. S_{beg} is the reservoir storage at the beginning of a year (m^3), C is the max storage capacity of the reservoir (m^3), I_a is the mean total annual inflow (m^3 /yr), α is an empirical coefficient.

Hydropower potential (HP)

HP = min(R_m × h × g, Installed Hydropower Capacity)

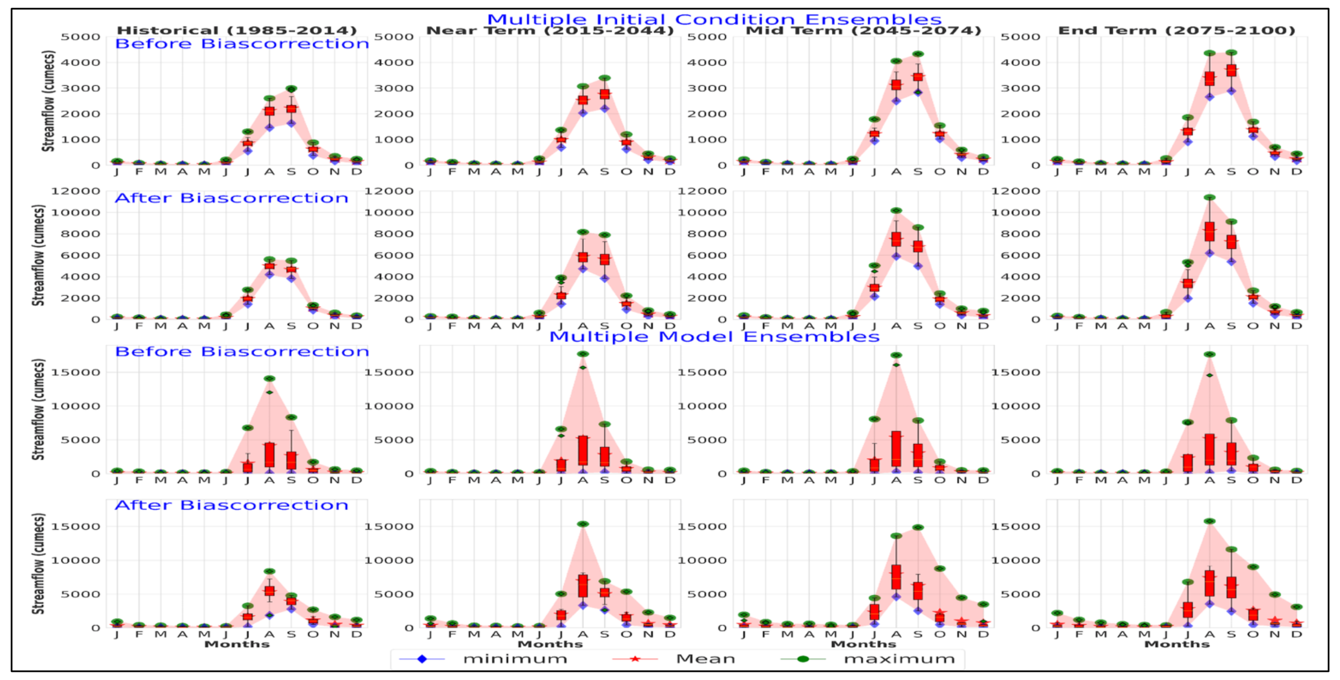
5. Results

Effect of Bias Correction



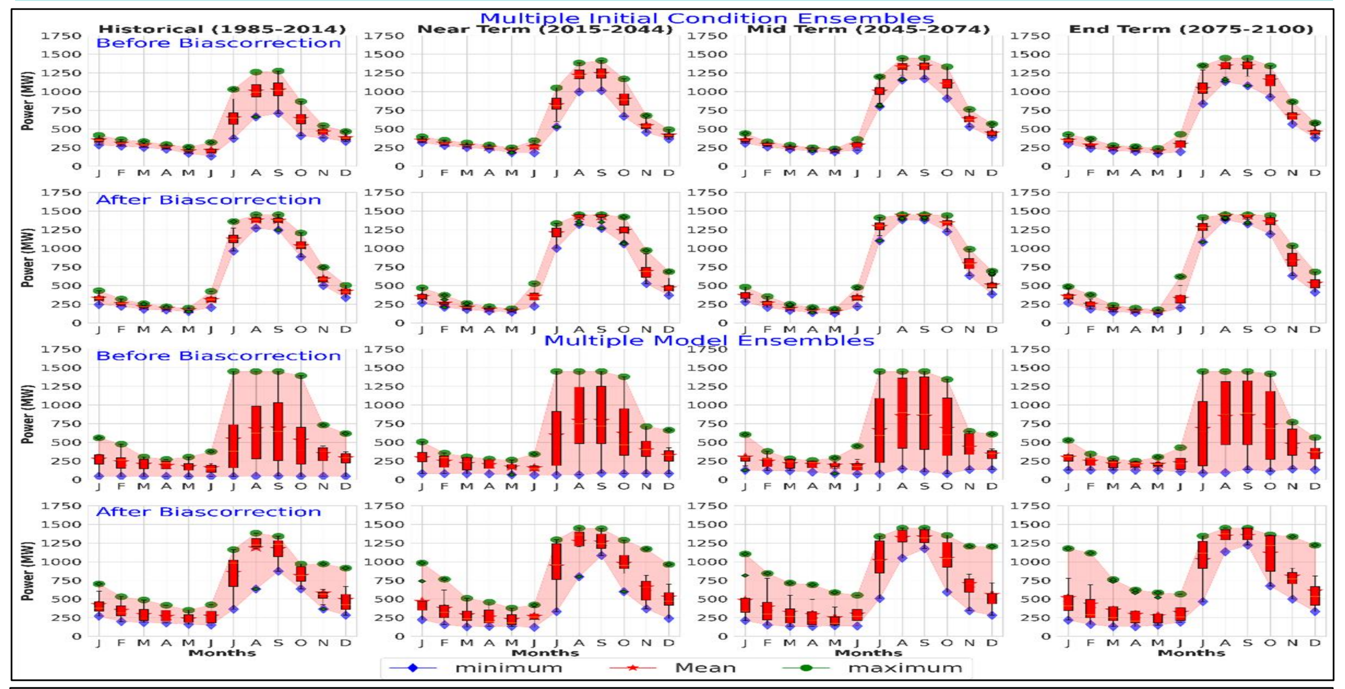
The monthly precipitation, T_{max}, T_{min}, wind, and estimated streamflow using the non-bias corrected and bias corrected data.

Uncertainties in estimating streamflow



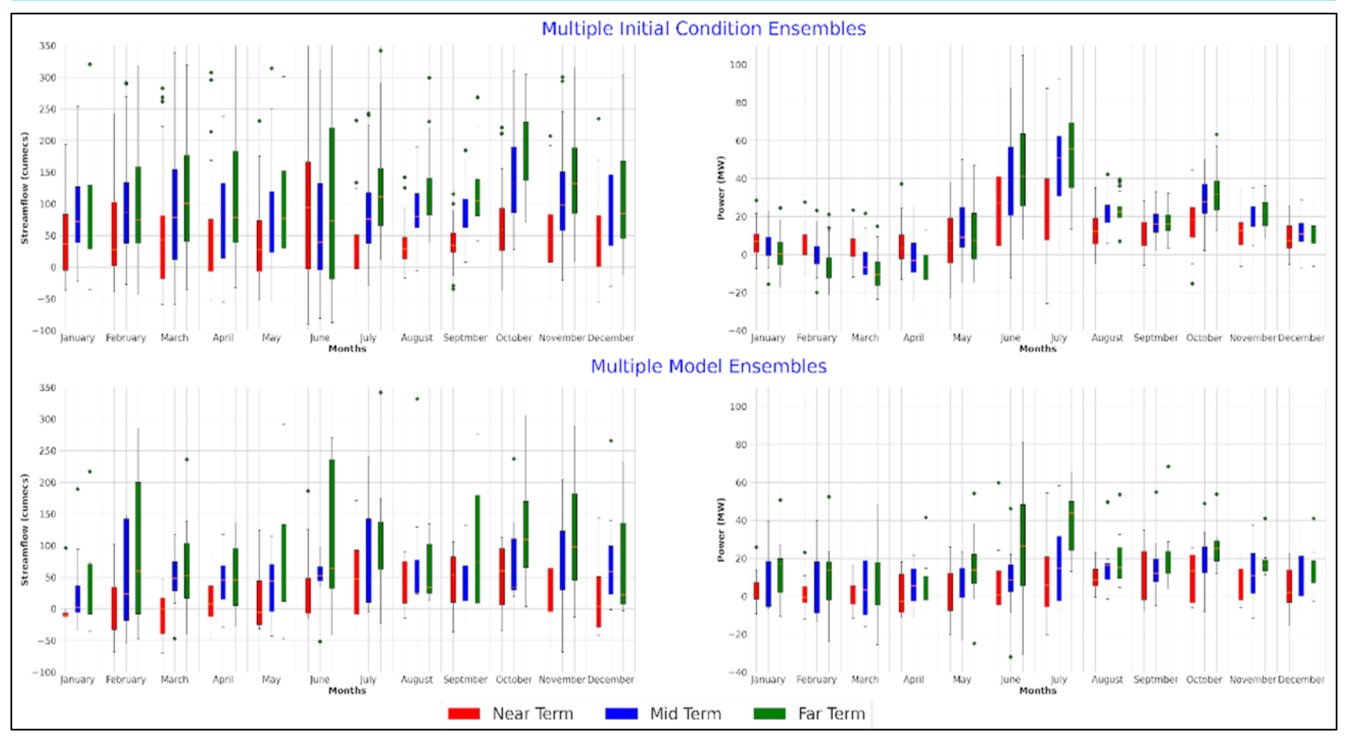
Inter Quartile Range (IQR) for estimated streamflow using bias and non-bias corrected data.

Uncertainties in estimating hydropower



IQR for estimated hydropower using bias and non-bias corrected data for Sardar Sarovar.

Percentage change of streamflow and hydropower



Percentage change in streamflow is not reflected in percentage change in hydropower.

6. Conclusions

1. ICV plays a significant role in estimating streamflow and hydropower estimation for monsoon and throughout the year, respectively.
2. Model uncertainty contributes more to total uncertainty than ICV in estimating the streamflow and potential hydropower. However, ICV is increasing towards the far term.
3. Bias correction does not preserve the internal variability in estimating the streamflow.
4. Although there is an increase in uncertainty for estimated streamflow, mean hydropower shows the decrease towards the far-term for February to May, more prominent for MICE than MME.

7. References

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- Upadhyay, D., Mohapatra, P., & Bhatia, U. (2021), Depth-Duration-Frequency of Extreme Precipitation Events Under Internal Climate Variability: Indian Summer Monsoon. *Journal of Geophysical Research: Atmospheres*, *126*(8), e2020JD034193.
- Upadhyay, D., Dixit, S., & Bhatia, U. (2022). Translating the internal climate variability from climate variables to hydropower production. *arXiv preprint arXiv:2203.01596*.

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Assessing Temporal Dynamics of Nitrogen Surplus in Narmada River Basin

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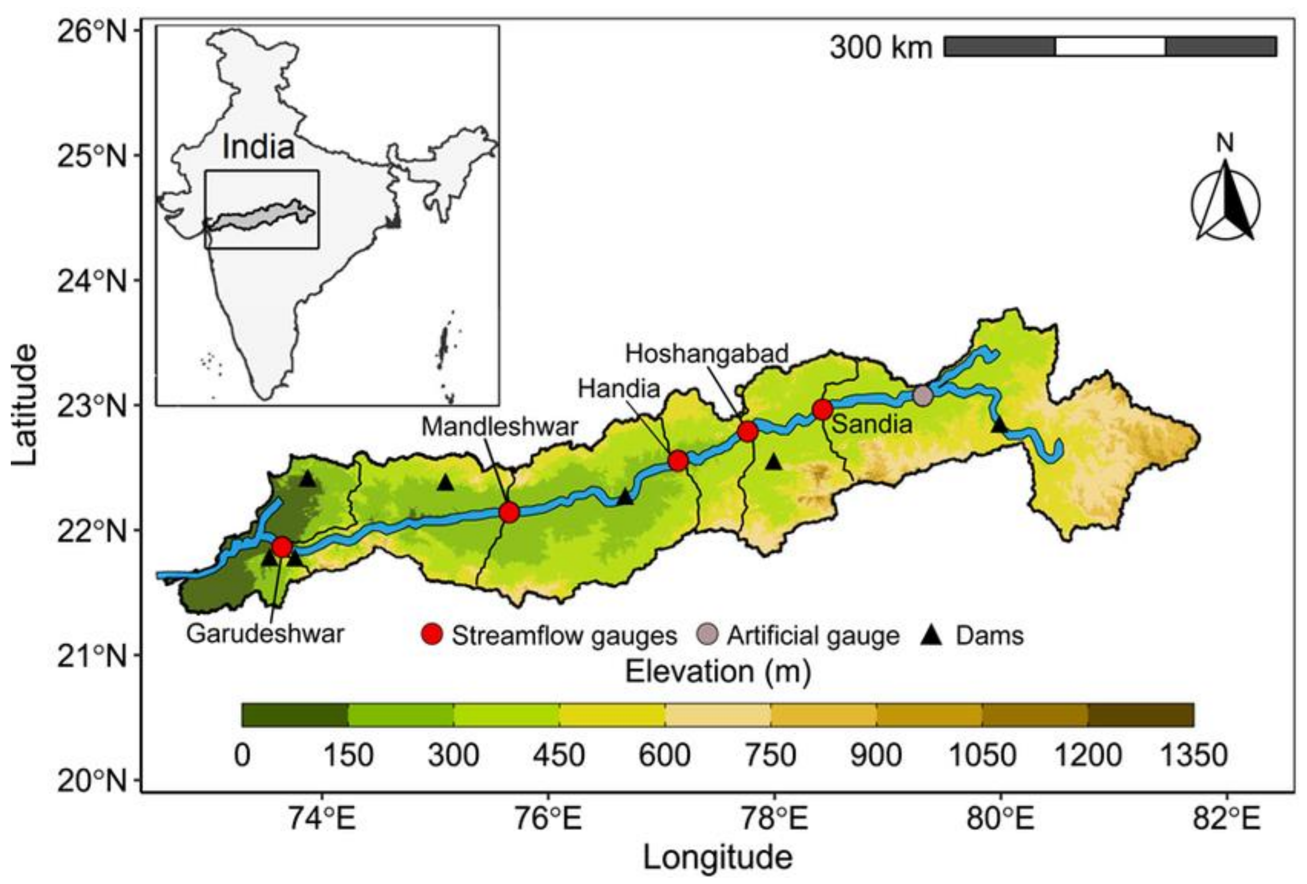
1. Introduction

- Nitrogen (N) is essential for agricultural productivity, yet its surplus poses significant environmental risks.
- Currently, more than half of the nitrogen applied to croplands is lost, resulting in resource wastage, contributing towards increased greenhouse gas emissions and biodiversity loss.
- To properly understand current environmental risks, it is essential to quantify the amount of surplus nitrogen applied in the past, which remains limited in the Indian context.

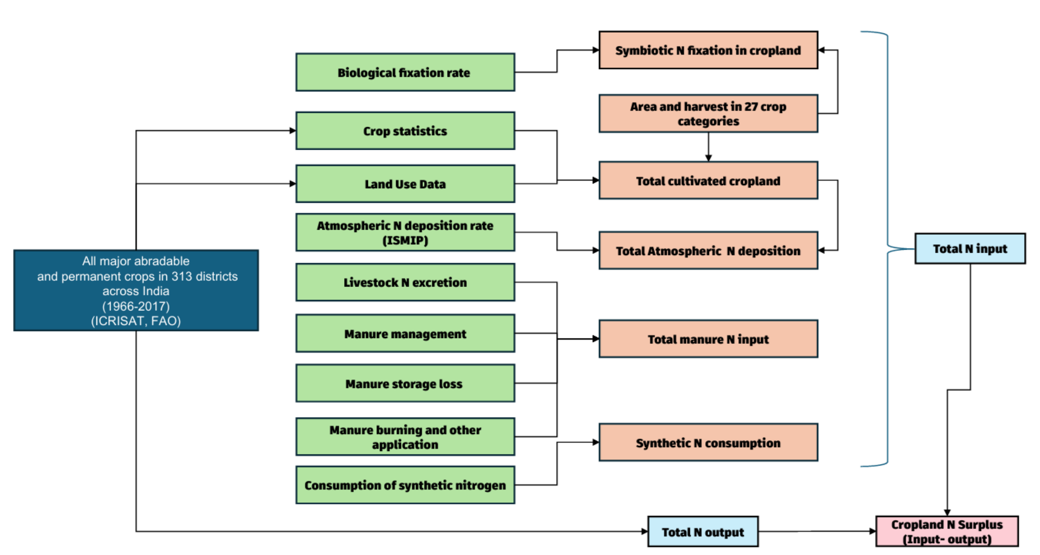
2. Objective

- To Quantify agricultural nitrogen budget in Narmada River basin

3. Study Area

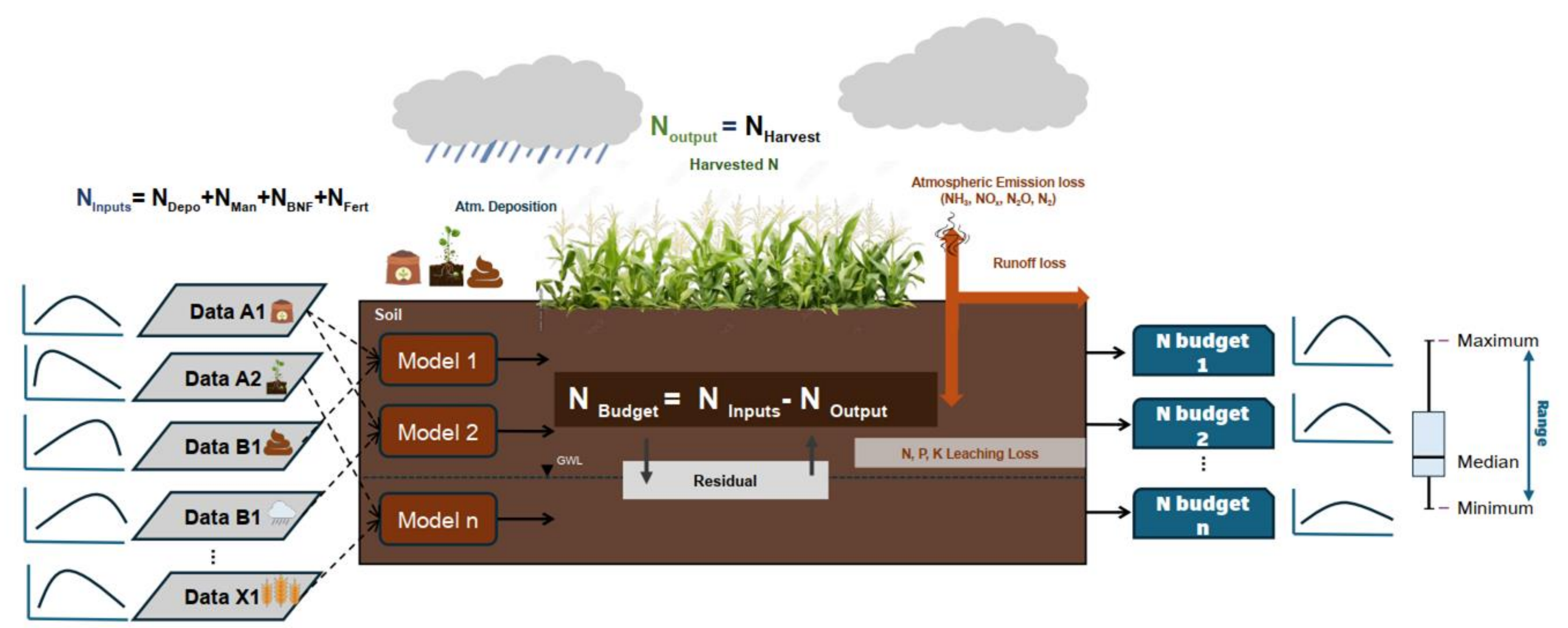


4. Methodology



Framework for Agricultural Nitrogen Surplus calculation

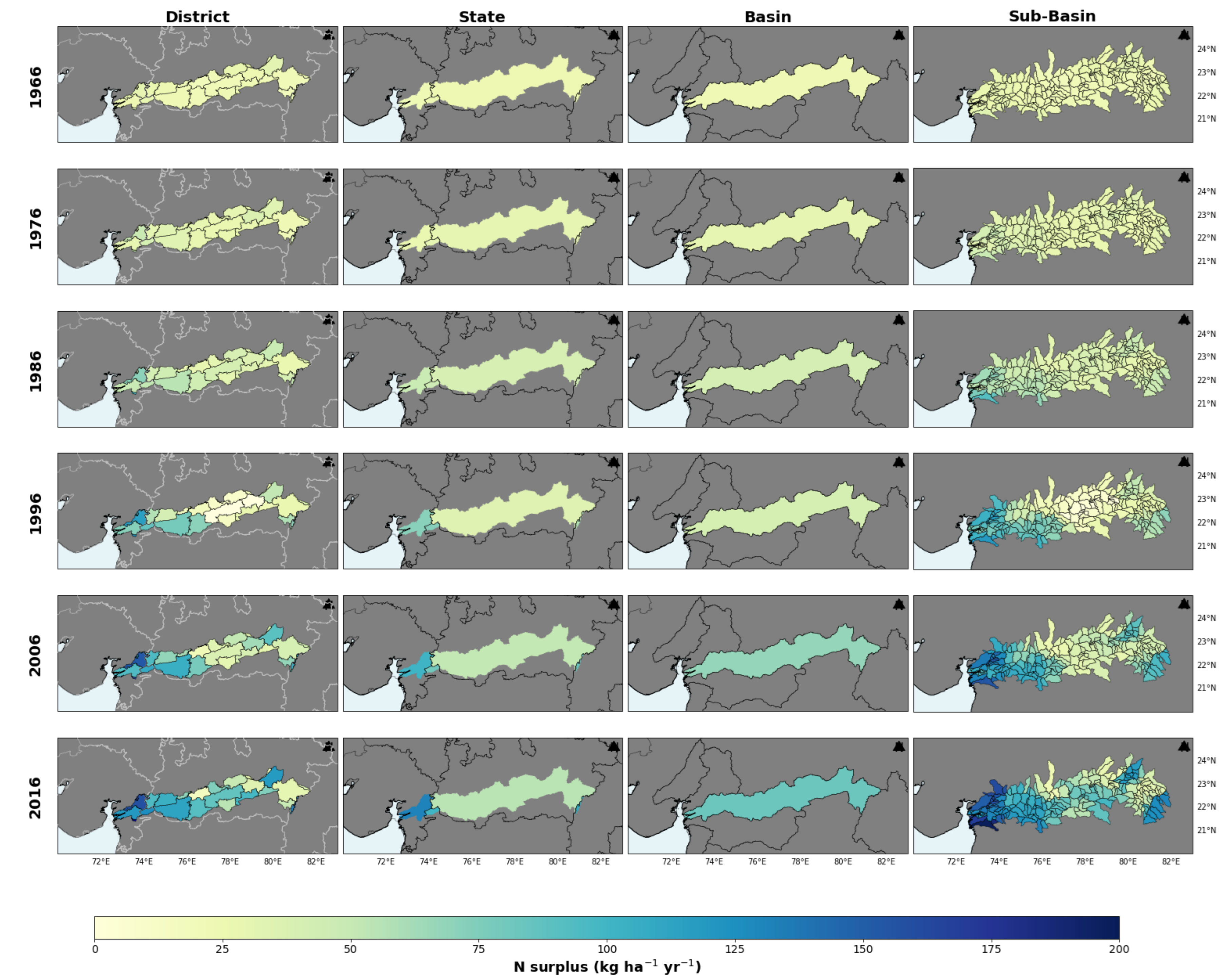
5. Conceptual Understanding



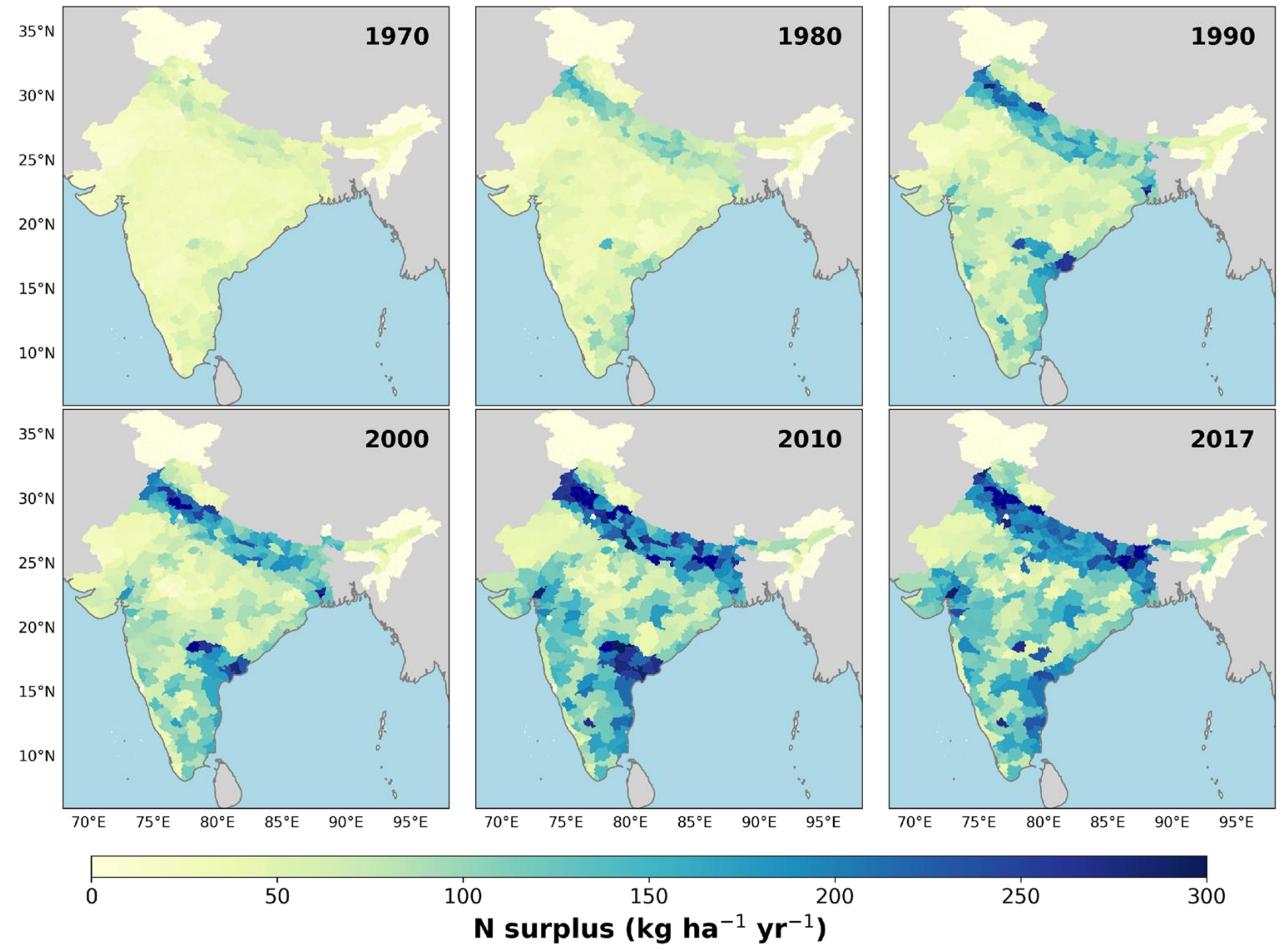
Conceptual figure of Nitrogen Surplus in Crop Production: nitrogen cycle in agricultural systems.

6. Results

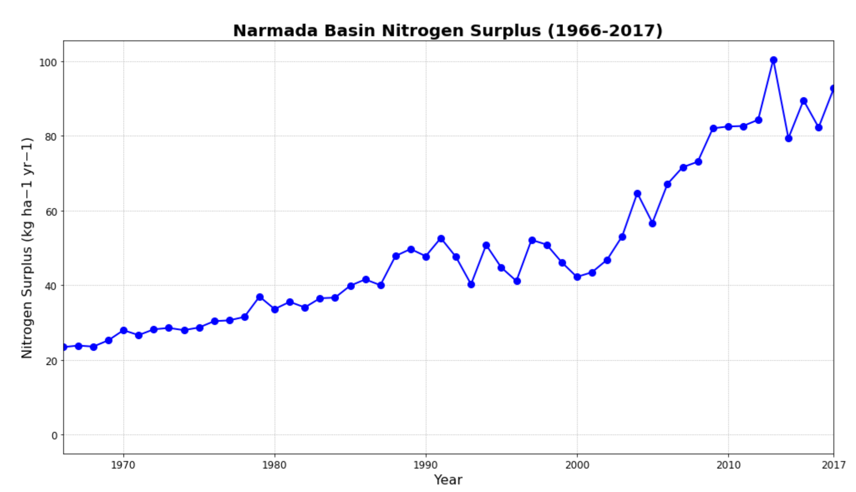
Spatial Distribution of Nitrogen Surplus in Narmada basin at various resolutions : Snapshots of the nitrogen surplus (kg N ha-1 of agricultural cropland area yr-1) across India at different levels

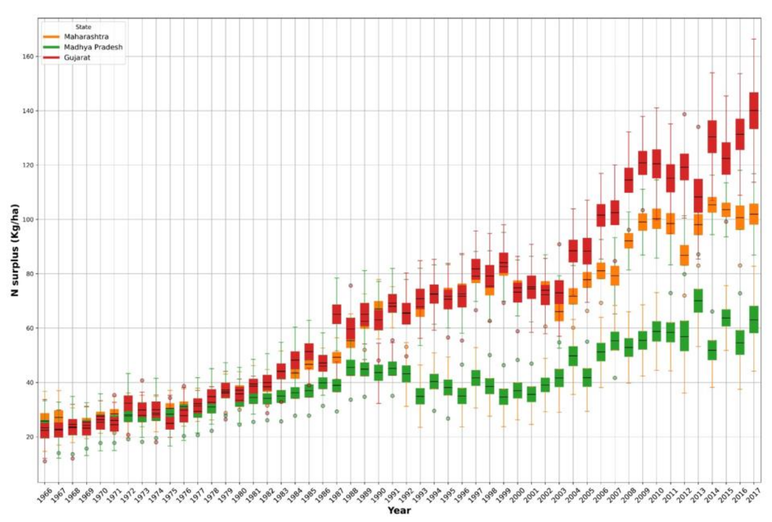


Nitrogen Surplus Across India at Various Spatio-Temporal Scale



Narmada River N Surplus (kg ha-1) temporal evolution





7. Conclusion

- Specifically, our total agricultural N surplus for India from 1966 to 2014 is 512.16 ± 36.78 Tg N
- Overall, the changes from 1966 to 2017 highlight a trend of increasing nutrient surplus over the decades, with peaks shifting to higher values and distributions becoming more spread out.

8. References

- Goyal, S.S., Kumar, R. and Bhatia, U., 2024. Assessing Temporal Dynamics of Nitrogen Surplus in Indian Agriculture: District-Scale Data from 1966 to 2017. (Under review)
- Ossandón, Á., Rajagopalan, B., Tiwari, A.D., Thomas, T. and Mishra, V., 2022. A Bayesian Hierarchical Model Combination Framework for Real-Time Daily Ensemble Streamflow Forecasting Across a Rainfed River Basin. Earth's Future, 10(12)

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- Travel support provided by Overseas research fund at IITGN, which enabled travel to UFZ where this work was conceived.