**BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL,
PRINCIPAL BENCH, DELHI**

ORIGINAL APPLICATION NO. 361 OF 2018

IN THE MATTER OF

Narmada Pradushan Nivaran Samiti ...APPLICANT

VERSUS

MoEF&CC & ORS. ...RESPONDENTS

INDEX FOR ADDITIONAL AFFIDAVIT IN COMPLIANCE WITH 21.01.2026 ON BEHALF OF RESPONDENT NO. 4 - NARMADA WATER RESOURCES, WATER SUPPLY AND KALPSAR DEPARTMENT

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Filed Through,

_____

Parth H. Bhatt,
Advocate
For Respondent No. 4

NOTARY
KISHORKUMAR J PANCHAL
RAJPIPLA
DIST. NARMADA
REG.NO. 8956/2019
EXPIRY DT. 22/06/2039
GOVT. OF INDIA

Superintending Engineer
Narmada Project Head Works Circle
S.S.N.N.L., Ekta Nagar

BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL, PRINCIPAL BENCH, DELHI

ORIGINAL APPLICATION NO. 361 OF 2018

IN THE MATTER OF

Narmada Pradushan Nivaran Samiti ...APPLICANT

VERSUS

MoEF&CC & ORS. ...RESPONDENTS

ADDITIONAL AFFIDAVIT IN COMPLIANCE WITH 21.01.2026 ON BEHALF OF RESPONDENT NO. 4 - NARMADA WATER RESOURCES, WATER SUPPLY AND KALPSAR DEPARTMENT

I, Shubham S Goyal, age - 31 years, serving as Superintending Engineer being authorized signatory and representative of Narmada Project Head Work Circle, Sardar Sarovar Narmada Nigam Ltd., having communication address at 406, 4th floor, New Administrative Building, Ektanagar, District Narmada, Gujarat – 393151 do hereby solemnly state on oath and submit that: -

1. The Hon'ble Tribunal has passed an Order dated 21.01.2026, wherein it was directed to file an affidavit disclosing communication received from CIFRI and other material indicating the prayer for extension of time and status of the report of Central Inland Fisheries Research Institute Barrackpore, Kolkata (Hereinafter referred as "CIFRI").

NOTARY RISHIKUMAR J. PANCHAL RAJPIPLA DIST. NARMADA REG.NO. 3056/2010 EXPIRY D: 22/06/2030 GOVT. OF INDIA

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2. It is humbly submitted that the CIFRI, Kolkata was awarded with the work of "*The assessment of Environmental Flow Towards River Habitat and Ecological Requirements with a focus on downstream Fish Species of Sardar Sarovar Dam (SSD) in Narmada River*" covering pre monsoon and post monsoon period on 27.03.2025 and it was estimated to be completed within nine months by December 2025. The study outlines hydrological discharge particularly representing pre-monsoon and post-monsoon at the selected sampling sites and estimating marine ecology based on environmental flows between the SSD to Bhadbhut.

3. The Answering Respondent admits to regularly following up with CIFRI regarding the status of the report. It was informed by CIFRI to Answering Respondent that the study is still ongoing and they are expecting to complete the study by April 2026. In response to follow ups by Answering Respondent, the CIFRI issued letter dated 04.02.2026 confirming the fact that they would endeavor to complete the study by April 2026. Copy of such letter dated 04.02.2026 of CIFRI addressing Chief Engineer of the answering respondent is annexed and marked as **ANNEXURE – A.**

4. Upon request of Answering Respondent, the CIFRI has prepared and furnished an Interim Progress Report

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indicating the present status of the study. The answering Respondent humbly submits the interim report dated 12.02.2026 submitted by ICAR-CIFRI is attached herewith as **ANNEXURE – B.**

5. The answering respondent has extracted and reproduced certain relevant portions of the said report for ready reference of this Hon'ble Tribunal. It is humbly submitted that the said observations /findings are preliminary and are therefore subject to the findings of the final report, which is under preparation.

THE STUDY / ASSESSMENTS CONDUCTED BY CIFRI. -

5.1. **Habitat profile of the river Narmada**

A. The habitat profile of the river Narmada was assessed during the study period. The *habitat profile* explains the condition of the river environment and suitability for fish and other aquatic organisms. The physical condition of river habitat such substrate type, deep pools, scar pools, riparian vegetation, water depth, water flow, river gradient, width of the wetted channel, flood plains, etc influences habitat of aquatic creatures.

B. The values of the habitat profile obtained during the study period showed no significant variations in habitat profile in both seasons, except for depth

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and water velocity and the remaining parameters were almost the same, which is acceptable for aquatic life.

5.2. **Acoustic Doppler Current Profiler (ADCP) survey**

A. An Acoustic Doppler Current Profiler (Hereinafter referred as "ADCP") survey is a method used to measure the flow characteristics of a river, lake, or sea using sound waves. ADCP calculates Water velocity (speed of flow), Direction of flow, Water discharge (total volume of water flowing) and Flow profile at different depths. In the study conducted by CIFRI width of the channel, water discharge, depth, mean depth, and water velocity were the key parameters recorded by the ADCP survey.

B. Downstream variations of river width towards the estuarine zone were recorded, which gradually increased. Width ranged from Garudeshwar to Bhadbhut, with notable widening at Bharuch and Sakkarpura. Maximum water velocity was recorded from Bhadbhut, and the minimum water velocity was recorded from Jhanor.

5.3. **Fish Diversity and Species Richness in Narmada River -** A total of 3352 fish belonging to 12 orders, 20 families, 36 genera, and 47 fish species have been

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documented from the sampling sites of the river Narmada during pre-monsoon and post-monsoon sampling. A total of 36 fish species were recorded pre-monsoon and 42 species post-monsoon. Maximum species richness in both seasons was recorded at Garudeshwar, Sisodra, Poicha, and Jhanor. Significantly, it has been found that species richness gradually decreased with the decrease in river elevation.

5.4. **Index of Biotic Integrity (IBI)** - Index of Biotic Integrity (hereinafter referred as "IBI") is a scientific tool used to evaluate the ecological health of a river based on the condition of its biological community, especially aquatic creatures. The IBI was calculated in all 9 sampling stations, and the calculated score showed acceptable and moderately acceptable, which are favourable for freshwater habitats.

5.5. **Water Quality Assessment** - As far as water quality is concerned, no significant differences were found in pH, Hardness, Total Alkalinity, Conductivity, Salinity, TDS, Free CO2, D.O., Total Hardness, Nitrate, Silicate, Chlorinity, BOD, Chlorophyll, Available and Phosphate, Total Nitrogen, and nutrient parameters except water temperature and dissolved oxygen. During the pre-monsoon period, water temperature across the

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sampling stations remained relatively high compared to post-monsoon period.

5.6. **Phytoplankton Diversity in downstream of Sardar Sarovar Dam** – Phytoplanktons are microscopic plant like organisms which require light for photosynthesis. It plays crucial role in maintaining oxygen balance in water bodies and carbon cycling. A total of six phytoplankton taxa was observed from the downstream during the pre-monsoon study from 9 different sampling stations.

5.7. **Zooplankton Community Structure** –

A. Zooplanktons are small, microscopic or tiny floating animals that drift in water, it feed on phytoplankton. During the pre-monsoon season, the zooplankton community was dominated by species in abundant. In contrast, the post-monsoon season showed a slight variation in species composition. The less abundance and limited diversity of zooplankton during both the seasons indicates a sparse zooplankton community structure in Zooplankton the study area.

5.8. **Macro and Meiobenthic Fauna Downstream of Sardar Sarovar Dam** –

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A. Macro and meiobenthic fauna are animals living on or near the riverbed(benthos). Macrobenthos are aquatic animals having larger organism dwelling near riverbed, while Meiobenthos are smaller organism dwelling near riverbed usually microscopic.

B. A total of thirteen macro and meiobenthic taxa were recorded from the downstream stretch of the Sardar Sarovar Dam (SSD) on the Narmada River during the pre-monsoon season and six benthic macroinvertebrate species were recorded during the post-monsoon season.

6. **MAJOR CONCLUSION DRAWN IN THE PROGRESS REPORT**

6.1. **Optimal Water and Habitat Quality in the Narmada River** - The water and sediment quality (D.O, pH, Electrical conductivity, TDS, Salinity, Free CO2, Total alkalinity, etc.) of the river Narmada, at the majority of the sites, had optimal water quality for fish and aquatic organisms. Physical parameters like water velocity and depth were found ideal and favourable for aquatic habitats.

6.2. **Fish Diversity with Decline in Indigenous Carps and Presence of Exotic Species** - In the present study, a total of 47 species of fish belonging to 20 families were recorded from the main channel of the river Narmada.

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6.3. **Updated and Illustrated Checklist of Fish Species** - A latest updated list of fish available in the main channel of the river Narmada is presented with clear, lively photographs and salient diagnostic characters for reference by workers interested in identifying available species.

6.4. **Seasonal and Spatial Hydrological Variations Impacting River Health** - ADCP reading indicates that distinct spatial variations in hydrological conditions across the lower Narmada River persist. Comparison with pre-monsoon data indicates significant seasonal modulation of depth and flow, with clear implications for river health and fisheries sustainability. Maintaining ecological flow, especially in upstream sites like Garudeshwar, is essential to preserve habitat continuity, sediment balance, and fish migration pathways in the lower Narmada River system.

6.5. **Acceptable habitat profile across the sampling sites** - Habitat profile of the selected sites has been portrayed during both seasons, and data indicate that overall acceptable conditions prevailed in each of the sampling sites.

6.6. **Fish Biotic Integrity status (IBI)** - In the river Narmada from Garudeshwar to Bhadbhut, 9 sites were

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assessed in relation to their fish biotic integrity. Sisodra represented the reference site for IBI studies. It indicated that the stretches of Garudeshwar and Sisodra were in acceptable condition in terms of fish assemblages; the remaining seven sites were moderately impaired but close to acceptable condition.

6.7. **Impact of Anthropogenic activities on flow and Carp Recruitment** - In general, it is assumed that the water velocity in the river was moderate and has diminished at two sites due to various anthropogenic activities in the form of hydraulic structures, water extraction, river channelling, sedimentation, and sand gravelling. This is also reflected in the diminished water velocity at Jhanor and Shuklatirth, altering the aquatic environment. This has hampered the recruitment process of the carps, which require inundation of the floodplains for spawning. The decrease in major carp abundance in the river is evident, along with a significant rise in the exotic carp because of favourable habitat for the latter. During the present investigation, there are no such conditions prevailing in the highest degree except water lifting from the river in one site, and it has reflected in fish diversity and ecological integrity of the study area.

6.8. **Linking Environmental Flow with Fisheries and Livelihood** - The riverine fisheries offer the main

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economic activity to our fishermen, and it would be necessary to link the improvement of environmental flow with the biotic community, particularly fish diversity. It has been considered that fish and their presence with rich diversity in the river will ultimately indicate the level of ecological integrity.

6.9. **Final estimation of Fish Based Environmental Flow – Data Awaited -** SSNL is committed to provide the time series hydrological discharge data with the river cross sections at all 9 sampling sites for estimation of fish based environmental flow. Final estimation will be made once these data are available to ICAR-CIFRI. This will support towards aquatic species restoration, livelihood improvement and nutritional security of those people associated with the river Narmada.

7. The interim E-flow assessment for the downstream stretch from the Sardar Sarovar Dam to Bhadbhut, covering hydrology & habitat, water and sediment quality, fish diversity & ecological integrity, plankton & benthos and environmental flow implications, indicates that the present flow regime is broadly supportive of the riverine ecology of the Narmada River. The final fish habitat-based environmental flow will be determined after receipt of the required discharge time-series data and river cross-sections from SSNNL.

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8. It is humbly submitted that after submission of the first interim report, site-specific discharge data for Garudeshwar and the main tributaries, Karjan and Orsang, has been compiled and furnished, marking the principal recent developments in the study. The interim report presents the initial findings from the pre-monsoon and post-monsoon sampling, while additional seasonal and time-series hydrological data are being compiled to enable a comprehensive and scientifically robust assessment of environmental flows. Coordination with the concerned authorities continues to ensure timely receipt of all required data.

9. The answering respondent craves leave to file further submissions or material, if so, directed by this Hon'ble Tribunal.

10. This Hon'ble Tribunal may please to pass any Order as deem fit and proper in the interest of justice. The answering Respondent assures to abide by all or any directions that may be issued by this Hon'ble Tribunal.

11. The contents of this affidavit are true and best of my knowledge and belief.

Date – 21/02/2026

Place – Rajpipla

Deponent

Superintending Engineer
Narmada Project Head Works Circle
S.S.N.N.L., Ekta Nagar

NOTARY
BHUPENDRAKUMAR J. PANCHAL
RAJPIPLA
DIST. NARMADA
REG. NO. 36/05/2010
EXPIRY ON
GOVT. OF INDIA

VERIFICATION

I, Shubham S. Goyal, age - 31 years, serving as Superintending Engineer being authorized signatory and representative of Narmada Project Head Work Circle, Sardar Sarovar Narmada Nigam Ltd., having communication address at 406, 4th floor, New Administrative Building, Ektanagar, District Narmada, Gujarat – 393151 solemnly states that the contents of the Affidavit are true and correct and best of my knowledge, nothing stated therein is false and nothing material has been concealed therefrom.

Date – 21/02/2026

Place – Rajpipla

Deponent

Superintending Engineer
Narmada Project Head Works Circle
S.S.N.N.L., Ekta Nagar

NOTARY
HASMUKHKUMAR J. PANCHAL
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REG.NO. 8405/2010
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BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL,
PRINCIPAL BENCH, DELHI

ORIGINAL APPLICATION NO. 361 OF 2018

IN THE MATTER OF

Narmada Pradushan Nivaran Samiti ...APPLICANT

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Reg.No. 1424
Date: 27/02/2026

AFFIDAVIT

I, Shubham S Goyal, age - 31 years, serving as Superintending Engineer being authorized signatory and representative of Narmada Project Head Work Circle, Sardar Sarovar Narmada Nigam Ltd., having communication address at 406, 4th floor, New Administrative Building, Ektanagar, District Narmada, Gujarat – 393151.

I have gone through the Reply and I state that the reply is drafted under my instructions. Contents and statements made herein in para ____ to ___ of the above reply are true and correct to the best of my knowledge and belief; and as per the datas available on the record.

Solemnly affirmed on 21th day of February 2026 at Rajpipla.

IDENTIFIED BY ME
ADVOCATE
Name: Surmaben M. Vasava
En. No. GJ/5595/2025
Address: At. Chopdi, Dediyapada

Deponent

Superintending Engineer
Narmada Project Head Works Circle
S.S.N.N.L., Ekta Nagar

NOTARY K.J.PANCHAL Narmada District Regd. No. 8066/2010 Commission Expire on Dt. 22/6/2030 GOVT. OF INDIA

NOTARY KISHORKUMAR J. PANCHAL RAJPIPLA DIST.NARMADA REG.NO. 8066/2010 EXPIRY DT. 22/06/2030 GOVT. OF INDIA

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SOLEMNLY AFFIRMED BEFORE ME
BY Shubham S. Goyal.
Who is identified by Surmaben M. Vasava (Advocate)
whom she/he know personally.

KISHORKUMAR J. PANCHAL
NOTARY
GOVT. OF INDIA

Annexure A

भाकृअनुप–केन्द्रीय अंतर्स्थलीय मात्स्यिकी अनुसंधान संस्थान
आई एस ओ 9001: 2015 प्रमाणित संगठन
(भारतीय कृषि अनुसंधान परिषद)
बैरकपुर, कोलकाता – 700120 (पश्चिम बंगाल)
ICAR-Central Inland Fisheries Research Institute
An ISO 9001:2015 Certified Organization
(Indian Council of Agricultural Research)
Barrackpore, Kolkata –700120,West Bengal

डा. बसंत कुमार दास, निदेशक
Dr. Basanta Kumar Das, Director

F. No. Project (SSNNL)-51(1)/2025-D Cell

Dated 04.02.2026

To,

The Chief Engineer (Dam)
SSNNL, 5th Floor
Administrative complex, Ekta Nagar
Gandhinagar-382010, Gujarat
E-mail: cedam-ssnnl-brd@gujarat.gov.in

Sub. : 1. **Discharge data requirement for finalisation of e-flows study**
2. **Three-month extension for finalisation –reg.**

Ref. : Letter no. SSNNL/ENV/CIFRI6212025 dt 13/10/2025

Sir,

Inviting to the above reference, ICAR-CIFRI has not received the discharge data from all the selected sampling sites (9) in the main river channel, nullahs, streams that are contributing to the main stream of river Narmada for three seasons including zero discharge i.e. 10 daily discharge for a period of last 10 years. The same has been requested as per the above reference (Copy of correspondence dated 13th Oct. 2025 enclosed). These data form the basic requirement for the environmental flows calculation. Therefore, it is requested to provide the same data for initiation of e-flows estimation.

After receiving these discharge data from your end, we will be able to initiate the estimation process. Looking into the time period of the data analysis, I request for approving the extension of the project period till April, 2026 without any additional financial requirement to enable successful completion of the remaining work.

Yours sincerely,

(B. K. Das)

Copy to:
The Add. Prin. Chief Conservator of Forests, Sardar Sarovar Narmada Nigam Ltd. (SSNNL), Environment Cell, Block No: - 12, 9th Floor, Gandhinagar-382010, Gujarat.
e-mail: envirmentcell@gmail.com

Annexure B

Interim REPORT

ON

ASSESSMENT OF ENVIRONMENTAL FLOW TOWARDS RIVER HABITAT AND ECOLOGICAL REQUIREMENT WITH A FOCUS ON DOWNSTREAM FISH SPECIES OF SARDAR SAROVAR DAM (SSD) IN NARMADA RIVER

Submitted to:

SARDAR SAROVAR NARMADA NIGAM LTD, Govt. of Gujarat

ICAR – CENTRAL INLAND FISHERIES RESEARCH INSTITUTE

BARRACKPORE, KOLKATA-700120

PROJECT TEAM

Project Co-Ordinator

Dr. Basanta Kumar Das (Director, ICAR– CIFRI)

Project Investigator

Dr. A.K. Sahoo (Principal Scientist, ICAR-CIFRI)

Project Co-Investigators

Dr. D. K. Meena (Sr. Scientist, ICAR-CIFRI)

Dr. Ajoy Saha (Sr. Scientist, ICAR-CIFRI)

Dr. S. P. Kamble (Sr. Scientist, ICAR-CIFRI)

Young Professionals

Mr. Rajiv Ranjan (ICAR–CIFRI)

Miss. Subhasmita Behera (ICAR–CIFRI)

Skilled Technical

Mr. S. K. Paul (ICAR–CIFRI),

Mr. Dibyasingh Dev Parida (ICAR–CIFRI)

Sponsored By:

Sardar Sarovar Narmada Nigam Limited, Govt. Of Gujarat

Submitted By:

ICAR – Central Inland Fisheries Research Institute

Barrackpore, Kolkata-700120

भा.कृ.अनु.प. - केंद्रीय अन्तर्स्थलीय मात्स्यिकी अनुसंधान संस्थान
AN ISO 9001 : 2015 Certified Organization
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Barrackpore Kolkata, West Bengal - 700 120

Foreword

SSNL vide letter no. **SSNNL/Env/CIFRI/e-flow/119** dated **15/03/2025**, requested for technical expertise from ICAR-Central Inland Fisheries Research Institute (CIFRI), Barrackpore under a consultancy project for "**Assessment of Environmental flow towards river habitat and Ecological requirement with a focus on downstream fish species of Sardar Sarovar Dam (SSD) in Narmada River**". The expert team from CIFRI visited the sites during pre-monsoon and post-monsoon and investigated on both biotic and abiotic factors determining the optimum environmental flows. This interim report outlines the results of the study analysis highlighting the diversity of fish species, and migratory fish species, habitat, fish food organisms and benthic community as river health assessment. ADCP survey highlighted the post-monsoon discharge and velocity of the river at the selected 9 sampling sites. These data in addition to the biological data are the preliminary requirement for the developing habitat suitability curve for the selected fish species particularly Mahseer, *Tor pitutora* in the downstream stretch of SSD and Hilsa (*Tenualosa ilisha*) in the middle and estuarine stretches. I appreciate the efforts of all the Scientists, Technical Officers, Administrative and Supporting Staff for support rendered in sampling, data analysis and report preparation, and representatives from SSNL and NCA who assisted during the site visit and co-ordination.

Date:12-02-2026
Place: Barrackpore

(Basanta Kumar Das)
DIRECTOR

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Executive Summary

An investigation on "**Assessment of Environmental Flow Towards River Habitat and Ecological Requirements With a Focus on Downstream Fish Species of Sardar Sarovar Dam (SSD) in Narmada River**" was carried out during June 2025 and November 2025 covering pre-monsoon and post-monsoon with the following objectives 1) to assess the seasonal hydrological and hydraulic dynamics in the study area 2) to assess the seasonal habitat requirement (ecology) of the key stone fish species and major fish diversity 3) to estimate E-flow for fish diversity employing the hydraulic cum habitat simulation method. Based on fish abundance, pollution discharge point, varying substrate, and to estimate the possible impact of downstream of SSD due to environmental flow. Nine sampling sites were identified from downstream of SSD to Bhadbhut covering about 130 km longitudinally.

The habitat profile of the river Narmada was assessed during the study period. The habitat factors that influenced fish to complete their lifecycle are substrate type, deep pools, scar pools, riparian vegetation, water depth, water flow, river gradient, width of the wetted channel, flood plains, etc. The values of the habitat profile obtained during the study period showed no significant variations in habitat profile in both seasons, except for depth and water velocity. In pre-monsoon sampling average depth in the sampling sites varied from 3.26 m. to 10.3 m, whereas it was between 0.97 and 6.85 m. during the post-monsoon period, which showed slightly less value than the pre-monsoon season. Water velocity recorded ranged from 0.25 to 1.30 m./sec. in the pre-monsoon season and 0.17 to 1.06 m./sec in post-monsoon sampling, which is again a slightly higher value during the pre-monsoon season than post monsoon. The remaining parameters were almost the same in both the seasons, which is acceptable for aquatic life.

During the post-monsoon season, Acoustic Doppler Current Profiler (ADCP) survey was conducted along the lower stretch of the Narmada River. Width of the channel, water discharge, depth, mean depth, and water velocity were the key parameters recorded by the ADCP survey. Downstream variations of river width towards the estuarine zone were recorded, which gradually increased. Width ranged from 213.7 m at Garudeshwar to 965.95 m at Bhadbhut, with notable widening at Bharuch (785.55 m) and Sakkarpura (589.9 m). Maximum water velocity (3.03 m/s) was recorded from Bhadbhut, and the minimum water velocity (0.85 m/s) was recorded from Jhanor. Other parameters, like depth and water discharge data, were also recorded during the survey.

A total of 3352 fish belonging to 12 orders, 20 families, 36 genera, and 47 fish species have been documented from the sampling sites of the river Narmada during pre-monsoon (June' 25) and post-monsoon (November'25) sampling. During pre-monsoon sampling 36 no. fish species have been documented, and 42 species have been recorded during the post-monsoon period. *Rhinomugil corsula, Labeo bata, Labeo gonius, Protonibea diacanthus, Osteochilus vittatus, Channa punctatus, Channa striatus, and Cynoglossus cynoglossus* were recorded during *the* post-monsoon season, whereas *Labeo dyocheilus, Channa marulius* and *Parambassis ranga* were documented in the pre-monsoon season, and the remaining species were recorded in both seasons. As a result, obtained from the above study, cyprinid was the major group (36.07%), followed by Bagridae (8.51%), Channidae (6.38%), and Sciaenidae (4.25%) respectively. Maximum species richness in both seasons was recorded at Garudeshwar (n=30, 63.82%), followed by Sisodra (n= 29, 61.70%), Poicha (n=24, 51.06%), and Jhanor (n=21, 44.68%), respectively. Significantly, it has been found that species richness gradually decreased with the decrease in river elevation.

The Index of Biotic Integrity (IBI) was calculated in all the sampling stations, and the calculated score showed acceptable and moderately acceptable, which are favourable for freshwater habitats.

As far as water quality is concerned, no such significant differences were found in pH, Hardness, Total Alkalinity, Conductivity, Salinity, TDS, Free CO_2, D.O., Total Hardness, Nitrate, Silicate, Chlorinity, BOD, Chlorophyll, Available and Phosphate, Total Nitrogen, and nutrient parameters except water temperature and dissolved oxygen. During the pre-monsoon period, water temperature across the sampling stations remained relatively high, ranging from about 25.5 to 28.03 °C. In contrast, during the post-monsoon period, water temperature declined at all stations, ranging between 23 and 27 °C.

A total of six phytoplankton taxa were observed from the downstream of the Sardar Sarovar Dam (SSD) on the Narmada River during the pre-monsoon study from 9 different sampling stations. Among all the recorded phytoplankton groups, *Pediastrum simplex* was found to be the most abundant. During the post-monsoon period, a total of five phytoplankton taxa were recorded during this period. Among the recorded taxa, *Pediastrum* sp. exhibited the highest cell density (1300 cells/ml), indicating its dominance and strong adaptability under post-monsoon environmental conditions.

During the pre-monsoon season, the zooplankton community was dominated by copepods, with *Mesocyclops* being the most abundant. In contrast, the post-monsoon season showed a slight variation in species composition, with the occurrence of *Keratella* sp. (Rotifera) and *Cyclops* sp. The less abundance and limited diversity of zooplankton during both the seasons indicates a sparse zooplankton community structure in the study area.

A total of thirteen macro and meiobenthic taxa were recorded from the downstream stretch of the Sardar Sarovar Dam (SSD) on the Narmada River during the pre-monsoon season. During the post-monsoon season, six benthic macroinvertebrate species, all belonging to Mollusca, were recorded from the same study area. The gastropod assemblage comprised *Tarebia granifera, Bellamya crassa*, *Thiara tuberculata*, and *Bellamya dissimilis*, while the bivalve fauna included *Corbicula striatella* and *Parreysia favidens*. The occurrence of both gastropod and bivalve species during the post-monsoon period reflects a moderately diverse molluscan assemblage in the downstream stretch of the SSD.

Hydrological discharge particularly representing pre-monsoon and post-monsoon at the selected sampling sites and the river cross sections are the pre-requisite for estimating fish based environmental flows between the SSD to Bhadbhut. The present report highlights the ecological integrity of the river based on fisheries as the indicator of the aquatic habitat for estimation of environmental flow. Through ADCP, the seasonal discharge and river cross sections were generated for post-monsoon season. Fish diversity and period of migration of these fish between the selected stretch has been already documented. Considering these fish species data with the time series hydrological data (10 daily for 10 years) will help us to generate the environmental flows requirement between SSD and Bhadbhut. For final estimation of environmental flows, the time series hydrological discharge data from the selected sampling sites are pre-requisite, which is awaited. SSNL has committed to provide the time series data for estimating Fish based environmental flows between the selected stretch of river Narmada.

Introduction

Environmental flow:

In a word, environmental flow can be described as the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and human livelihood and well-being that depend on these ecosystems. Environmental flow within a river plays a pivotal role for provides important goods and ecological services to society, including fisheries. It is supporting habitat, maintaining water tables, and facilitating fish species movement. Water provides in the river supports ecological integrity, reduces aquatic weeds, improves river health, sustenance of native fish species, river dependence plants and animals that rely on different flows to trigger migration and breeding. It is evident that due to the overall environmental degradation, like diminishing water flow and manmade interferences in the catchment area of the river basin, there has been a perceptible decline in both fish productivity and diversity. Therefore, it is necessary to give added emphasis to fisheries as well as the changed environmental conditions for eco-restoration and development of norms for management towards the sustenance of the necessary environmental flow in the river. With this backdrop, the present investigation was designed to address the following objectives

Objectives of the study:

- To assess the seasonal hydrological and hydraulic dynamics in the study area
- To assess the seasonal habitat requirement (ecology) of the key stone fish species and major fish diversity
- To estimate E-flow for fish diversity employing the hydraulic cum habitat simulation method

River Narmada

Large rivers and their floodplains support a significant proportion of the world's biodiversity and provide economic upliftment, drinking water, agriculture through irrigation, facilitate transport, and serve as habitats for diverse ecosystems, including fisheries. From time immemorial, the river Narmada has been India's river of faith, devotion, and worship. The Narmada, a Sanskrit word meaning 'the Giver of Pleasure', is one of the most sacred rivers in India. It is the longest west-flowing river rising from a spring at a height of 1057 m. above MSL on the **summit** of Amarkantak hill in Shadol district of Madhya Pradesh. The total length

of the Narmada from the source of its outfall into the Gulf of Cambay in the Bharuch district of Gujarat is 1312 kms.

The Narmada basin lies between east longitudes 72° 32′ to 81° 45′ and north latitude 21° 20′ to 23° 45′, lying on the northern extremity of the Deccan plateau and extending over an area of 98796 km^2 (38,145.3 sq. mi.). The basin covers large areas in the states of Madhya Pradesh (86%), Gujarat (14%), and a comparatively smaller area (2%) in Maharashtra. In the river course of 1,312 km (815.2 mi.), there are 41 tributaries, out of which 22 are from the Satpura range and the rest on the right bank are from the Vindhya range.

The river serves as an important source of livelihood for the artisanal fishermen. However, over the years, various anthropogenic activities have altered the aquatic environment (environmental flow) of the river. Of late, it is assumed that the production process at different trophic levels of fish has been impeded, resulting in a decline in fish production and diversity. With this belief, an investigation was undertaken to assess the present status of the environmental flow with respect to the fish diversity and other aquatic ecological integrity in the limited stretches of the river Narmada.

Significance of sampling in limited stretches

The present study concentrated on a limited stretch of the river Narmada to estimate E-flow for fish diversity employing the hydraulic cum habitat simulation method from downstream of SSD to Bhadbhut. Sampling in limited stretches of the river focuses on gathering representative data within a defined area of a river, often in response to comprehensive information on the ecological integrity of the river Narmada about water quality status. To assess the likely changes in the fish species in rivers due to environmental stress and any deviation from the environmental flow.

Study area and sampling sites

The stretch from downstream of SSD to Bhadbhut is a critical stretch for indigenous fish species, including the migratory fish. Therefore, focus was given to those sites important for the fish-based environmental flows estimation. Sampling undertaken in the rivers at regular intervals (Seasonal) to obtain information about population density of fish, their abundance, species-wise occurrence, often in relation to the habitat they occupy and other biotic and abiotic factors. Any interruption in seasonal sampling may lead to a missing link in obtaining accurate statistical data. Therefore, it is mandatory to adopt a sampling approach logistically. Keeping

the above aspects in view, a team of ICAR-CIFRI under the Narmada e-flow study project carried out sampling in the river Narmada in the year 2025, covering the pre-monsoon (Lean period) and monsoon season. Pre-monsoon field campaign was carried out during June 23rd to 27th, 2025, and post-monsoon sampling undertaken during November 7th to 14^{th,} 2025, to mount a survey to collect fish and other hydrological data from different selected sites in the river Narmada at Garudeshwar, Poicha, Sisodra, Lilod, Jhanor, Shuklatirth, Bharuch, Sakkarpura, and Bhadbhut of Gujarat (Table.1). Nine sampling sites were selected covering about 130 km. downstream of the Sardar Sarovar Dam (SSD) of the river Narmada. The positional coordinates ranged from N 21.807099, E 73.656058 to N 21.680952, E 72.845297 at an elevation between 60.57 and 25.47 m. of msl (Table.1 & Fig. 1). Sampling sites were selected based on fish abundance, pollution discharge point, varying substrate, and to estimate the possible impact of downstream and upstream due to environmental flow. The distance between the sampling sites is almost equal at all the sites except for Sakkarpura to Bhadbhut (Table 2).

Table 1: Details of sampling sites

Sampling sites	**River basin**	**District**	**GPS Coordinates**	**Elevation (m. MSL)**
Site-I (Garudeshwar)	Narmada	Narmada	N 21.887099 E 73.656058	60.57
Site-II (Poicha)	Narmada	Narmada	N 21.975716 E 73.458628	36
Site-III (Sisodra)	Narmada	Navsari	N 21.913903 E 73.347048	37.3
Site –IV (Lilod)	Narmada	Vadodara	N 21.878093 E 73.233343	29.0
Site –V (Jhanor)	Narmada	Bharuch	N 21.8388 E 73.134	20.0
Site- VI (Shuklatirth)	Narmada	Bharuch	N 21.747727 E 73.123398	36.9
Site- VII (Bharuch)	Narmada	Bharuch	N 21.690182 E 73.00644	15.9
Site- VIII (Sakkarpura)	Narmada	Bharuch	N 21.682 E 73.907	14.8
Site- IX (Bhadbhut)	Narmada	Bharuch	N 21.680952 E 73.845297	17.47

Table 2. Distance between the sampling sites

Sampling sites		Distance (km.)
From	**To**	
Garudeshwar	Poicha	25.18
Poicha	Sisodra	19.28
Sisodra	Lilod	23.52
Lilod	Jhanor	19.12
Jhanor	Shuklatirth	10.78
Shuklatirth	Bharuch	15.46
Bharuch	Sakkarpura	10.84
Sakkarpura	Bhadbhut	6.65

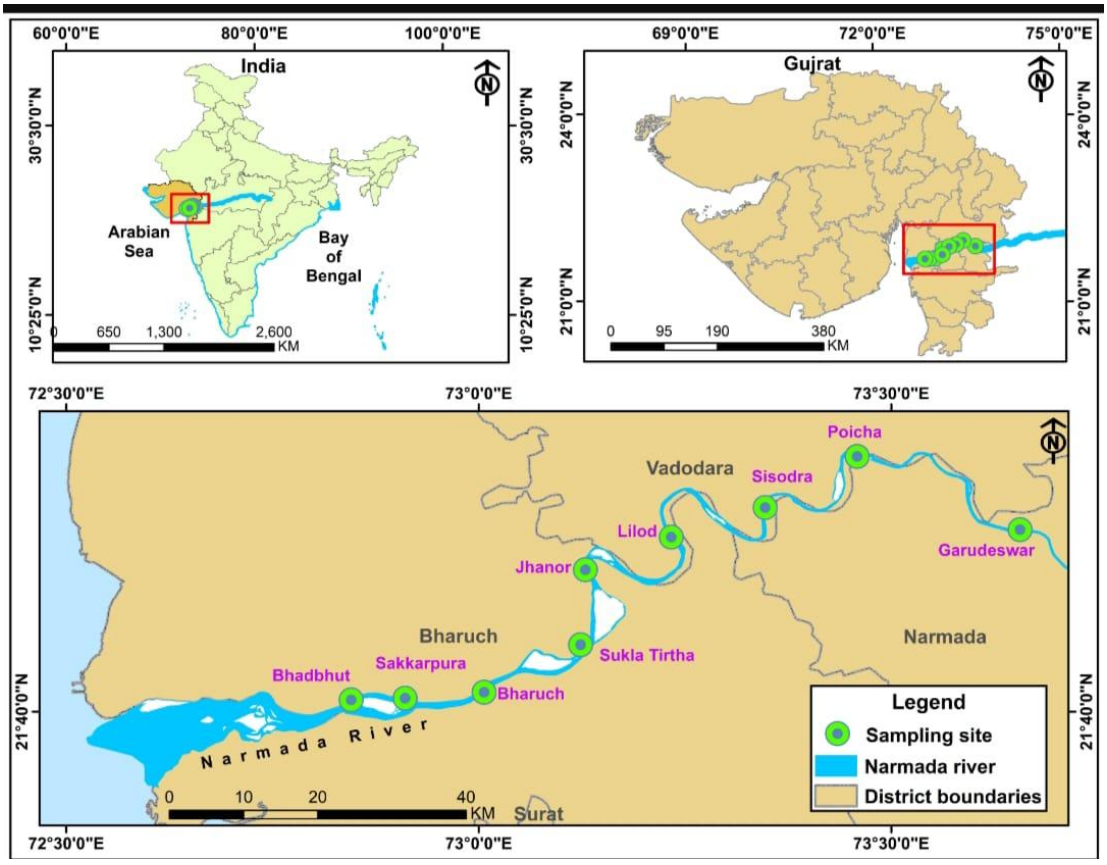


Fig 1. GIS map depicting sampling sites along the river Narmada

Sampling and Methodology

Water quality parameters

Water samples from different stations were collected across the river as well as two banks, and also from the sub-surface layer of the middle of the river to obtain composite water from each centre. Water quality characteristics, including temperature, pH, electrical conductivity, salinity, dissolved oxygen (DO), free carbon dioxide, alkalinity, total hardness, total phosphorus, available phosphorus, nitrate-nitrogen, total nitrogen, silicate, chloride, and biological oxygen demand (BOD), were monitored throughout the experiment according to methods of APHA (2017).

Hydrological parameters

Shoreline depth of left and right bank, mid-channel depth was measured by using Eco sounder (PS-7, LCD Digital sounder), ADCP, and wetted perimeter, water flow was measured by using digital flow meter (Make - Global Water Instrument: model FP 111, USA), and ADCP. Transparency of the water at each sampling stations was measured by the Secchi Disk.

Sediment parameters

Sediment samples were collected by an Ekman dredge across the river as well as two banks, and also from the bottom of the middle of the river to obtain a composite sediment sample from each centre. The sediment characteristics, including pH, conductivity, organic carbon, texture, free calcium carbonate ($CaCO_3$), total nitrogen and total phosphorus, were monitored throughout the experiment according to methods of APHA (2017).

Planktonic status in the river Narmada

To explore the planktonic communities of the Narmada River downstream of the Sardar Sarovar Dam (SSD), 100 liters of water were filtered using a plankton net with a mesh size of 50µm. The concentrated 10 ml sample was preserved in 5% formalin. Numerical enumeration was carried out following the method described by Welch (1948). Identification of plankton

was performed using standard taxonomic keys and literature, including those by Pennak (1978), Davis (1955), Ward & Whipple (1959), Cox (1966), and Needham & Needham (1972).

Benthic communities

Benthos samples were collected by using Petersen Grab having area of 19.0 x 19.5 cm^2 from each site. Three random hauls constituted one sample which was preserved in 10% formalin after sieving through Sieve No. 40. The qualitative and quantitative enumerations have been carried out by following Welch (1948), Subba Rao (1989), Ramakrishna & Anirudha Day (2007) and APHA (2017).

Habitat profile

In the present investigation, during pre-monsoon and post-monsoon sampling, the habitat profile of each site was recorded based on types of substrates, bedrocks, riparian vegetations, deep pools, refill, etc. Water velocity, depth, and width of the river were measured using a flow meter and an Acoustic Doppler Current Profiler (ADCP) system. However, deep pools were measured using an echo sounder at the shoreline and mid-channel. Agriculture practices on the river banks, if any, were recorded based on interaction with local people and visualized in the sampling site. The width of the river (bank to bank) channel was measured physically.

Fish sample collection and analysis

Sampling for fish was done from the main channel as well as the adjacent area. Though the river was bank full due to heavy rain during the pre-monsoon season, fish were collected from the river using gill nets, hook and lines, and drag nets of assorted mesh sizes from all possible habitat niches along the sampling sites, assuming that the existing species and their abundance would be reflected in the sample. The fish samples were collected mainly through experimental fishing and from adjoining landing centres. The experimental fishing was carried out along the longitudinal gradient of the river within 5 km. up and downstream. A sampling effort of 6 hours for the gill net was carried out. Further, the abundance of species indicated in the observations is the total number of fish of the individual species collected. Fish catch data and samples were also collected from fish landing stations at all the sampling sites. Representative specimens

(n=5) of all fish species were identified and preserved in 10% formalin and brought to the laboratory for analysis.

The identification of the fish specimen from various sites of river Narmada was conducted using the keys as per Francis Day (1889), Mishra (1962), Talwar and Jhingran (1991), Jayaram (1981 & 2006), Nath and Dey (2000).

Observations

Aquatic habitat assessment

Aquatic habitat plays a significant role in the successful colonization of fish and other aquatic organisms. It is well known that water alone will not ensure the survival of fish. Along with quality water, fishes need an ideal and suitable aquatic habitat for their growth, breeding, migration, etc. In general, freshwater can be categorized into lentic (standing) and lotic (flowing) water habitats. Habitat diversity can vary tremendously within these two broad categories, and few fish taxa can be found in both habitats. The habitat factors that influenced fish to complete their lifecycle are substrate type, deep pools, scar pools, riparian vegetation, water depth, water flow, river gradient, the width of the wetted channel, flood plains, etc. Some indigenous fish also have to move between different habitats as they mature and breed. Different fish species have different habitat requirements, and these may change as they grow older. Significantly, it has been found that there are not many seasonal variations in the habitat profile over the short period of time, except for the width of the wetted channel, average depth, and water velocity.

Habitat profile during pre-monsoon period

During pre-monsoon period habitat profile of each sampling site of the river Narmada is shown in Table 3. Some significant variations were recorded in each sampling site. The mean depth of the studied stretches varied from 3.26 m. to 10.3 m. Depth was recorded from the shoreline (L and R banks) and mid-channel. The substrate type was dominated by boulders, coarse sand, gravels, and sandy clay at upper stretches of the river (Garudeshwar to Sisodra) and sandy clay and sand in all remaining sites (Lilod to Bhadbhut), which are considered to be ideal habitats for the freshwater ecosystem. In the site Garudeshwar to Sisodra, substrates were predominant with boulders, gravels, cobbles, and coarse sand, which are an ideal habitat for catfish. Water velocity recorded ranged from 25 to 130 cm/sec which is supposed to be acceptable for freshwater rivers. This is common features in a lean period. Deep pools were

recorded from the sampling sites, which are significant for aquatic fauna for their shelter and breeding ground, especially in the lean period. A significant observation was that agricultural practices were observed in catchment areas in the sampling sites, which is a serious concern as the pesticides used for agricultural practices may be deposited into the river through runoff. Good riparian vegetation on the catchment area and riverbanks is considered to be an important part of the river habitat.

Habitat profile during post-monsoon period

Habitat profile during post monsoon period (Nov. 2025) at each sampling site of river Narmada has been portrayed (Table 4.), and data were recorded in a printed proforma prepared for this purpose. Some significant habitat variations were recorded in each sampling site. The mean depth of the studied area varied from 0.97 to 6.85 m as per ADCP data. Minimum depth (0.97 m) recorded from Garudeshwar and maximum depth (6.85 m) recorded from Jhanor, which are acceptable for a lotic water body. Depth was recorded by the ADCP system from the shoreline (L and R banks) and mid-channel. Width of wetted channel varied from 198.0 m to 965.95 m It is evident from the present study that the width of the river Narmada (wetted channel) increased as the river gradient goes further towards downstream. In general, heavy rainfall over the year, afforestation of bank vegetation, and the resistance of river banks to erosion plays a crucial role in determining the channel's width. The substrate type was dominated by boulders, coarse sand, gravels, and sandy clay at upper stretches of the river (Garudeshwar, Poicha and Sisodra) sandy clay and sandy in all remaining sites (Lilod, Jhanor, Shuklatirth, Bharuch, Sakkarpura and Bhadbhut), which are considered to be ideal habitats for the freshwater ecosystem. In site, Garudeshwar, Poicha and Sisodra substrates were predominant with boulders, gravels, cobbles and coarse sand which are ideal habitat for cat fishes. Water velocity recorded ranged from 0.17 to 1.06 m/sec (ADCP data). Minimum water velocity (0.17 m/sec) recorded from Lilod site, whereas maximum (1.06 m/sec) was recorded from Sakkarpura site which are supposed to be acceptable for freshwater rivers. This is common features in late post-monsoon season. Deep pools were recorded from the sampling sites which are significant for aquatic fauna for their shelter and breeding ground, especially in the lean period. Significant observation was that agricultural practices were not observed in catchment areas in the sampling sites, which is favourable for aquatic habitat. As it is evident that use of pesticides for agricultural practices may be deposited into the river through runoff and make the river polluted. Good riparian vegetation on the catchment area and riverbanks is considered to be an important part of the river habitat.

Remarks

In pre-monsoon sampling average depth in the sampling sites varied from 3.26 m to 10.3 m whereas it was between 0.97 and 6.85 m during the post-monsoon period, which showed slightly less value than the pre-monsoon season. The possible reason was that heavy rain during the pre-monsoon sampling made the river deeper. Water velocity recorded ranged from 0.25 to 1.30 m/sec in the pre-monsoon season and 0.17 to 1.06 m/sec in post-monsoon sampling, which is again a slightly higher value during the pre-monsoon season than post monsoon sampling due to heavy downpour and added additional rain water into the main channel from catchment area which enhanced the water velocity. The water velocity in both seasons is supposed to be acceptable for freshwater rivers. Remaining habitat parameters like substrate type, deep pools, and meandering nature remained almost the same in both seasons. Width of wetted channel, width of bank to bank was slightly varied due to a sudden increase in water level due to heavy rain during the pre-monsoon season.

Riparian vegetation growing on the catchment area and river banks of the stream is considered to be an important part of the river habitat. In the present investigation, fairly good bank vegetation was observed in all the sampling sites, both in pre- and post-monsoon seasons. Good, diverse bank vegetation in the sampling sites, which, as a whole act as a filter for runoff from the surrounding land, partly purifying the water before it enters the stream. The more or less meandering nature of the stream was observed in the studied area.

Table 3. Habitat profile of sampling stations (pre-monsoon)

	Garudeshwar	Poicha	Sisodra	Lilod	Jhanor	Shuklatirth	Bharuch	Sakkarpura	Bhadbhut
Width of channel (wetted)	300 m	300 m	200 m	500 m	450 m	400 m	700 m	500 m	900 m
Bank to bank width	800 m	800 m	800 m	700 m	700 m	700 m	1000 m	700 m	1200 m
Depth (Avg.)	3.5 m	3.26 m	3.9 m	9.6 m	5.46 m	4.7 m	11.46 m	5.2 m	7.76 m
Water velocity	1.30 m/sec	1.10 m/sec	0.75 m/sec	0.42 m/sec	0.32 m/sec	0.36 m/ sec	0.25 m/sec	0.61 m/sec	0.56 m/sec
Substrate composition	Boulders 25%, coarse sand 45%, gravels 10%, clay and others 20%.	Coarse sand 25%, gravels 15%, cobbles 10% clay and others 50%.	Small gravels 15%, sand 35%, clay and others 50%	Sandy clay and others 100%	Sandy clay	Sandy clay	Clay and organic materials	Sandy clay	Sandy clay
Deep pools	2 nos. identified with average depth of 18.5 ft	1 no (depth 12 m)	Not recorded	Recorded (1 no. with 30 m depth)	Not recorded	Not recorded	Not recorded	Not recorded	Not recorded
Riparian vegetation	Trees 45%, Herbs 15%, Shrubs 25%, grass land 15%	Trees 40%, Herbs 20%, Shrubs 25%, grass land 15%	Trees 35%, shrubs 15%, herbs 15%, grass land 25%	Trees 40%, shrubs 10%, herbs 15%, grass land 35%	Trees 20%, shrubs 25%, herbs 15%, grass land 40%	Trees 15%, shrubs 25%, herbs 20%, grass land and others 40%	Trees 20%, shrubs 25%, herbs 20%, grass land and others 35%	Trees 25%, shrubs 15%, herbs 10%, grass land and others 50%	Rich riparian vegetation (Trees, shrubs, herbs, grass land and others)
Other information	Check dam constructed, ritual activities by the local people were visualized, temple exist. No pollution sources were observed.	Pollution source not recorded, bank soil erosion observed, instream cover not found.	Ritual activities visualized, sources of pollution not found.	Temple exists, no significant pollution discharge source identified.	Water lifting pump installed in the bank of the river, no pollution sources were found.	Ritual activities observed as the site considered as one of the holiest shrines.	Urban area, city sewage being discharged into the river, railway and road bridge constructed over the river.	Water lifting pump installed in the shoreline of the river, no instream cover was recorded.	Island formed in the middle of the river, Temples are located on the bank of the river, barrage under construction.

Table 4. Habitat profile of selected sampling stations (post-monsoon)

Parameters	Sampling sites								
	Garudeshwar	Poicha	Sisodra	Lilod	Jhanor	Shuklatirth	Bharuch	Sakkarpura	Badbhut
Width of wetted channel (m.)	213.70	271.30	198.00	242.50	461.70	300.90	785.55	589.90	965.95
Width of the bank to bank of the river (m.)	800.00	300.00	800.00	500.00	700.00	650.00	900.00	750.00	1200.00
Av. Depth (m.)	0.97	3.85	6.71	6.84	6.85	3.30	4.40	3.28	4.66
Deep pools	Present (2 nos.)	Present (1 no.)	Not recorded	Present (1 no.)	Not recorded	Not recorded	Not recorded	Not recorded	Not recorded
Scar pools	Present	Not recorded	Present	Present	Present	Not recorded	Present	Present	Not recorded
Substrate type	Boulders 25%, coarse sand 45%, gravels 10%, clay and others 20%.	Coarse sand 25%, gravels 15%, cobbles 10% clay and others 50%.	Small gravels 15%, sand 35%, clay and others 50%	Sandy clay (	Sandy clay &others (	Sandy clay & others (40%, 50%, 10%)	Clay and organic materials	Sandy clay (55%, 40%, 5% others))	Sandy clay & others (40%, 50%, 10%)
Elevation (m.)	6.57	36.0	37.3	29.0	20.0	36.9	15.9	14.8	17.47
Riparian vegetation	Trees 40%, Herbs 15%, Shrubs 25%, grass land 20%	Trees 35%, Herbs 25%, Shrubs 25%, grass land 15%	Trees 35%, shrubs 20%, herbs 25%, grass land 20%	Trees 35%, shrubs 15%, herbs 15%, grass land 35%	Trees 20%, shrubs 20%, herbs 15%, grass land 45%	Trees 15%, shrubs 20%, herbs 20%, grass land and others 40%	Trees 15%, shrubs 30%, herbs 15%, grass land and others 35%	Trees 20%, shrubs 15%, herbs 15%, grass land and others 50%	Rich riparian vegetation (Trees, shrubs, herbs, grass land and others)
Water velocity (m/sec)	0.39	0.80	0.38	0.17	0.18	0.26	0.44	1.06	0.47

In-stream cover	Present	Not found	Present	Present	Not found	Present	Present	Not found	Not found
Meandering nature	Less meandering	Observed	Observed	Less meandering	Observed	Observed	Observed	Less meandering	Observed
Source of pollution	Not found.	Not recorded,	Not found.	No significant pollution discharge source identified	No pollution sources were found.	Not found.	City sewage being discharged into the river	Not found.	Not found.
Agriculture practices	Not found	Not found	Not found	Not found	Not found	Not found	Not found	Not found	Not found
Other observations	Check dam constructed, Ritual activities by the local people were visualized, temple exist.	bank soil erosion observed, instream cover not found.	Ritual activities visualized.	Temple exists	Water lifting pump installed in the bank of the river	Ritual activities observed as the site considered as one of the holiest shrines.	Urban area, railway and road bridge constructed over the river.	Water lifting pump installed in the shoreline of the river,	Island formed in the middle of the river, Temples are located on the bank of the river, barrage under construction.

Physico-chemical parameters of water

Water Temperature

During the pre-monsoon period, water temperature across the sampling stations (S_1–S_9) remained relatively high, ranging from about 25.5 to 28.03 °C. The highest temperatures were recorded at S_8 and S_9, while comparatively lower values were observed at S_1 and S_6. In contrast, during the post-monsoon period, temperatures declined at all stations, varying approximately between 23 and 27 °C, with the lowest temperature at S_5 (Fig. 2). This seasonal reduction in temperature reflects the cooling effect of monsoonal rainfall and enhanced water mixing across the study area.

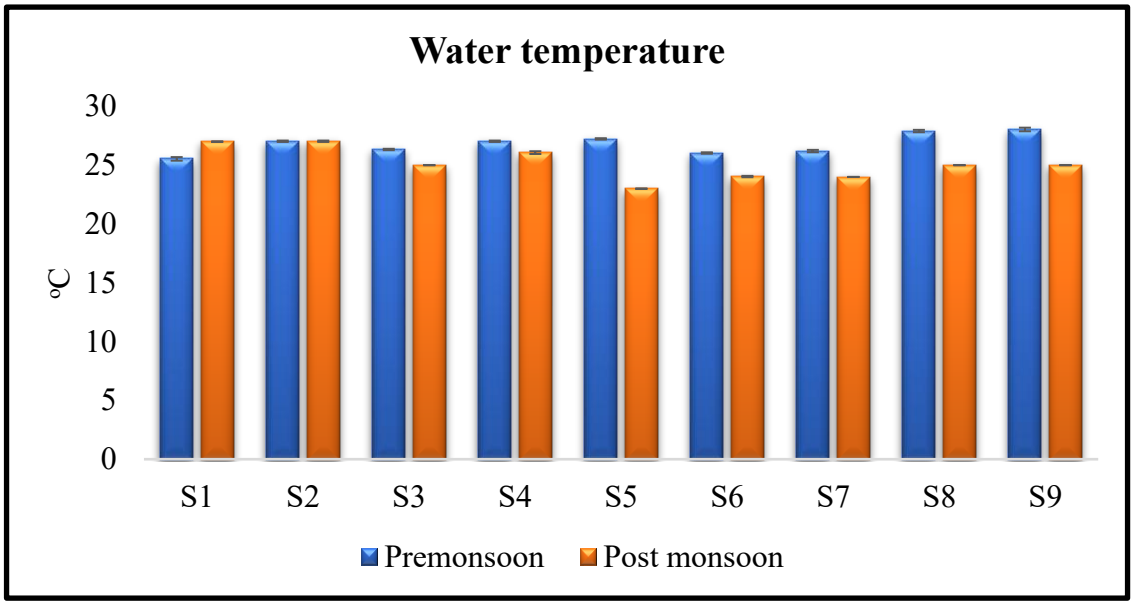


Fig 2. Diagram representing comparative water temperature in pre- and post-monsoon season

Water Flow

During the pre-monsoon period, water flow showed pronounced spatial variation across the sampling sites, with the highest velocity recorded at S_1 (1.296 m/sec), followed by S_2 (1.103 m/sec). Moderate flow conditions were observed at S_3 (0.756 m/sec), S_8 (0.616 m/sec), and S9 (0.55 m/sec), whereas relatively lower velocities were recorded at S_4 (0.42 m/sec), S_6 (0.3633 m/sec), and S_5 (0.32 m/sec). The lowest pre-monsoon flow occurred at S_7 (0.246 m/sec). In contrast, during the post-monsoon period, water flow decreased sharply across all sites, with velocities remaining very low throughout the stretch. Slight increases were noted at downstream locations such as at S_8 and S_9, where at S_8 it was found to be maximum among the study sites (Fig. 3). Though these values were still substantially lower than pre-monsoon levels. During the pre-monsoon sampling, due to heavy rain, a higher value of

water flow was recorded across the sampling sites. There was a significant reduction in flow during the post-monsoon season, the possible reason was due to less influx of water into the main channel from the catchment area which stabilized hydrological conditions. m/sec

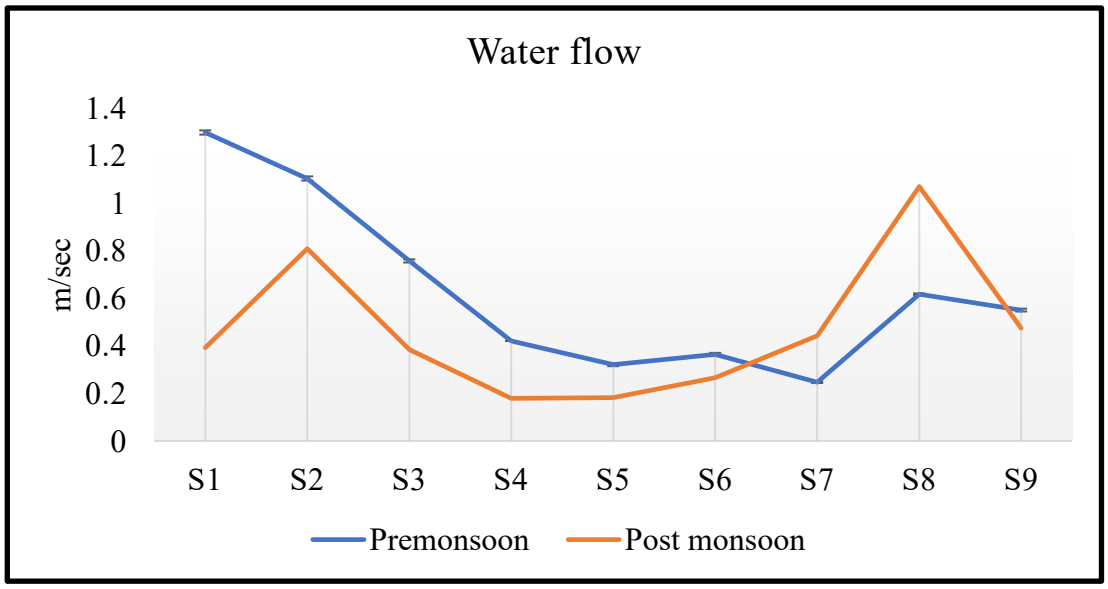


Fig. 3 Diagram showing comparative water flow pattern in both the seasons.

Water pH

During the pre-monsoon period, the pH of the Narmada River remained slightly alkaline across all sampling stations (S_1–S_9), ranging approximately from 8.1 to 8.37, indicating stable buffering conditions and limited spatial variation. In the post-monsoon period, pH values increased at all stations, reaching about 8.3–8.7, with the highest values observed at downstream locations such as S_7, S_8, and S_9, reflecting the strong buffering capacity of the river system (Fig. 4). The consistently alkaline nature of the Narmada River during both seasons indicates stable hadrochemical conditions, while the relatively higher pH observed during the post-monsoon period suggests the influence of monsoon runoff, enhanced water mixing, and increased photosynthetic activity, particularly in the downstream stretches.

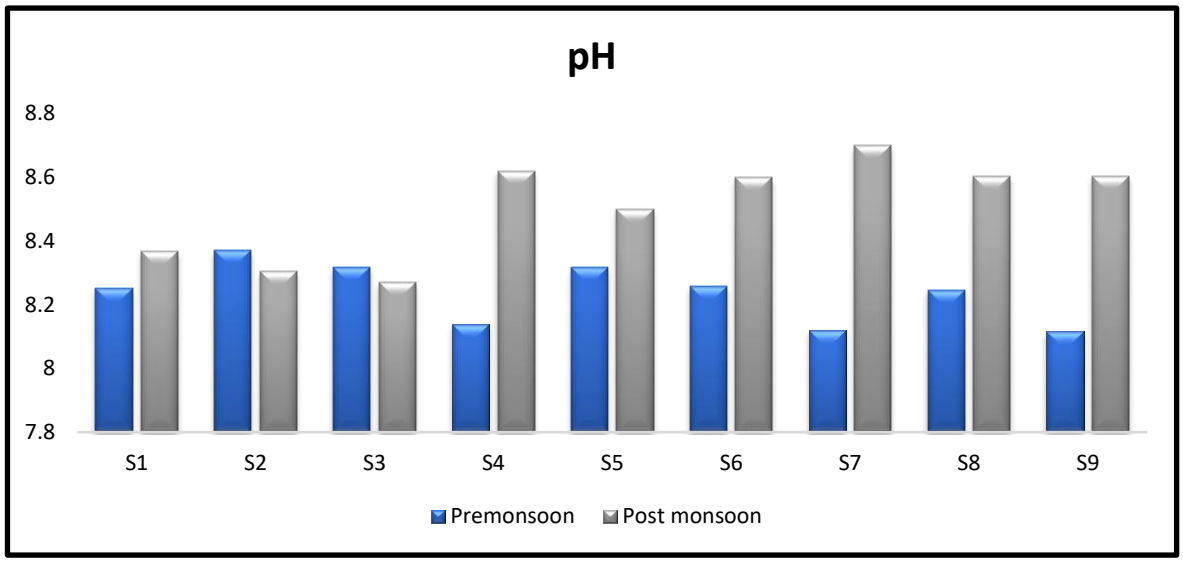


Fig. 4 Sidewise pH value in pre-monsoon and post-monsoon season

Electrical Conductivity of water

Electrical conductivity (EC) of the Narmada River exhibited clear seasonal variation across the sampling stations. During the pre-monsoon period, EC values were comparatively lower, ranging from about 186.6 to 386 µS/cm, with reduced values at midstream sites and relatively higher values toward the downstream reaches due to heavy rainfall during sampling. In the post-monsoon period, EC increased across all stations, varying approximately between 304 and 424.3 µS/cm, with pronounced elevation at downstream locations (S_7–S_9) because these are comes under estuarine zone (Fig. 5). This post-monsoon rise in EC may be attributed to increased ionic input from catchment runoff and reduce in water volume.

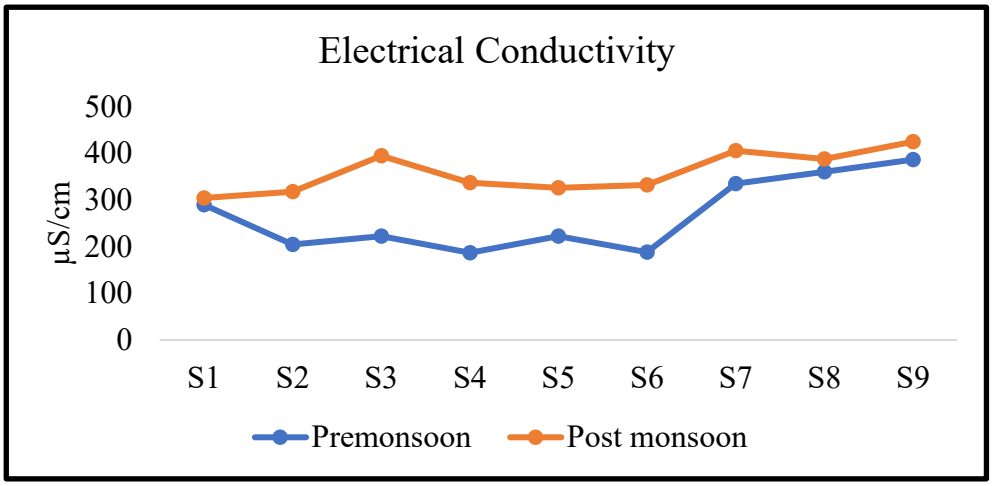


Fig. 5 Conductivity recorded during the study period

Total Dissolved Solids

Total dissolved solids (TDS) exhibited clear seasonal variation across the sampling sites. Pre-monsoon values were comparatively lower and showed moderate spatial fluctuations, with a gradual rise toward downstream sites and a peak around S_7. Post-monsoon TDS was consistently higher at all sites, indicating enhanced inputs from surface runoff. The elevated post-monsoon values found maximum at sites S_3, S_7, S_8 and S_9 reflects cumulative downstream enrichment of dissolved solids (Fig. 6).

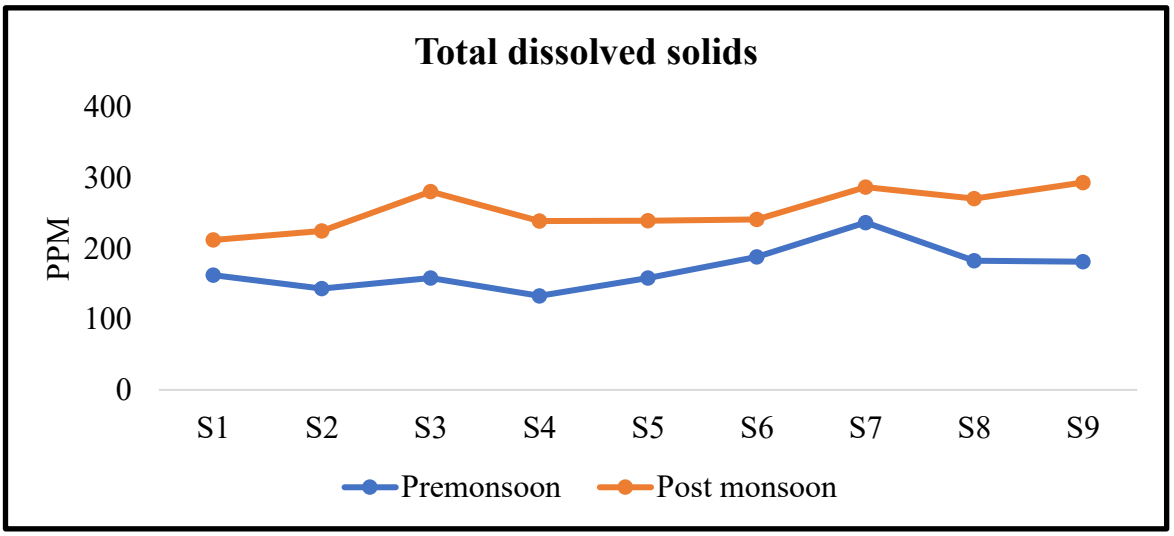


Fig. 6 Linear diagram representing comparative TDS value in pre and post-monsoon period

Salinity

During the pre-monsoon season, salinity values were relatively low and ranged from about 0.081 to 0.268 ppt, with a gradual increase toward the downstream sites and a sharp rise at S7, S8, and S9. In contrast, post-monsoon salinity ranged from nearly 0.01 to 0.17 ppt and was generally lower than pre-monsoon values at the downstream stations. At upstream sites (S_2 and S_3), post-monsoon salinity was slightly higher than pre-monsoon. However, from S_6 onward, pre-monsoon salinity exceeded post-monsoon values, particularly at S_7–S_9. Overall, the graph indicates dilution of salinity during the post-monsoon season and concentrated volume during the pre-monsoon period, especially in the lower river stretch (Fig. 7).

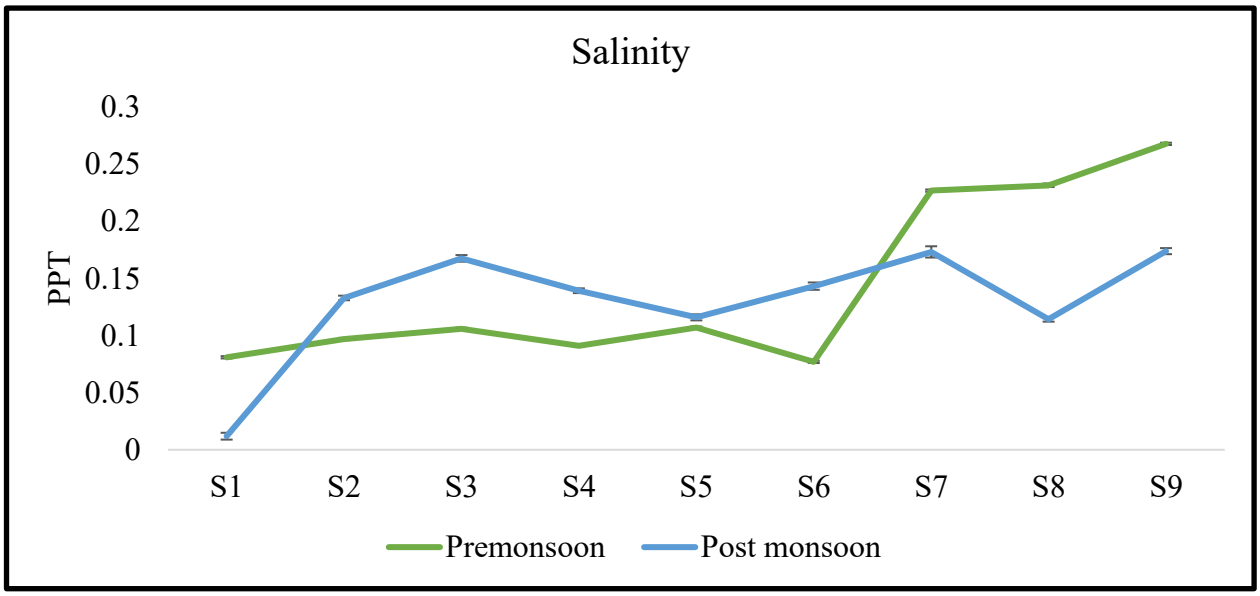


Fig. 7 Diagram represent salinity range recorded during pre-monsoon and post-monsoon period

Free Carbon Dioxide

Free CO_2 showed very limited spatial and seasonal occurrence along the river stretch. During the pre-monsoon period, free CO_2 was absent at all the sampling sites (S_1–S_9), indicating well-aerated conditions. In the post-monsoon season, free CO_2 was detected only at S6 and S7, with a volume of about 7.4 mg L^{-1} at S_6 and 6.1 mg L^{-1} at S_7 (Fig. 8). The appearance of free CO_2 at these two sites after the monsoon suggests the presence of organic matter pollution.

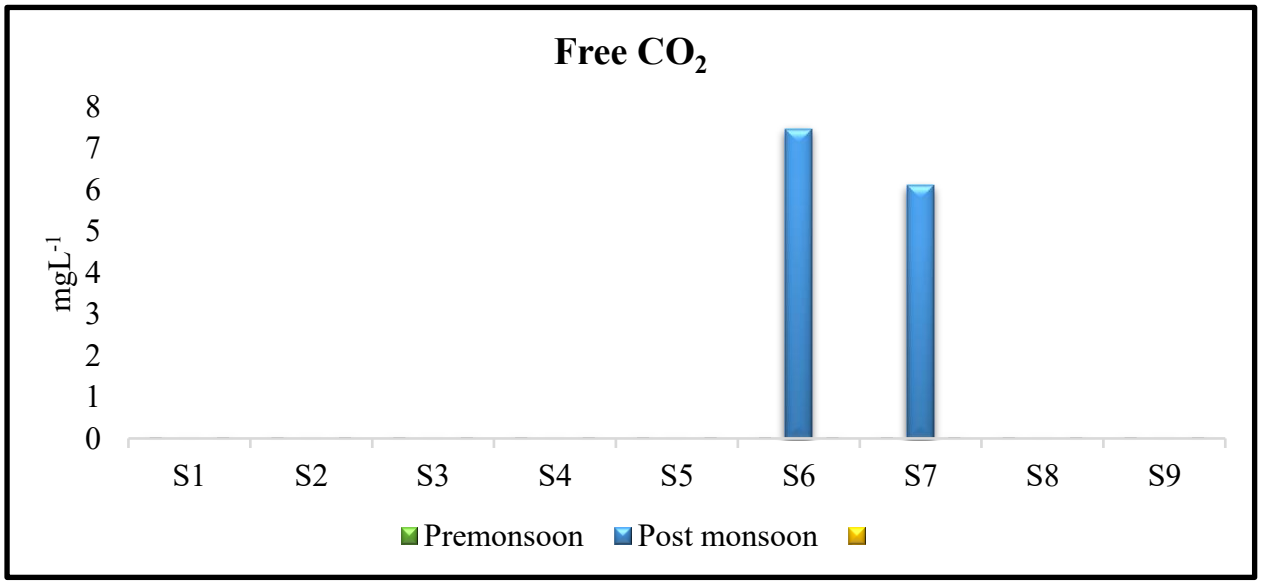


Fig. 8 Diagram showing free CO_2 value in both the seasons

Total Alkalinity

Alkalinity showed a clear difference between the two seasons across all sampling sites. In the pre-monsoon period, alkalinity values were comparatively lower, ranging roughly from 77 and 177.6 mg L^{-1}. Low values were found at S_2, S_4, S_5, S_6, and S_8, whereas S_1, S_3, S_7, and S_9 recorded relatively higher concentrations, indicating site-specific influences under low-flow conditions. During the post-monsoon season, alkalinity increased uniformly at all stations, with values lying in the range of about 133 to 152.6 mg L^{-1} (Fig. 9). Higher at S_7 and S_8 highlight

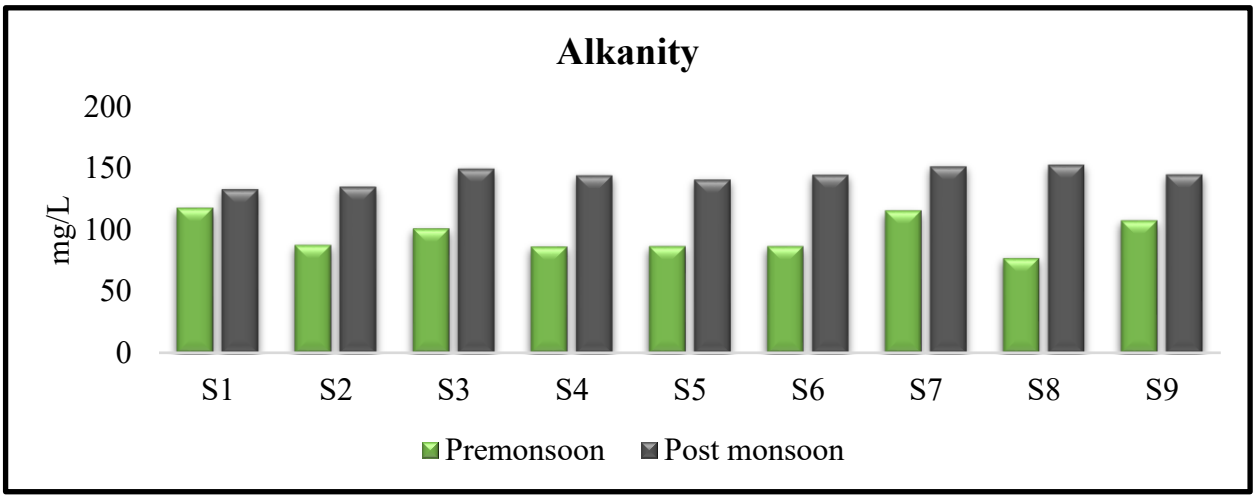


Fig. 9 Diagram representing site-wise total Alkalinity value recorded in both the seasons

stronger buffering conditions in the downstream stretch. This seasonal rise in alkalinity reflects the contribution of bicarbonates and carbonates through monsoon runoff. Overall, the post-monsoon period exhibits enhanced and more stable alkalinity compared to the pre-monsoon pattern.

Dissolved Oxygen (DO)

During the pre-monsoon period, DO concentrations were relatively higher at most stations, ranging from about 4.96 to 7.1 mg L^{-1}, with maximum values observed at S_1 (7.12 mg L^{-1}) and S_2 (7.12 mg L^{-1}). Slightly lower DO value during pre-monsoon season was recorded at S_3, S_7, and S_9 (Fig. 10). While during the post-monsoon season, DO values ranged from 5.16 to 7.19 mg L^{-1} and exhibited a mixed pattern. Higher post-monsoon DO was found at S_3 and S_7. Conversely, at stations such as S_1, S_2, S_6, and S_8, post-monsoon DO was marginally lower than pre-monsoon levels, likely reflecting enhanced organic load and microbial respiration. Overall,

the dissolved oxygen remained within a favourable range at all sites, with seasonal shifts influenced by flow conditions and organic inputs.

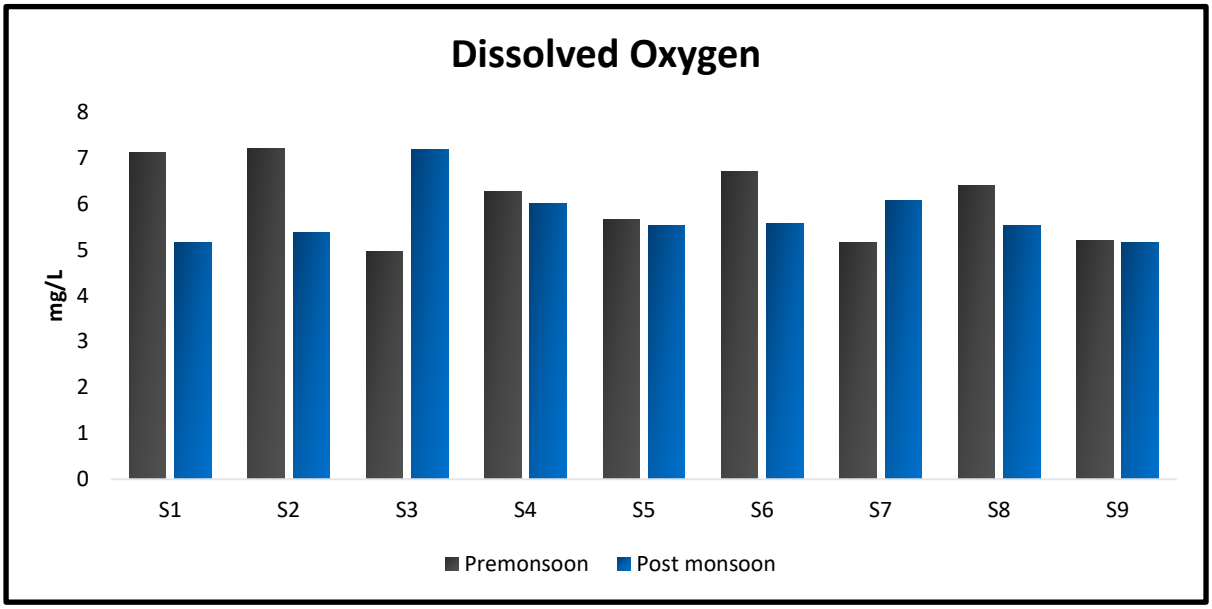


Fig. 10 Dissolved Oxygen (DO) variation during the study period

Total Hardness

Water hardness is an important water quality parameter influencing fish growth and is determined mainly by the concentration of divalent cations, particularly calcium and magnesium. Spatial and seasonal analysis of the Narmada River showed moderate variation in total hardness. During the pre-monsoon period, hardness ranged from about 68.26 to 108 mg L^{-1}, with lower values at S_2 and S_6 and relatively higher values at S_1, S_7, and S_9. During post-monsoon season hardness increased across all sites, ranging from approximately 115.33 to 148.66 mg L^{-1}, with peak values observed at S_3 and S_7 (Fig. 11).

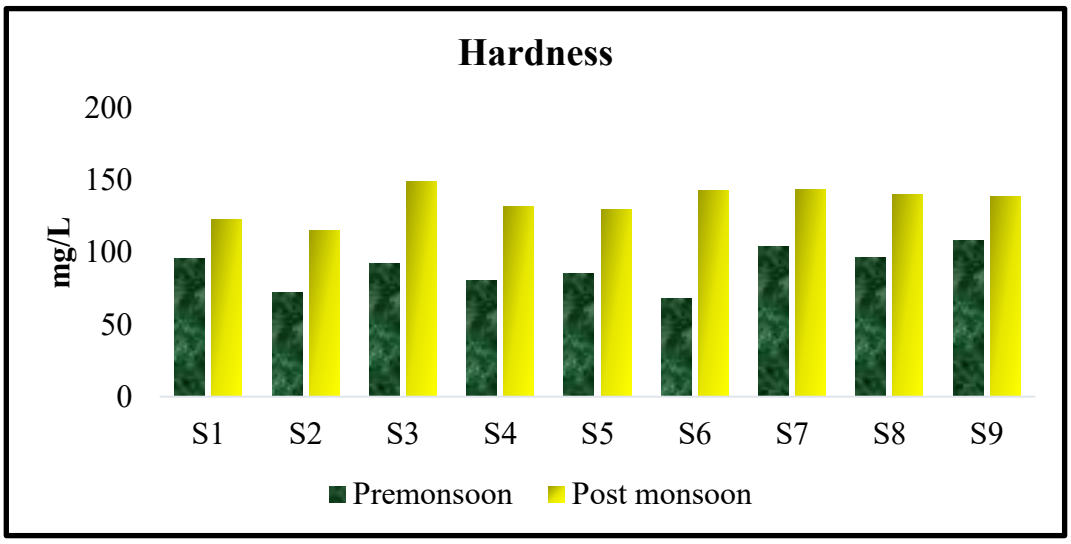


Fig. 11 Comparative total hardness during the study period

Nitrate -N

Nitrate (NO_3–N) is the most prevalent form of nitrogen present in soils and freshwater systems. It is naturally generated through nitrification process, and is readily used by phytoplankton. However, excessive concentrations of nitrate-N, can lead to eutrophication which can have adverse effects on water quality and aquatic organisms. Nitrate concentrations exhibited clear seasonal variation along the Narmada River. During the pre-monsoon period, nitrate levels were generally low, ranging from about 0.05 to 0.25 mg L^{-1}, with slightly higher values observed at S_2 and S_9. In contrast, during post-monsoon season nitrate-N content increased markedly at all sampling sites, varying from approximately 0.55 to 1.60 mg L^{-1}. The highest post-monsoon nitrate-N levels were recorded at S_3 and S_5 (Fig. 12).

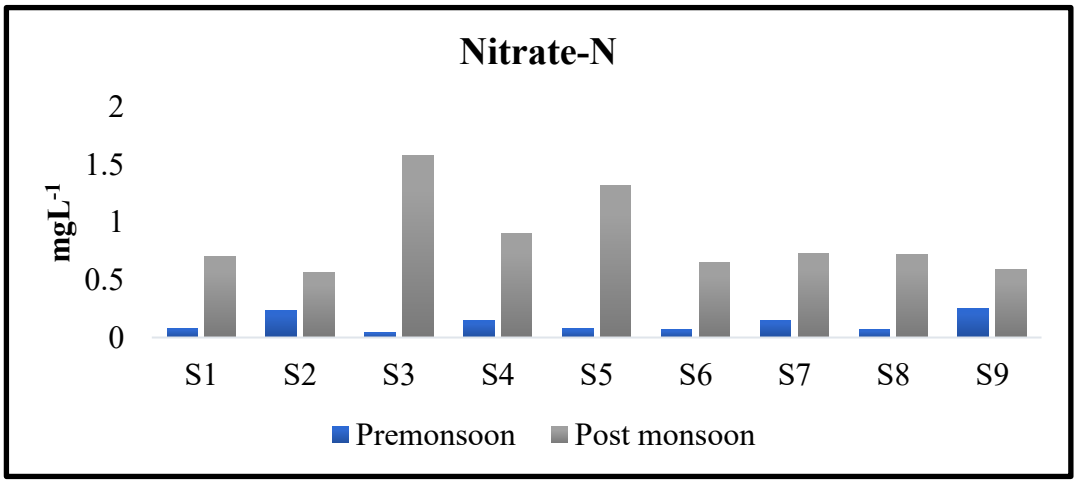


Fig. 12 Site-wise representation of Nitrate value recorded during the study

Silicate

The silicate concentration in the Narmada River showed clear spatial and seasonal variation. silicate levels during the pre-monsoon period ranged approximately from 7.7 to 11.8 mg L^{-1}, with lower values observed at sites such as S_4 and S_6 and higher concentrations at S_3 and S_9. In the post-monsoon season, silicate concentrations were consistently higher, ranging from about 10.53 to 12.82 mg L^{-1} across the sampling sites (Fig. 13). Relatively higher values at downstream sites indicate cumulative enrichment along the river stretch, while lower volume was recorded during pre-monsoon season which reflects less water flow and dilution.

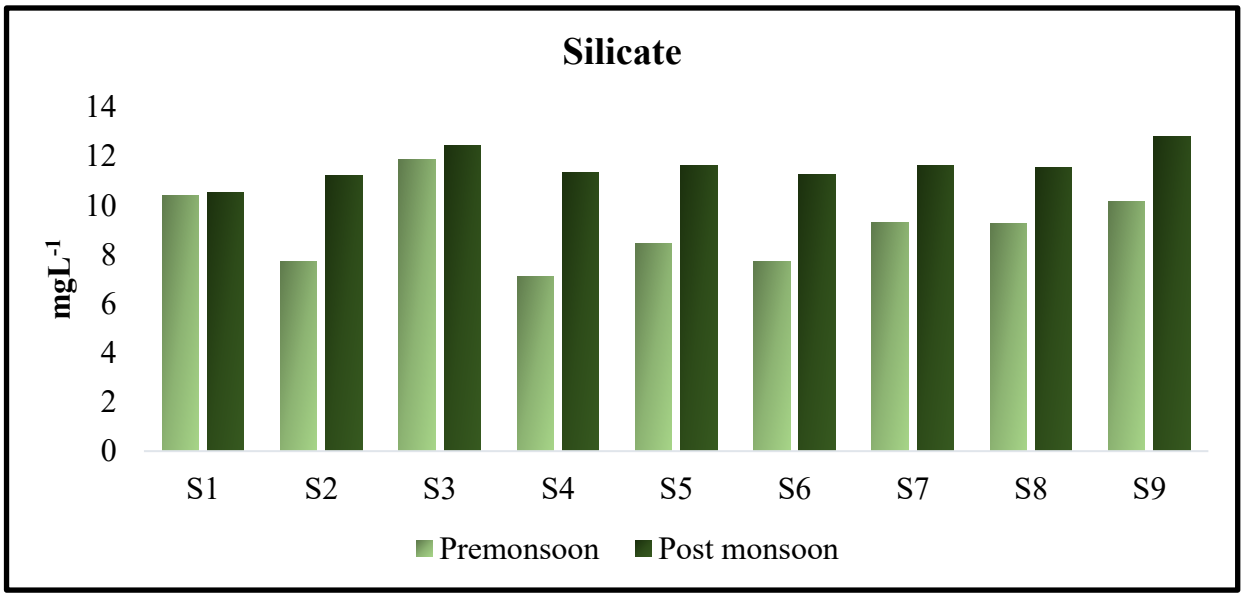


Fig.13 Figure presenting silicate concentration during the study period.

Chlorinity

Chlorinity levels (mgL^{-1}) measured across nine sampling stations (S_1 to S_9) during the pre-monsoon and post monsoon periods. Post monsoon chlorinity is generally higher than pre-monsoon chlorinity across most stations (S_2 to S_9), with levels ranging from about 17.33 mgL^{-1} to 49.73 mgL^{-1} (Fig. 14). In pre-monsoon found maximum 22.99 mgL^{-1} at Station S_9. Station S_1, where the Post monsoon level (6.46 mgL^{-1}) is notably lower than its Pre-monsoon level (16 mgL^{-1}).

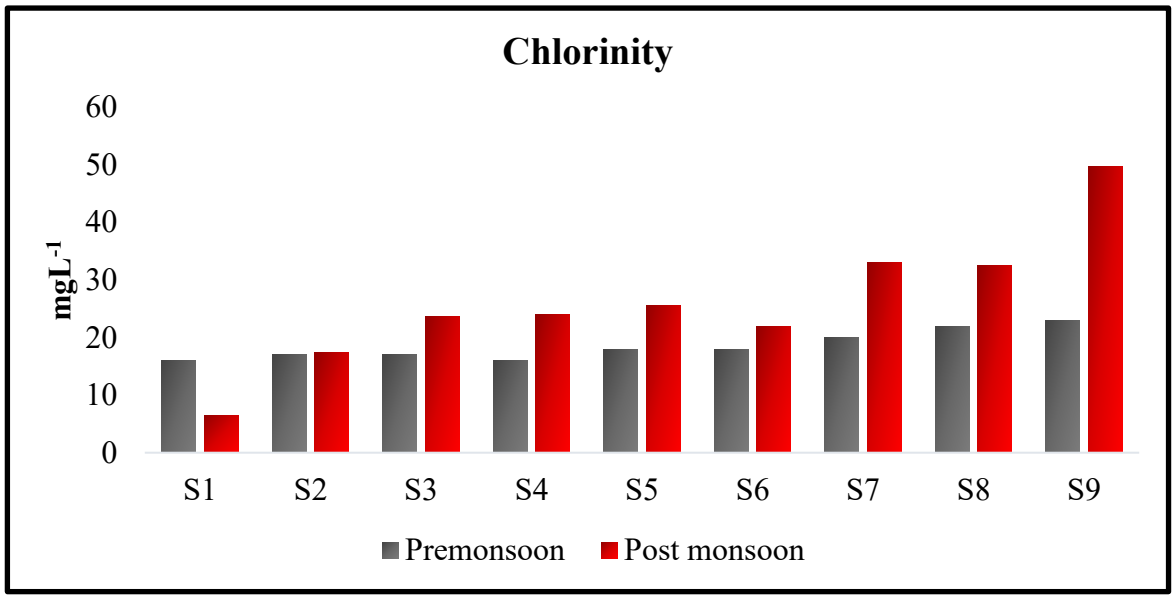


Fig. 14 Chlorinity range recorded in all the sites during the study period

Biological oxygen demand (BOD)

Biological oxygen demand (BOD) showed variation across the sampling sites (S_1–S_9). In general, pre-monsoon BOD values are higher than post-monsoon, indicating greater organic load and reduced dilution during the low-flow period. Sites S_4, S_6, and S_7 record notably high pre-monsoon BOD. During the post-monsoon season, BOD values decline at most sites (S_1, S_2, S_5), likely due to increased river discharge and dilution. However, S_3 and S_7 showed comparatively higher post-monsoon BOD values, which may be attributed to runoff-driven inputs of organic matter after rainfall. Overall, the BOD levels mostly remain within a moderate range suggesting low organic pollution (Fig.15).

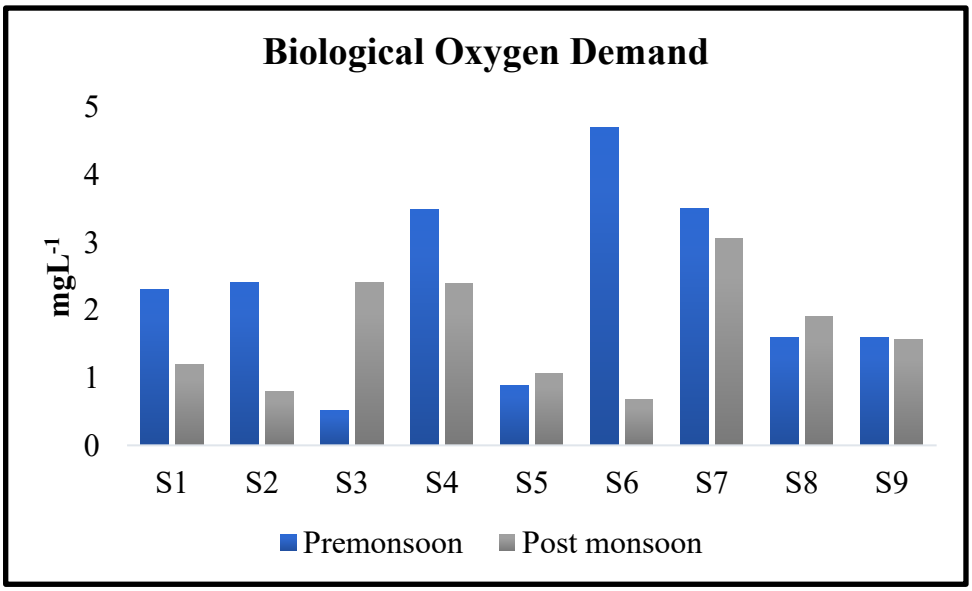


Fig. 15 Diagram showing BOD value recorded during the study period.

Chlorophyll

Across all sites (S_1–S_9), chlorophyll pigments show lower concentrations during the pre-monsoon and higher concentrations during the post-monsoon (Fig. 16). For chlorophyll-a, pre-monsoon values remain low, ranging approximately from 0.069 mg L^{-1} at S1 to 0.26 mg L^{-1} at S_3.

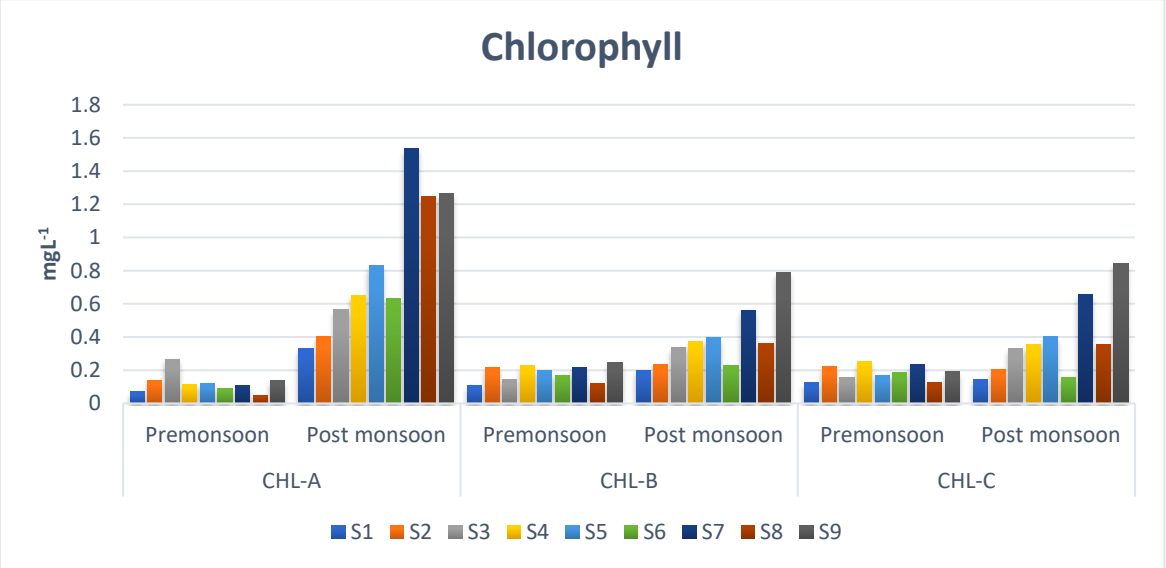


Fig. 16 Comparative value of chlorophyll concentration recorded during the study period.

In the post-monsoon, chlorophyll-a increases markedly, with values rising to about 0.33 mg L^{-1} at S1, 0.56 mg L^{-1} at S3, 0.63 mg L^{-1} at S6, and reaching the highest levels at S_7 (1.54 mg L^{-1}), S_8 (1.245mg L^{-1}), and S_9 (1.264 mg L^{-1}). Chlorophyll-b shows pre-monsoon values between 0.10–0.244 mg L^{-1}, with the lowest at S_1 and relatively higher values at S_4–S_6. During the post-monsoon, chlorophyll-b increases across all sites, from about 0.20 mg L^{-1} at S_1 to 0.22 mg L^{-1} at S_6, with a distinct peak at S_9 (0.789 mg L^{-1}). For chlorophyll-c, pre-monsoon concentrations are consistently low, varying from 0.128 mg L^{-1} at S_1 to 0.25 mg L^{-1} at S_4. Post-monsoon values show an increasing toward downstream, starting from 0.14 mg L^{-1} at S_1, 0.405 mg L^{-1} at S_5, and attaining the highest concentrations at S_9 (0.85 mg L^{-1}). Overall, the trend indicates a site-wise increase in chlorophyll-a, b, and c from pre-monsoon to post-monsoon, with the most pronounced increases consistently observed at S7, S8, and S9.

Available and Total phosphorus

During the pre-monsoon season, available phosphorus remained very low at all sites, ranging from 0.012–0.033 mg L^{-1}, with slightly higher values at S_2 and S_3, while S_5 recorded the lowest

concentration. In contrast, total phosphorus during the same period showed comparatively higher values, generally between 0.20–0.33 mg L^{-1}, except at S_6, which exhibited a markedly elevated concentration (3.03 mg L^{-1}), clearly standing out from all other sites. In the post-monsoon season, available phosphorus increased substantially at most sites, indicating enhanced bioavailable fractions.

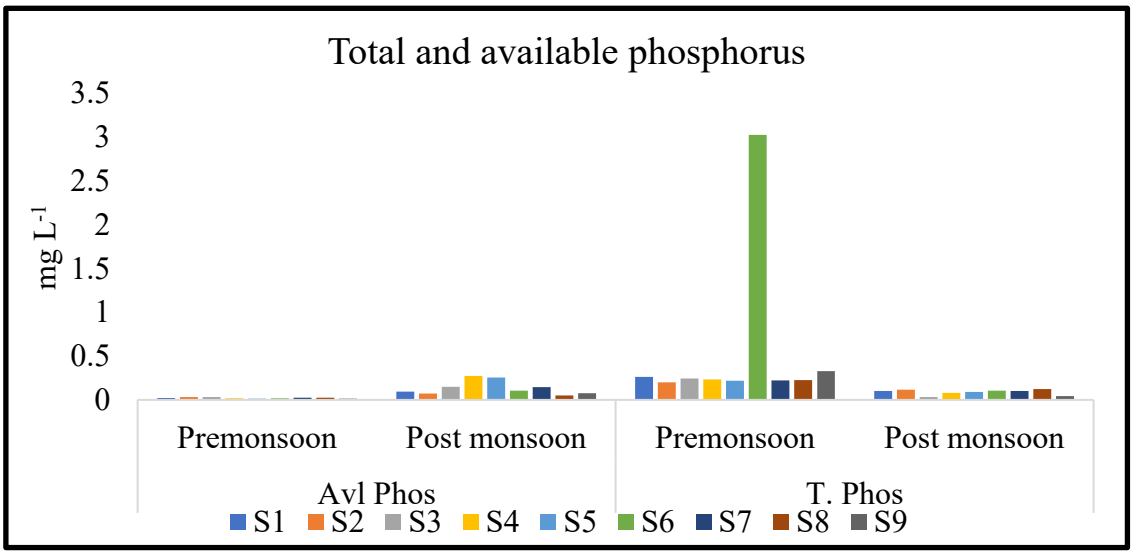


Fig.17 Available total phosphate recorded during pre-monsoon and post-monsoon season

The highest post-monsoon available phosphorus was recorded at S4 (0.273 mg L^{-1}) and S_5 (0.256 mg L^{-1}), followed by S_3 and S_7, while S_8 showed the lowest value (0.052 mg L^{-1}). Conversely, total phosphorus declined sharply at all sites during the post-monsoon, falling within a narrow range of 0.034–0.125 mg L^{-1}, with the lowest value at S_3 and relatively higher values at S8 and S2 (Fig. 17). Overall, the result indicate an opposite seasonal trend between total and available phosphorus, with higher total phosphorus during the pre-monsoon and a notable increase in available phosphorus during the post-monsoon, alongside a general reduction in total phosphorus across most sites.

Total Nitrogen

Post-monsoon total nitrogen in the Narmada River varied across sites S_1–S_9, ranging from about 0.06 to 0.115 mg/L. The highest concentrations occurred at S_1, S_3, and S_6, while the lowest was recorded at S_7, followed by S_8. Overall, the trend shows noticeable spatial variability, with moderate to higher values at upstream and midstream sites and comparatively lower levels at downstream locations. The detailed value of all the water quality parameters is depicted in the below Table. 5

Table 5. Water quality parameter of pre and post monsoon season

S. no	Parameters	Garudeshwar	Poicha	Sisodra	Lilod	Jhanor	Shuklatirth	Bharuch	Sakkarpura	Bhadbhut
1.	Temperature (^{O}C)	25.53±0.15	27.03±0.05	26.33±0.05	27.03±0.05	27.23±0.05	26.03±0.05	26.2±0.10	27.9±0.10	28.03±0.15
		27±0.00	27.03±0.06	25±0.00	26.06±0.11	23±0.00	24.03±0.06	24±0.00	25±0.00	25±0.00
2.	Water flow (m/s)	1.30±0.01	1.10±0.01	0.76±0.01	0.42±0.00	0.32±0.01	0.36±0.01	0.25±0.00	0.62±0.00	0.55±0.01
		0.39±0.00	0.81±0.00	0.38±0.00	0.18±0.00	0.18±0.00	0.27±0.00	0.44±0.00	1.07±0.00	0.47±0.00
3.	Depth (m)	3.5±0.00	3.26±0.00	3.9±0.00	9.6±0.00	5.46±0.00	4.7±0.00	11.46±0.00	5.2±0.00	7.76±0.00
		0.96±0.00	3.86±0.00	6.72±0.00	6.85±0.00	6.86±0.00	3.30±0.00	4.41±0.00	3.28±0.00	4.67±0.00
4.	Transparency (cm)	6.8±0.00	9.7±0.00	8.2±0.00	8.5±0.00	10.3±0.00	11.1±0.00	7.6±0.00	8.1±0.00	7.9±0.00
5.	pH	8.25±0.01	8.37±0.00	8.31±0.00	8.14±0.02	8.31±0.00	8.25±0.02	8.12±0.01	8.24±0.01	8.11±0.01
		8.36±0.05	8.30±0.06	8.27±0.06	8.62±0.04	8.5±0.04	8.6±0.05	8.7±0.00	8.60±0.10	8.60±0.11
6.	EC (µS/cm)	289.03±0.05	204.1±0.10	222.1±0.10	186.66±0.30	222.16±0.47	188.2±0.20	334.53±0.50	360.06±0.40	386.06±0.81
		212±2.64	225±4.58	280.67±4.50	238.66±2.08	239.33±4.50	241±5.56	286.67±0.58	270.33±3.78	293.33±5.50
7.	TDS (mg/L)	162.13±0.15	143.37±1.27	158.3±0.26	133.03±0.05	158.03±0.55	188.23±0.25	236.73±0.74	182.63±0.60	181.27±0.30
		212±2.64	225±4.58	280.66±4.50	238.33±2.08	239.33±4.50	241±5.56	286.66±0.58	270.33±3.78	293.33±5.50
8.	Salinity (ppt)	0.08±0.00	0.10±0.00	0.11±0.00	0.09±0.00	0.10±0.00	0.08±0.00	0.23±0.00	0.23±0.00	0.27±0.00
		0.01±0.00	0.13±0.00	0.17±0.00	0.14±0.00	0.12±0.00	0.14±0.00	0.17±0.00	0.11±0.00	0.17±0.00
9.	Dissolve oxygen (mg/L)	7.12±0.02	7.20±0.01	4.96±0.02	6.26±0.03	5.66±0.02	6.70±0.01	5.15±0.02	6.40±0.03	5.21±0.01
		5.16±0.04	5.36±0.02	7.19±0.04	6±0.05	5.53±0.04	5.57±0.02	6.06±0.04	5.53±0.05	5.16±0.02
10.	Free CO_2 (mg/L)	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00
		0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	7.46±0.83	6.10±0.17	0.00±0.00	0.00±0.00

11.	Total alkalinity (mg/L)	117.66±0.57	87.66±2.51	101.00±1.00	86.33±2.51	86.66±2.30	86.66±2.51	115.33±1.15	77.00±1.73	107.33±2.08
		133±2.64	135±5.19	149.67±3.21	144±3	140.66±2.30	144.66±4.93	151.33±1.52	152.67±1.15	145±5.56
12.	Hardness (mg/L)	95.83±0.76	72.07±0.30	92.10±0.36	80.17±0.76	85.4±4.85	68.27±0.25	103.97±0.45	96.10±0.36	108±0.20
		122.66±3.78	115.33±3.05	148.66±3.21	131.66±3.51	129.66±1.52	143±4.35	143.66±0.57	139.67±2.08	138.67±1.52
13.	Nitrate-N(mg/L)	0.08±0.00	0.24±0.01	0.05±0.00	0.14±0.00	0.07±0.00	0.07±0.00	0.15±0.00	0.07±0.00	0.25±0.00
		0.70±0.00	0.56±0.00	1.57±0.00	0.90±0.00	1.31±0.00	0.65±0.00	0.72±0.00	0.72±0.00	0.60±0.00
14.	Silicate (mg/L)	10.41±0.02	7.74±0.02	11.85±0.00	7.12±0.00	8.45±0.00	7.74±0.00	9.30±0.00	9.25±0.01	10.17±0.00
		10.53±0.03	11.24±0.02	12.44±0.01	11.33±0.06	11.61±0.04	11.25±0.05	11.62±0.03	11.54±0.05	12.82±0.05
15.	Chlorinity (mg/L)	16.01±0.01	17.00±0.00	17.00±0.01	16.00±0.00	18.00±0.00	18.00±0.00	20.00±0.01	22.00±0.02	23.00±0.01
		6.46±0.06	17.33±0.42	23.66±0.58	23.96±0.87	25.6±1.15	21.9±1.01	33.03±2.43	32.5±0.50	49.73±0.30
16.	Avl. Phosphate (mg/L)	0.02±0.00	0.03±0.00	0.03±0.00	0.02±0.00	0.01±0.00	0.02±0.00	0.03±0.00	0.03±0.00	0.02±0.00
		0.09±0.00	0.07±0.00	0.15±0.00	0.27±0.00	0.25±0.00	0.10±0.00	0.14±0.00	0.05±0.00	0.07±0.00
17.	BOD (mg/L)	2.31±0.02	2.40±0.01	0.52±0.00	3.48±0.02	0.88±0.01	4.70±0.02	3.51±0.01	1.60±0.02	1.60±0.01
		1.20±0.00	0.8±0.00	2.40±0.08	2.40±0.00	1.06±0.15	0.67±0.15	3.06±0.15	1.90±0.10	1.56±0.06
18.	Chlorophyll- *a* (mg/m^3)	0.07±0.00	0.14±0.00	0.27±0.00	0.12±0.00	0.12±0.00	0.09±0.00	0.12±0.00	0.05±0.00	0.14±0.00
		0.33±0.00	0.40±0.00	0.56±0.00	0.65±0.00	0.83±0.00	0.63±0.00	1.53±0.00	1.24±0.00	1.26±0.00
10.	Chlorophyll- *b* (mg/m^3)	0.11±0.00	0.22±0.00	0.14±0.00	0.23±0.00	0.20±0.00	0.17±0.00	0.22±0.00	0.12±0.00	0.25±0.00
		0.20±0.00	0.23±0.00	0.33±0.00	0.37±0.00	0.39±0.00	0.22±0.00	0.56±0.00	0.36±0.00	0.78±0.00
20.	Chlorophyll-*c* (mg/m^3)	0.12±0.00	0.22±0.00	0.16±0.00	0.25±0.00	0.17±0.00	0.19±0.00	0.24±0.00	0.13±0.00	0.19±0.00
		0.14±0.00	0.20±0.00	0.33±0.00	0.35±0.00	0.40±0.00	0.15±0.00	0.65±0.00	0.35±0.00	0.84±0.00
21.	Total Nitrogen (mg/L) (Postmonsoon)	0.12±0.00	0.08±0.00	0.11±0.00	0.08±0.00	0.10±0.00	0.11±0.00	0.06±0.00	0.07±0.01	0.09±0.01

Sediment quality Parameters

pH

The sediment pH of the Narmada River across the nine sampling sites (S_1–S_9) remained in the alkaline range during both seasons. In the pre-monsoon, sediment pH showed a gradual increase from S_1 (7.6) to S_7 (8.59), followed by a slight decrease at S_8 and a marginal rise at S_9. During the post-monsoon, sediment pH values were generally higher, ranging from about 7.6 at S_4 to nearly 8.72 at S_9. Higher post-monsoon pH was observed at all the sampling sites, with noticeable higher value at S1, S_6, S_7, and S_9, while comparatively lower values at S_3, S_2 and S_4. Overall, the result indicates clear spatial variation in sediment pH along the Narmada River, with consistently alkaline conditions in both pre- and post-monsoon periods (Fig 18).

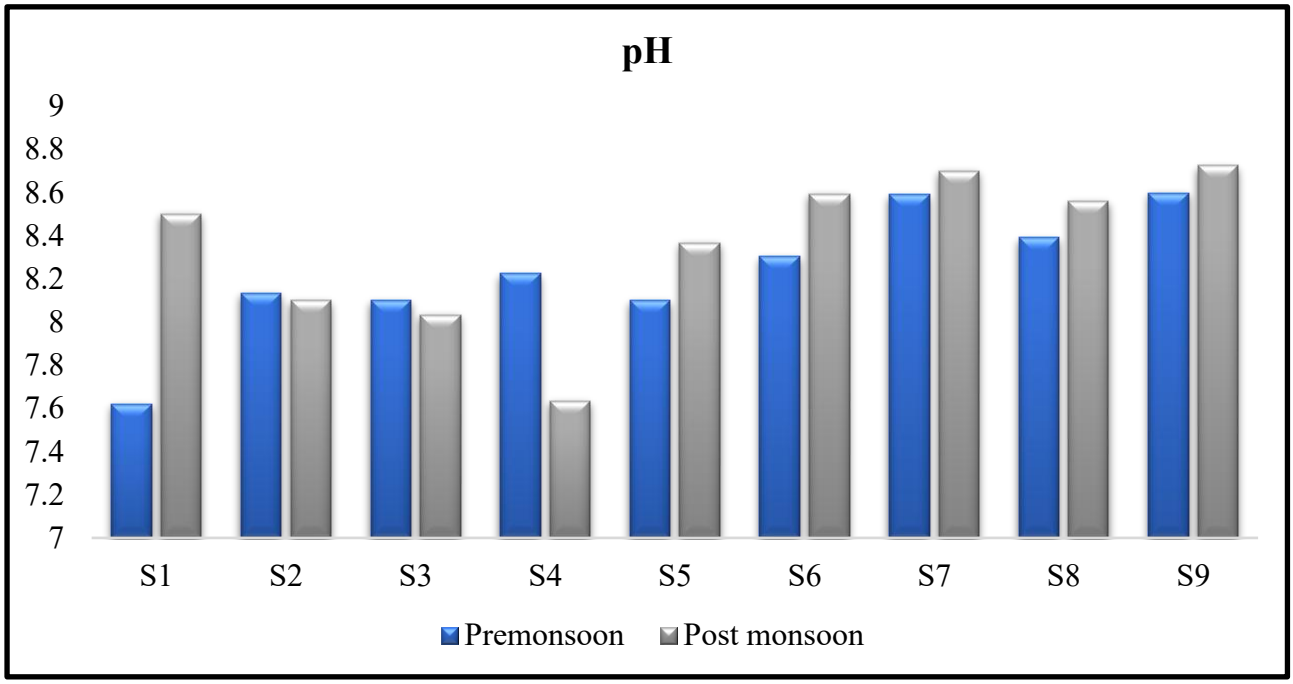


Fig. 18 Diagrammatic representation of comparative pH value recorded during the study period

Electrical Conductivity

Electrical conductivity (EC) of soil is an indicator of the total soluble salt content present in the soil matrix. It is widely used to assess soil salinity status. Electrical conductivity (EC) of Narmada River sediment exhibited marked spatial and seasonal variation across the sampling sites. During the pre-monsoon period, sediment EC ranged from about 69 µS/cm at S_2 to 391 µS/cm at S_3, with intermediate values at S_4 and S_5, and relatively lower value at S_6 and S_7. In the post-monsoon season, sediment EC increased at all sites, varying from 25 µS/cm at S_2 to a

maximum of 286 µS/cm at S_3, while S_7 and S_8 showed comparatively lower conductivity levels (Fig. 19).

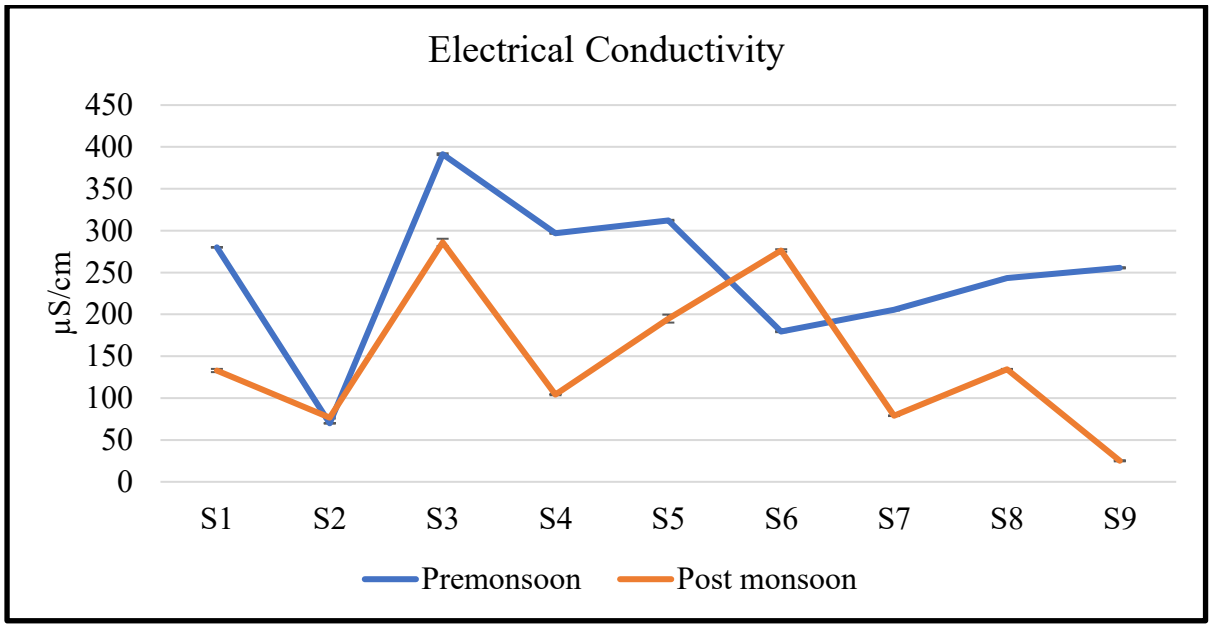


Fig. 19 Conductivity range recorded in sampling stations during the study period.

Organic Carbon

During the pre-monsoon season, organic carbon content was highest at S_1 (1.28%), indicating comparatively richer carbon content at this site. Lower values were observed at S_2 (0.37%), while moderate to relatively higher concentrations were recorded at S_3 (0.85%), S_4 (0.94%), and S_5 (0.88%). Further downstream, organic carbon showed moderate levels at S_6 (0.65%) and

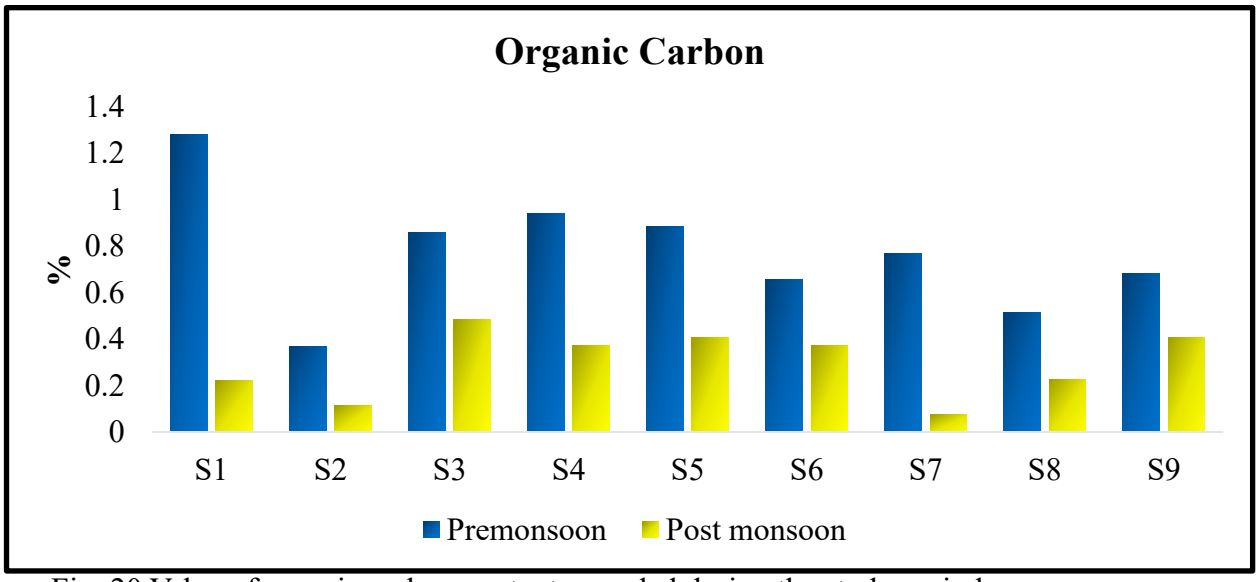


Fig. 20 Value of organic carbon content recorded during the study period.

S_7 (0.77%), followed by a decline at S_8 (0.51%) and a slight increase again at S_9 (0.68%). In contrast, the post-monsoon period showed consistently lower organic carbon percentages across all sites. Values ranged from 0.07% at S_7 (lowest) to 0.48% at S_3 (highest). Moderate concentrations were observed at S_4, S_5, S_6, and S_9, while comparatively lower values occurred at S_1, S_2, and S_8. Overall, organic carbon content was notably reduced during the post-monsoon season across the river stretch (Fig. 20).

Free calcium carbonate

Free calcium carbonate ($CaCO_3$) content in the sediment showed significant seasonal variation during the study period. During the pre-monsoon season, less free $CaCO_3$ concentration was recorded across the sites, ranging from about 3.0 mg/L at S_2 to 9.03 mg/L at S_8. Site S_1 exhibited lower values, while moderate concentrations were observed at S_3, S_4, S_5, and S_6. A relative increase was observed at S_7 and S_8, followed by S_9 with slight reduction in value. In the post-

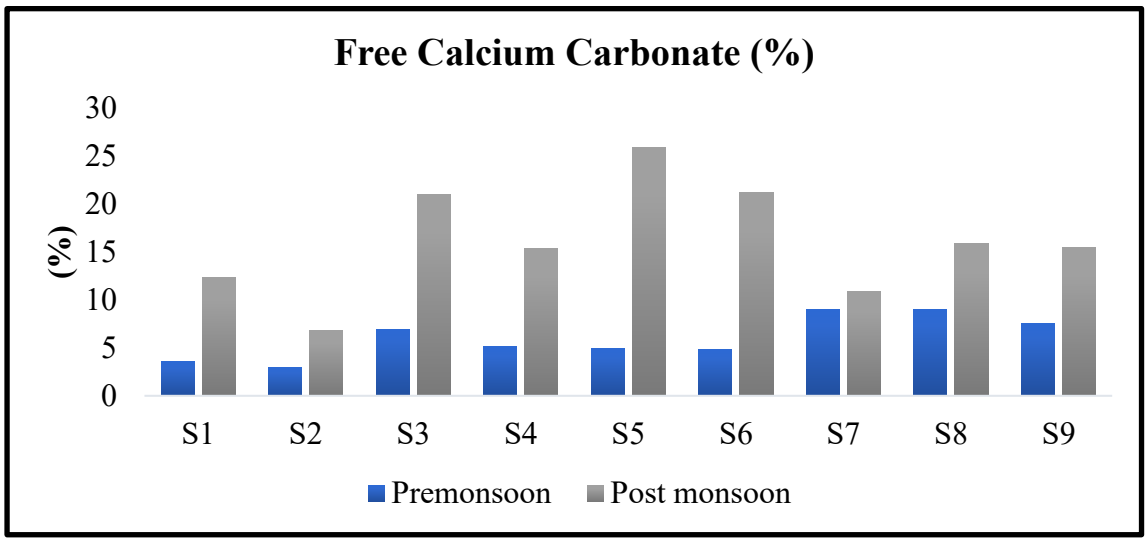


Fig. 21 Value of free calcium carbonate in all the sampling sites recorded during the study period.

monsoon period, free calcium carbonate levels increased markedly at all sampling locations. Values ranged from 6.8 mg/L at S_2 to a maximum of 25.8 mg/L at S_5. Elevated concentrations were also recorded at S_3 (21 mg/L) and S_6 (21.16 mg/L), while moderate levels were observed at S_4, S_8, and S_9. Comparatively lower but increased values were noted at S_1 and S_7, indicating overall enrichment of free calcium carbonate in sediments during the post-monsoon season (Fig. 21).

Total nitrogen

During the pre-monsoon season, total nitrogen ranged from about 0.025% at S_2 (lowest) to 0.14% at S_1 (highest). Moderate concentrations were observed at S_3 (0.09%) and S_5 (0.10%), while relatively lower values occurred at S_4, S_6, S_7, and S_9, indicating variability along the river stretch. In the post-monsoon period, total nitrogen levels increased across all sampling sites. Values varied from 0.075% at S_2 to a maximum of 0.23% at S_3, with consistently elevated concentrations at S_5, S_6, S_8, and S_9. Sites S_1, S_4, and S_7 showed moderate levels around 0.10% (Fig. 22).

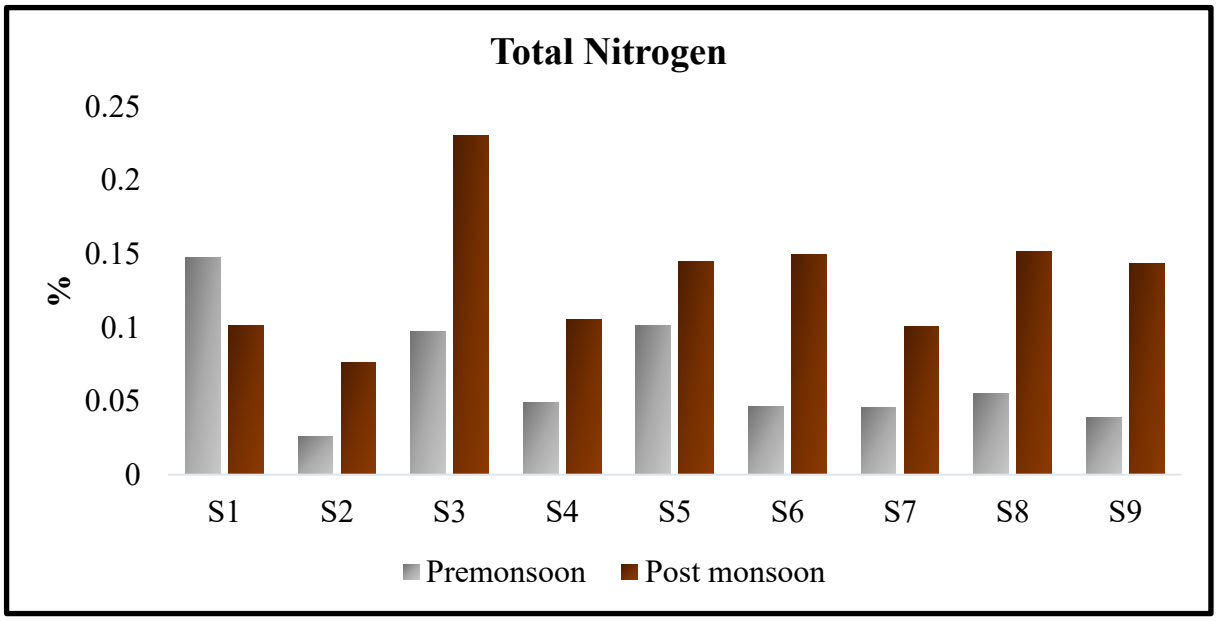


Fig. 22 Value of total nitrogen of sediment recorded during the study period.

Available Nitrogen

Available nitrogen in the sediment of the Narmada River showed pronounced spatial variation and a strong seasonal contrast between pre- and post-monsoon periods. During the pre-monsoon season, available nitrogen remained relatively low across all sites, ranging from about 4.4 mg/100 g to 9.0 mg/100 g. Moderate values were recorded at S_1 and S_3, while comparatively lower concentrations were observed at S_4, S_7, S_8, and S_9, indicating limited nitrogen availability before the monsoon. In contrast, the post-monsoon period exhibited substantially higher available nitrogen levels at all sampling locations. Values ranged from 23 mg/100 g at S_4 to a maximum of 40 mg/100 g at S_8. Elevated concentrations were also noted at S_1, S_3, S_5, and S_6,

while relatively lower but still increased values occurred at S_2, S_7, and S_9, reflecting overall enrichment of sediment available nitrogen following the monsoon (Fig. 23).

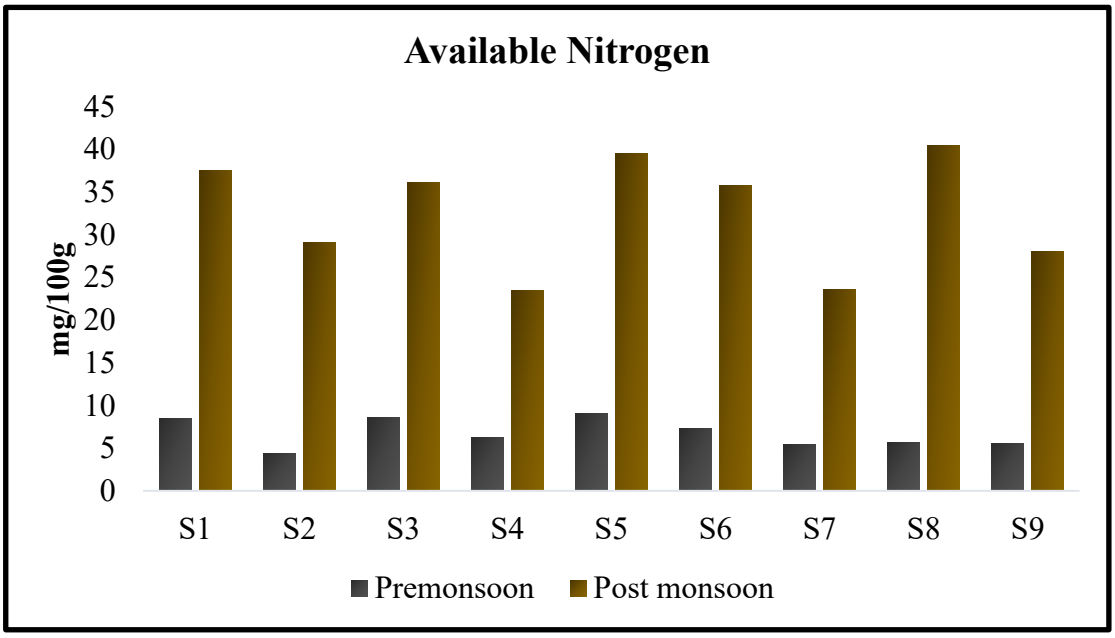


Fig.23 Available nitrogen of sediment recorded during the study period.

Available &Total Phosphorus

Phosphorus is a key nutrient in riverine sediments, playing a crucial role in regulating primary productivity, nutrient cycling, and overall ecosystem functioning. Sediment-bound phosphorus acts as both a sink and a potential source to the overlying water column, thereby influencing trophic status of aquatic systems. During the pre-monsoon period, the highest TP value was observed at S_1 (375 mg/kg), followed by S_2 and S_4. Sites S_3, S_5, and S_6 recorded comparable concentrations ranging from 295 to 305 mg/kg, whereas relatively lower values were noted at S7 (≈275 mg/kg) and S8 (≈220 mg/kg). In the post-monsoon season, TP concentrations declined at several locations. A noticeable reduction was recorded at S1 (315 mg/kg) and a pronounced decrease at S_5 (192.48 mg/kg). The lowest post-monsoon TP value was observed at S_5 (Fig. 24). Overall, the sediment TP levels indicate that pre-monsoon concentrations were higher than post-monsoon values at most sites.

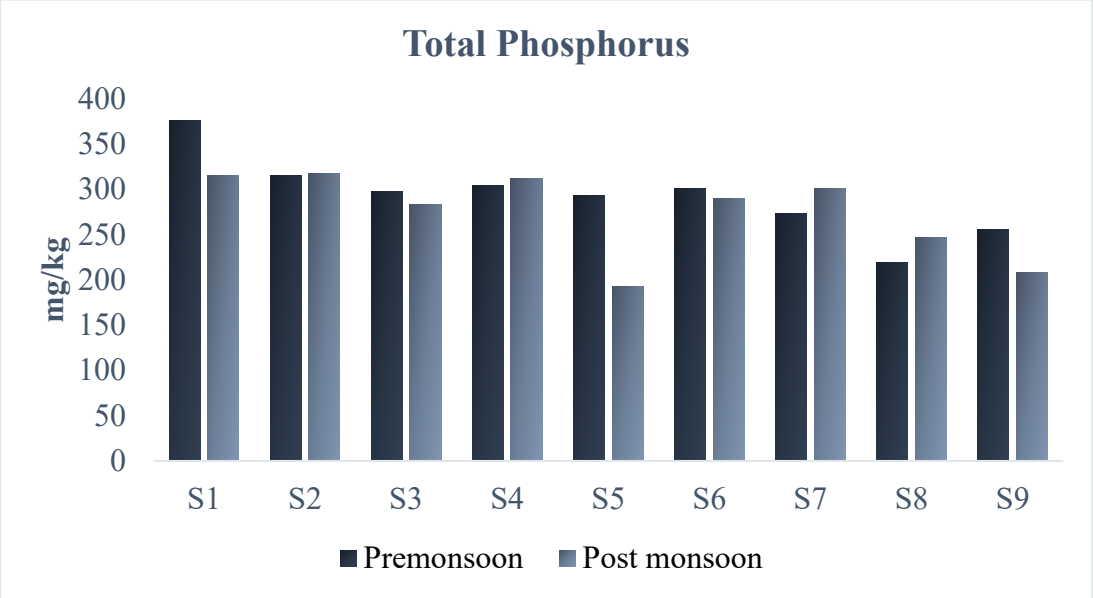


Fig. 24 Total phosphorous value recorded both in pre- and post-monsoon period

Available Phosphorus

Pre-monsoon concentrations were consistently higher at all sites (3.5–5.0 mg/L), with maximum values at S_1 and S_4, while relatively lower levels were observed at S_5. In contrast, post-monsoon available phosphorus declined sharply across all sites (0.3–1.2 mg/L), with the lowest value at S_3 and comparatively higher levels at S_1, S_7, and S_8 (Fig. 25).

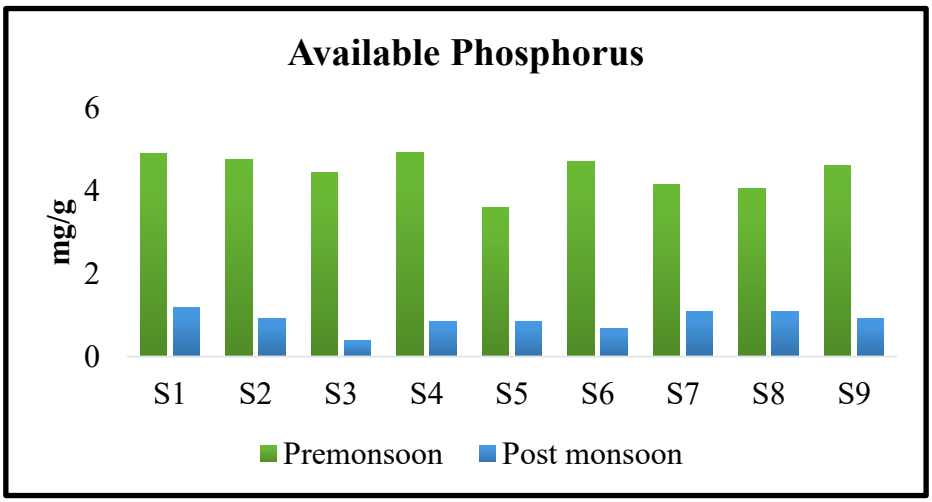


Fig. 25 Comparative value of available phosphorus recorded during the study period.

Overall, the data indicate a clear dominance of higher bioavailable phosphorus during the pre-monsoon season, followed by a substantial reduction in the post-monsoon period.

Soil Texture

During the pre-monsoon season, sand content ranged from 50–95%, with the highest proportion at S_2 (95%), followed by S_4 (70%) and S_5 (65%). Silt varied between 5–35%, being lowest at S_2 (5%) and highest at S_3 (35%), while clay content remained relatively low (0–20%), with maximum values at S_8 and S_9 (20%). In the post-monsoon season, sand content showed notable redistribution, ranging from 40–85%. Very high sand percentages were observed at S_1 and S_7 (85%), whereas lower values occurred at S_3 (40%) and S_4 and S_6 (50%). Silt content increased at several sites, ranging from 10–55%, with the highest value at S_5 (55%), followed by S_4 (45%) and S_3 and S6 (40%). Clay content generally increased during the post-monsoon, particularly at S_3 and S_5 (20%), while S_1 showed complete absence of clay (0%) (Fig.26). Overall, the sediment texture across the study sites remained sand-dominated, with a post-monsoon increase in silt and clay fractions at several locations, indicating seasonal redistribution of finer particles along the river stretch.

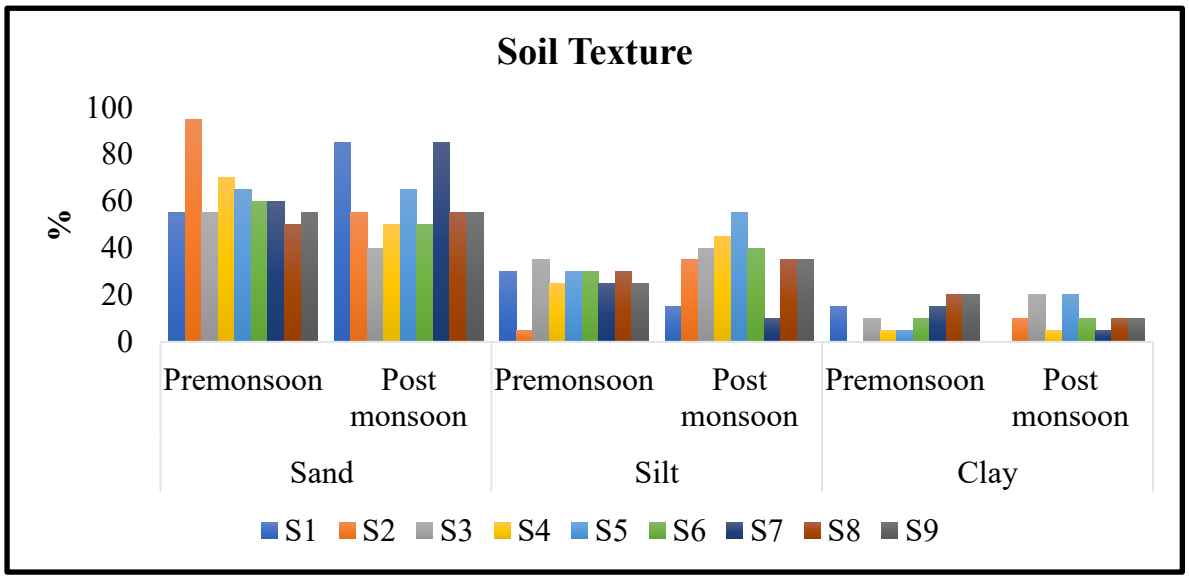


Fig. 26 Graphical representation of soil texture pattern (%) of selected sampling stations.

Plankton Dynamics

Phytoplankton dynamics

A total of six phytoplankton taxa were observed from the downstream stretch of the Sardar Sarovar Dam (SSD) on the Narmada River during the pre-monsoon study from nine different sampling stations. Among all the recorded phytoplankton groups, *Pediastrum simplex* was found to be the most abundant. The other species recorded included *Closterium* sp., *Coscinodiscus* sp., *Spirogyra* sp., *Ceratium* sp., and *Fragilaria* sp. A total of five phytoplankton taxa were observed during post-monsoon period. Among the recorded taxa, *Pediastrum* sp. exhibited the highest cell density (1300 cells/ml), indicating its dominance and strong adaptability under post-monsoon environmental conditions. *Eudorina* sp. was also recorded with a cell density of 200 cells ml^{-1}. Other phytoplankton taxa observed during the post-monsoon season included *Staurastrum sp*., *Spirogyra sp*., and *Coelastrum sp.*, reflecting a diverse phytoplankton community structure during this period. Phytoplankton observed during the pre- and post-monsoon seasons are shown in Annexure 1.

Zooplankton dynamics

Zooplankton diversity in the downstream stretch of the Sardar Sarovar Dam (SSD) on the Narmada River was comparatively low during the study period. A total of three zooplankton taxa were recorded, and their overall density remained very low across the sampling stations. During the pre-monsoon season, the zooplankton community was mainly represented by copepods, with *Mesocyclops* being the dominant form observed. In contrast, the post-monsoon season showed a slight change in species composition, with the occurrence of *Keratella sp.* (Rotifera) and *Cyclops sp.* The low abundance and limited diversity of zooplankton during both seasons indicate a sparse zooplankton community structure in the study area. Phytoplankton observed during the pre- and post-monsoon seasons are shown in Annexure 2.

Benthic communities

A total of 13 macro- and meiobenthic taxa were recorded from the downstream stretch of the Sardar Sarovar Dam (SSD) on the Narmada River during the pre-monsoon season. The benthic community included four molluscan species—*Thiara scabra, Tarebia lineata, Parreysia caerulea*, and *Indoplanorbis exustus*—of which three species were exclusively reported from the Sakkarpura sampling station. Crustacean forms such as prawn larvae and crab juveniles were observed at the Sisodara and Lilod sampling stations, respectively. In addition, arthropods were recorded from several sites along the study stretch. Notably, polychaetes belonging to the

family Syllidae were observed at the Bharuch and Bhadbhut stations. During the post-monsoon season, six benthic macroinvertebrate species, all belonging to Mollusca, were recorded from the same study area. The gastropod assemblage comprised *Tarebia granifera, Bellamya crassa*, *Thiara tuberculata*, and *Bellamya dissimilis*, while the bivalve fauna included *Corbicula striatella* and *Parreysia favidens*. The occurrence of both gastropod and bivalve species during the post-monsoon period reflects a moderately diverse molluscan assemblage in the downstream stretch of the SSD. Benthic diversity observed during the pre- and post-monsoon seasons are shown in Annexure 3.

Fish diversity and fisheries

Pre-monsoon Sampling

The Narmada river system has rich fish diversity. Since the present investigation has concentrated on limited stretches of the river, the fish diversity may not be matched with the total diversity available in the river Narmada. In the pre-monsoon sampling, a total of 1959 individual fish samples were recorded from selected sampling sites in pre-monsoon season. The fishes belong to 11 orders, 15 families, 28 genera, and 36 species (Table 6).

Total 36 fish species are reported from lower stretch of Narmada River during the pre-monsoon period. The highest number of species reported from station S_3 (23) while lowest was from S_9 (5) (Fig. 27). The relative abundance of fish species across different sampling stations (S_1–S_9) (Fig.28) during pre-monsoon shows that at S_1, the fish community was relatively diverse, with *Clupisoma garua* (19.83%) emerging as the dominant species, followed by *Osteobrama cotio* (15.01%) and *Salmophasia bacaila* (10.99%), while other species such as *Pethia conchonius* (8.57%) and *Systomus sarana* (9.91%) also contributed notably to the species diversity. In S_2, the composition changes, where *Pethia conchonius* (31.97%) was dominant followed by *Puntius sophore* (20.68%) forming the bulk of the catch, along with significant proportions of *Chanda nama* (14.10%) and *Salmophasia bacaila* (10.34%). In Sampling station 3 (S_3), *Amblypharyngodon mola* (24.15%) was the most abundant species, while *Pethia conchonius* (7.58%) and *Clupisoma garua* (4.19%) also maintained their presence, suggesting a moderately diverse fish assemblage. Some species were not reported such as *Salmophasia bacaila* which was found one of the dominant species in S_1 and S_2. In this site along with fin fish species *Macrobrachium rosenbergii* was also reported contributing to 9.98 % of relative abundance. The community structure at S_4 was dominated by *Salmophasia bacaila* (37.77%), followed by *Pethia conchonius* (20.74%) and *Macrobrachium rosenbergii* (20.37%). Similarly, in S_5 showed mixed relative dominance of *Clupisoma garua* (14.93%) and *Macrobrachium rosenbergii* (11.03%) constituting the highest percentage in this site, while *Pethia conchonius* and *Mystus cavasius* contribute equally (7.14%) remaining species contributed less than 4 % each. In S_6, *Salmophasia bacaila* (27.77%) again became dominant but the relative abundance was less as compared to S_4, followed by *Chanda nama* (16.66%) and *Mystus cavasius* (14.81%), showing the prominence of small-sized fishes and catfishes in this stretch. A marked shift in dominance was observed from S_7 onwards, where *Mystus cavasius* (19.56%) became the most abundant species, reflecting the dominance of catfishes

towards the downstream stretch. At S_8, *Tenualosa ilisha* was the most dominant species (39.28%), followed by *Escualosa thoracata* (19.64%) and *Otolithoides pama* (8.92%), indicating an increasing influence of clupeid fishes in the lower reaches due to estuarine zone. The trend was even more pronounced at S_9, only 5 species of fishes were reported among all *Tenualosa ilisha* majorly dominates due to migration to freshwater contributing relative abundance of 60.17%, followed by *Escualosa thoracata* (23.45%) and smaller proportions of *Otolithoides pama* (9.29%).

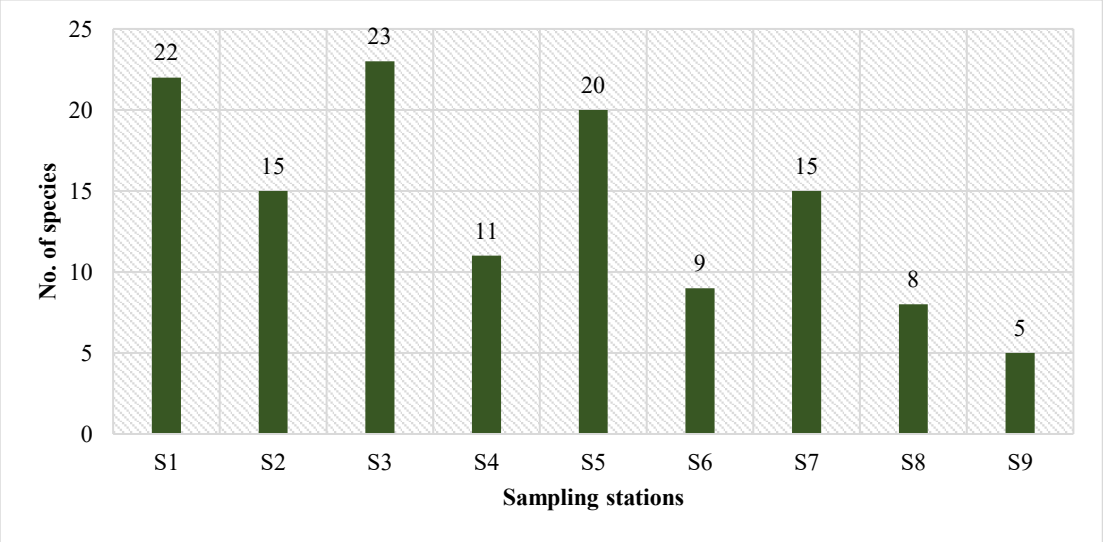


Figure 27: Number of species obtained during pre-monsoon from different sampling stations.

Table 6: Details of the fish species reported from the study area (Pre-monsoon)

Family	Fish species	IUCN status	Garudeshwar	Poicha	Sisodra	Lilod	Jhanor	Suklatirth	Bharuch	Sakkarpura	Bhadbhut
Ailiidae	*Clupisoma garua*	LC	+	+	+	-	-	-	-	+	-
Ambassidae	*Chanda nama*	LC	-	+	+	-	+	+	-	-	-
	Parambassis ranga	LC	-	-	+	+	+	+	-	-	-
Bagridae	*Mystus cavasius*	LC	+	-	+	+	+	+	+	-	-
	Sperata seenghala	LC	+	+	+	-	+	+	-	+	-
	Spreta aor	LC	+	-	+	-	+	-	+	-	-
	Rita rita	LC	+	-	+	+	-	-	+	+	-
	Mystus bleekeri	LC	-	+	+	+	+	-	+	-	-
Channidae	*Channa marulius*	LC	+	+	-	-	+	-	-	-	-
Cobitidae	*Lepidocephalichthys guntea*	LC	+	-	+	-	+	-	-	-	-
Cyprinidae	*Amblypharyngodon mola*	LC	+	+	+	-	+	-	-	-	-
	Cirrhinus mrigala	LC	+	+	+	+	-	+	-	-	-
	Cirrhinus reba	LC	+	-	+	-	-	-	-	-	-
	Labeo boga	LC	+	+	-	-	+	-	-	-	-
	Labeo boggut	LC	-	+	+	-	+	-	-	-	-
	Labeo calbasu	LC	-	+	+	-	+	-	+	-	-
	Labeo dyocheilus	LC	+	+	-	-	-	-	-	-	-
	Labeo rohita	LC	+	-	+	-	+	-	-	-	-
	Osteobrama cotio	LC	+	-	+	+	-	+	-	-	-
	Pethia conchonius	LC	+	+	+	+	+	-	+	-	-

	Puntius sophore	LC	+	+	+	-	+	-	+	-	-
	Salmophasia bacaila	LC	+	+	-	+	-	+	-	-	-
	Systomus sarana	LC	+	-	-	-	-	-	-	-	-
	Tor tor	DD	-	-	-	+	+	-	-	-	-
Mastacembelidae	*Mastacembelus armatus*	LC	+	-	+	-	+	-	+	-	-
Notopteridae	*Notopterus notopterus*	LC	+	-	+	-	+	+	+	-	-
Schilbeidae	*Eutropiichthys vacha*	LC	+	-	+	+	+	-	+	-	-
Siluridae	*Ompok bimaculatus*	NT	-	+	+	-	-	-	+	-	-
	Wallago attu	VU	+	-	+	+	+	-	+	-	-
Dorosomatidae	*Escualosa thoracata*	LC	-	-	-	-	-	-	+	+	+
Clupeidae	*Tenualosa ilisha*	LC	-	-	-	-	-	-	-	+	+
Sciaenidae	*Otolithoides pama*	DD	-	-	-	-	-	-	+	+	+
Scatophagidae	*Scatophagus argus*	LC	-	-	-	-	-	-	-	+	+
Cichlidae	*Oreochromis niloticus*	LC	+	-	-	-	-	-	-	-	-
Latidae	*Lates calcarifer*	LC	-	-	-	-	-	-	+	+	+
Palaemonidae	*Macrobrachium rosenbergii*	LC	-	+	+	+	+	-	-	-	-

IUCN Red List: DD-Data deficient, LC-Least concern, NT-Near threatened, VU-Vulnerable, EN-Endangered,

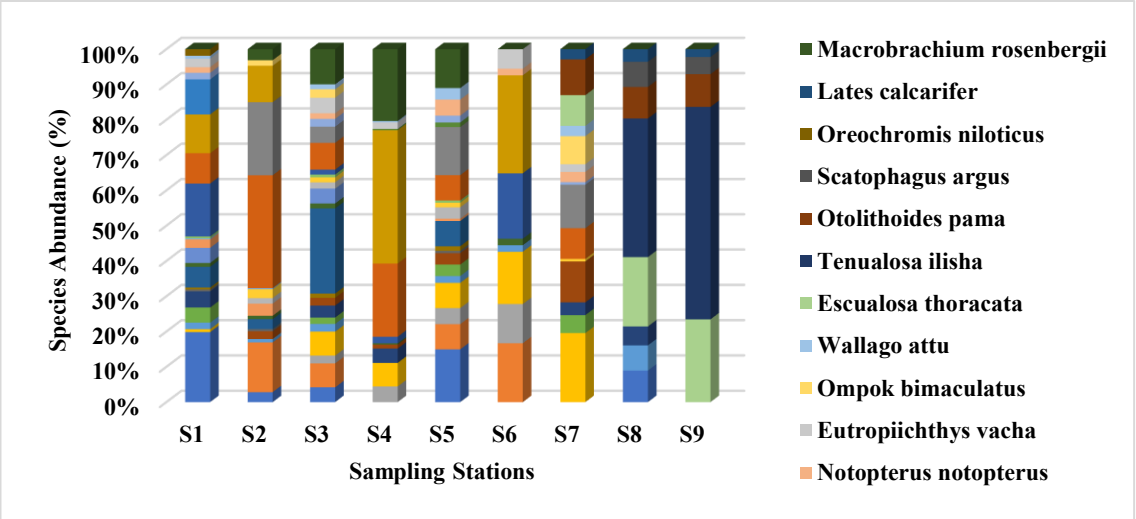


Fig 28: Species relative abundance percentage reported during pre-monsoon period from different sampling stations.

Cyprinidae is the most dominant family in the downstream of SSD, with the highest contribution recorded at S_2 (74.60%) and S_4 (61.11%). Its share, however, gradually decreases downstream, especially at S_7–S_9 due to estuarine zone (Fig. 29). Bagridae family is consistently

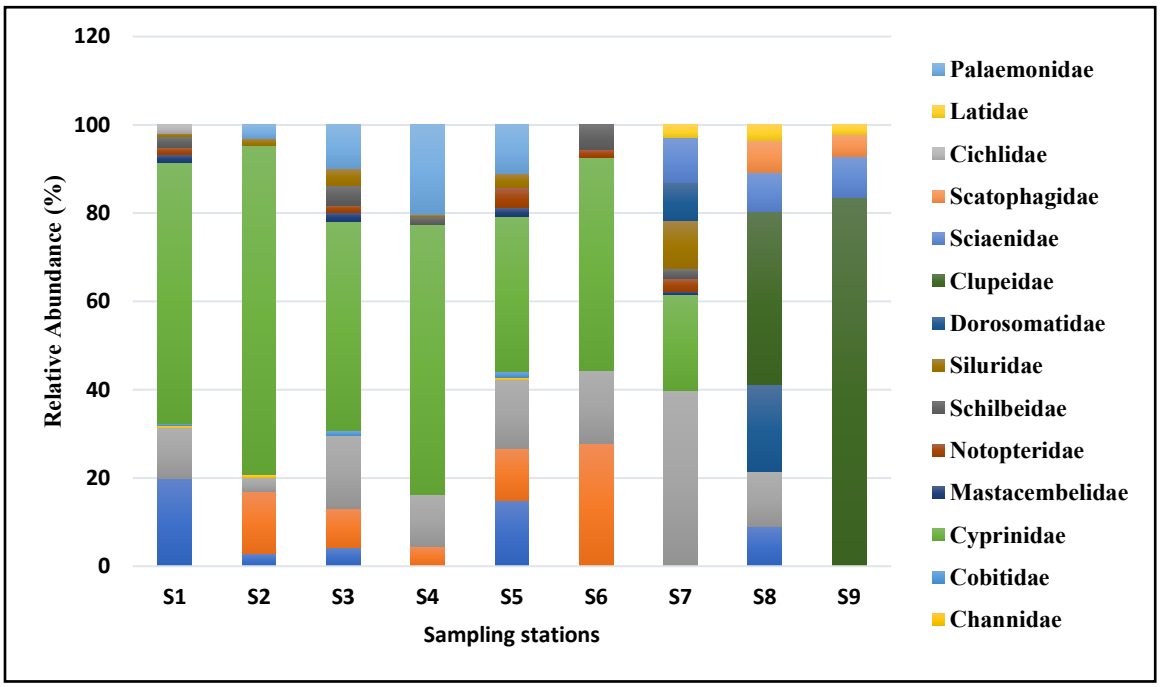


Fig 29: Relative abundance of fish species belonging to different families in the Narmada River downstream of SSD during pre- monsoon period.

present across most stations and becomes highly abundant at S_7 (39.85%), while Ambassidae shows its peak at S_6 (27.77%). Palaemonidae which include *Macrobrachium rosenbergii* occurs mainly in the midstream, with high values at S_4 (20.37%) and S_5 (11.04%). In the downstream stations, a major shift in dominance is observed where Clupeidae and Sciaenidae replace Cyprinidae as the leading families. Clupeidae dominates at S_8 (39.28%) followed by Dorosomatidae (19.64 %) and 83.62% at S_9, while Sciaenidae maintains considerable abundance at S_7–S_9, with more than 9% at each station. Other families such as Channidae, Cobitidae, Mastacembelidae, Notopteridae, Schilbeidae, Siluridae, Cichlidae, and Latidae occur in low percentages (< 10%) and are limited to specific sites. Overall, data showed that freshwater families like Cyprinidae dominates middle and upper stretch, whereas estuarine-associated families such as Clupeidae and Sciaenidae dominate downstream, showing a clear longitudinal shift in fish family composition.

Further, fish species documented during sampling are categorized into fourteen major fish groups. Catfishes (CTF) formed the major group with 9 fish species followed by (BML) Barbs, Minnows and Loaches, which mainly includes small indigenous fishes, and Minor and Peninsular Carps (MPC) (Fig.30).

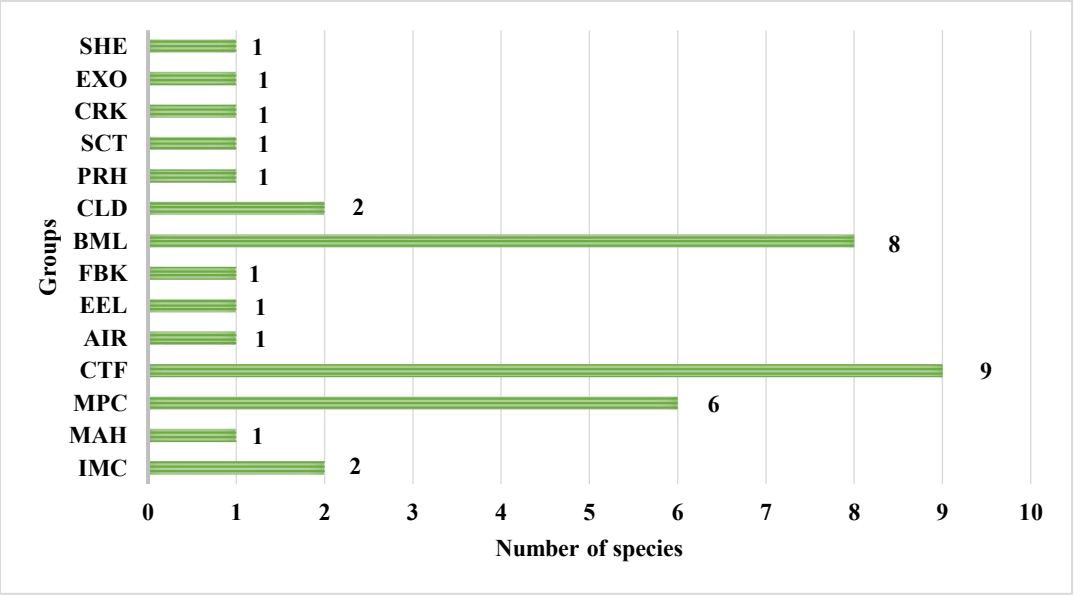


Figure 30: Group wise number of species reported during study period

Indian major carps IMC, MAH-Mahseer, MPC-Minor and peninsular carps, CTF- Catfishes, AIR-Air breathing fishes, EEL-Eels, FBK- Featherbacks, BML-Barbs, Minnows and Loaches, CLD- Clupids, PRH- Pearch SCT-Scat, CRK-Croaker, EXO-Exotics, SHE-Shell fish

Distribution of migratory fishes

In the present study during pre-monsoon season, the migratory fish species mostly available in the stretch between Garudeshwar to Bhadbhut were *Tor tor* and *Tenualosa Ilisha.* The stretch around Sisodra to Bhadbhut has been identified as hilsa fishing zone and as such there was no regular fishing activity in the upper stretches of river Narmada. In general, catch of *T. Ilisha* abundantly at Bhadbhut and Bharuch area whereas according to fishermen perception *T. Ilisha* occasionally caught at Sisodra area also during heavy rain. In the stretch between Garudeshwar to Shuklatirth, the migratory species *Tor tor* was found dominated during rainy season along with other fish species.

Early life stages of fishes

The early life stages of fishes in the natural aquatic environment including eggs, fry, larvae and juveniles play the crucial role for population success and ecosystem health because they are highly vulnerable to predators and environmental changes and their development determines the new recruitment of fish fauna diversity in the river habitats. During the sampling period significantly not much more juveniles and fry of the fish species were found due to the heavy downpour and overcast condition through entire tour period.

Fish diversity during post-monsoon season

In the post-monsoon sampling (Nov. 2025) a total of 1207 individual fish samples were recorded from selected sampling stations and surrounding places. The fishes belong to 12 orders, 19 families, 34 genera, and 42 species (Table 8.). One species of shell fishes *Macrobrachium rosenbergii* belonging to family Palaemonidae recorded from Bhadbhut. Cyprinid was the dominant group (38.09%) followed by Bagridae (7.14%), Schilbeidae (4.76 %) and Dorosomatidae (4.76 %) respectively (Fig 31.).

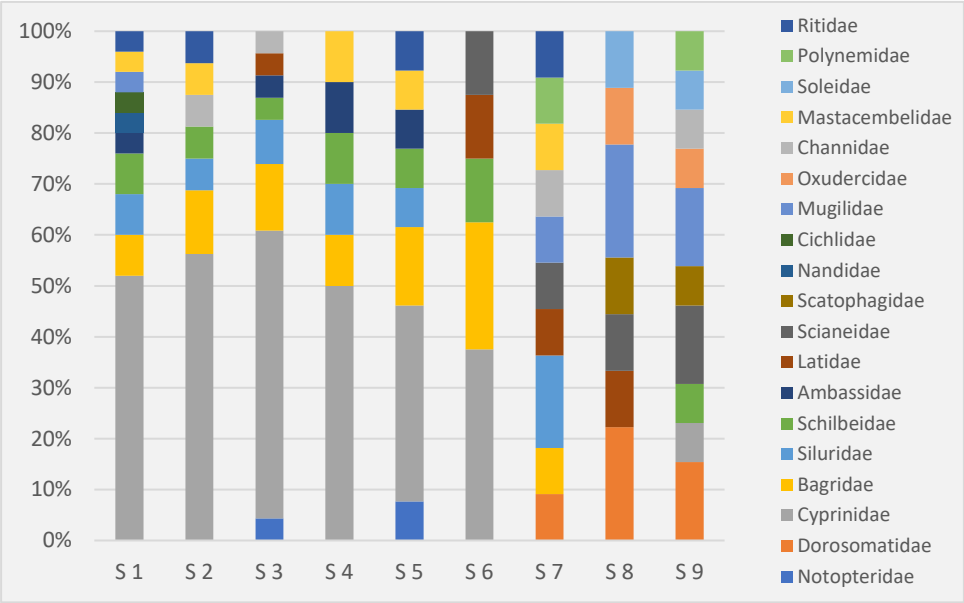


Fig 31. Overall site wise family distributions

Escualosa thoracata was the dominant species with Relative Abundance (RA) of 6.29 % and individual nos. (n) of 76 recorded from Bhadbhut followed by *Otolithoides pama* (RA 4.63 %, n= 56) from Bhadbhut, *Salmophasia bacaila* (RA 3.39%, n=41) recorded from Lilod, *Labeo boggu* (RA. 2.81%, n=34) from Garudeshwar and *Puntius sophore* (RA 3.06%, n=77) respectively. Other dominant species were *Osteobrama cotio* (RA 2.58%) and *Chanda nama* (RA 2.62%). Maximum species occurrence (n= 25) was recorded from Garudeshwar followed by Sisodra (n=23), Poicha (n=18), Bhadbhut (n=13) and Jhanor (n=12) respectively (Fig. 32).

Bagridae and Siluridae were the most well contributed group distributed in all the sampling sites except Sakkarpura and Bhadbhut followed by cyprinidae which was distributed in all the sampling sites except Bharuch, Sakkarpura and Bhadbhut. Thirteen species under the family cyprinidae recorded from Garudeshwar, 12 nos. species from Sisodra and 5 nos. species recorded from Lilod and Jhanor sites each respectively. Less nos. of species (n=3) under cyprinid group documented from Shuklatirth site. Ten family were identified which contributing only one species. The maximum occurrence of the

individual sample (n=76) and (n=56) was recorded from Bhadbhut followed by Lilod (n= 41) and Garudeshwar (n=34) respectively. Significantly, a stable population of fishes (9.52%) was found in the studied area which are considered as endangered as per IUCN criteria in other water bodies. Significantly 35.71 % of total species are considered as major food fishes, 40.47 % are recognized as food fishes and 21.42 % fishes are potential ornamental fishes which are very impressive as fish composition is concern.

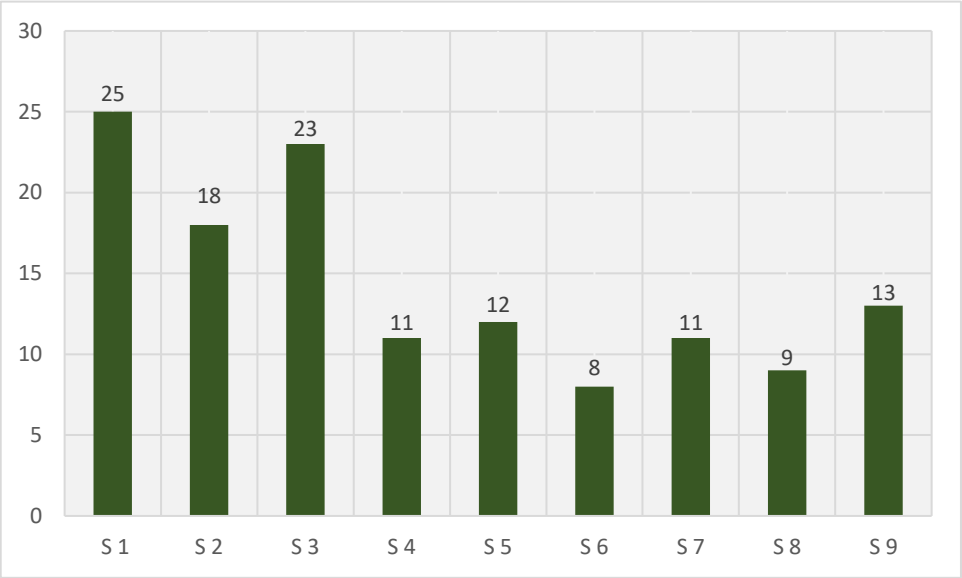


Fig 32. Graphical representation of site wise species richness

Among catfishes *Sperata aor, Sperata seenghala, Rita rita, Clupisoma. garua, Eutropichthys vacha* and *Mystus cavasius* were the most important species recorded from Garudeshwar to Bharuch which are located in upper stretches of the studied area. In the present study the most important species were found *Clupisoma garua, Rita rita, Cirrhinus reba, Eutropiichthys vacha, Labeo rohita, Cirrhinus mrigala Salmophasia bacaila, Tor tor, Labeo calbasu, Labeo boga, Labeo boggut, Tenualosa Ilisha and Lates calcarifer.*

Further, fish species documented during sampling are categorized into 19 major fish groups. Catfishes (CTF) formed the major group with 8 fish species followed by BML (Barbs, Minnows and Loaches), minor and peninsular carp (n=6), Indian Major Carp (n=3), Air breathing fish, Clupids, Croaker, Mullet with 2 species each. Remaining group contains 1 species each (Table 7. & Fig 33.). It is clearly indicating that the selected stretches of river Narmada inhabit rich ichthyofauna with diverse groups.

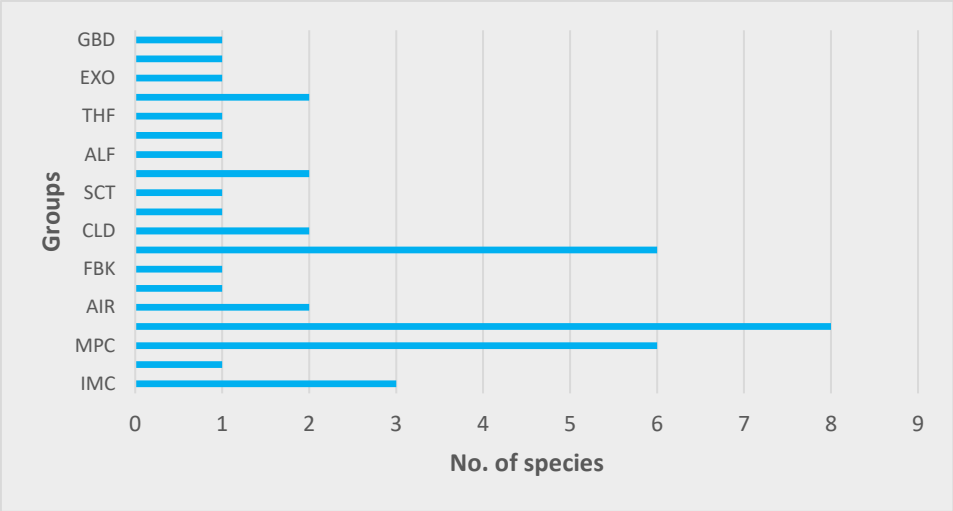


Fig 33. Graphical representation of major fish groups at various stations along river Narmada

IMC= Indian major carps; MAH=Mahseer; MPC = Minor and peninsular carps; CTF = Cat fishes; AIR = Air breathing fishes; EEL = Eel; FBK = Feather backs; BML = Barbs and minnows; CLD = Clupids; PRH = Perch; SCT = Scat; CRK = Croaker; ALF = Asian leaf fish; GTS = Gangetic tongue sole; THF = Threadfin Fish; GSM = Gold spot mullet; EXO = Exotic; SHF = Shell fish; GBD = Gobid.

Table 7. Fish group observed during the post-monsoon sampling at different stations

Sl. No.	Groups	Code	Species	Number
1.	Indian major carps	IMC	*Cirrhinus mrigala, Labeo rohita. Labeo calbasu*	3
2.	Mahseer	MAH	*Tor tor*	1
3.	Minor and peninsular carps	MPC	*Cirrhinus reba, Labeo boggut, Systomus sarana, Labeo boga, Labeo bata, Labeo gonius*	6
4.	Catfishes	CTF	*Wallago attu, Sperata seenghala, Clupisoma garua, Mystus cavasius, Ompok bimaculatus, Sperata aor, Eutropiichthys vacha, Rita rita*	8
5.	Air breathing fishes	AIR	*Channa Punctatus, Channa striatus*	2
6.	Eels, gobby	EEL	*Mastacembelus armatus*	1
7.	Featherbacks	FBK	*Notopterus notopterus*	1
8.	Barbs and Minnows	BML	*Puntius sophore, Salmophasia bacaila, Chanda nama, Amblypharyngodon mola, Osteobrama cotio, Pethia conchonius*	6
9.	Clupids	CLD	*Tenualosa ilisha, Escualosa thoracata*	2
10.	Pearch	PRH	*Lates calcarifer*	1

11.	Scat	SCT	*Scatophagus argus*	1
12.	Croaker	CRK	*Otolithoides pama, Protonibea diacanthus*	2
13.	Asian leaf fish	ALF	*Nandus nandus*	1
14.	Gangetic tongue sole	GTS	*Cynoglossus cynoglossus*	1
15.	Threadfin Fish	THF	*Eleutheronema tetradactylum*	1
16.	Gold spot Mullet, Mullet	GSM	*Liza parsia, Rhinomugil corsula*	2
17.	Exotics	EXO	*Oreochromis niloticus*	1
18.	Shell fish	SHF	*Macrobrachium rosenbergii*	1
19.	Gobid	GBD	*Odontamblyopus rubicundus*	1

Catch Per Unit Effort (CPUE):

Catch per unit effort (CPUE) is one of the important quantitative indices used worldwide to describe fish abundance and fish population. These indices may use for assessing the fish population, relative abundance, occurrence and composition of fish diversity of a particular stretch of river. CPUE can be applied to make a decision for how to manage conservation strategies, catch restriction and closed season. It is assumed that declining of CPUE reflect the decrease in fish stock. CPUE is calculated by dividing the total catch (in weight) in an hour by a single person or unit.

CPUE during pre-monsoon period

In the present investigation CPUE is calculated in each sampling sites (Figure 34). higher value of CPUE (1.6 kg/hr/person) recorded from Bhadbhut site and lowest value (0.55 kg/hr/person) recorded from Lilod. Significantly less fish diversity recorded from Bhadbhut but probably due to huge hilsa catch triggered the CPUE value at the site.

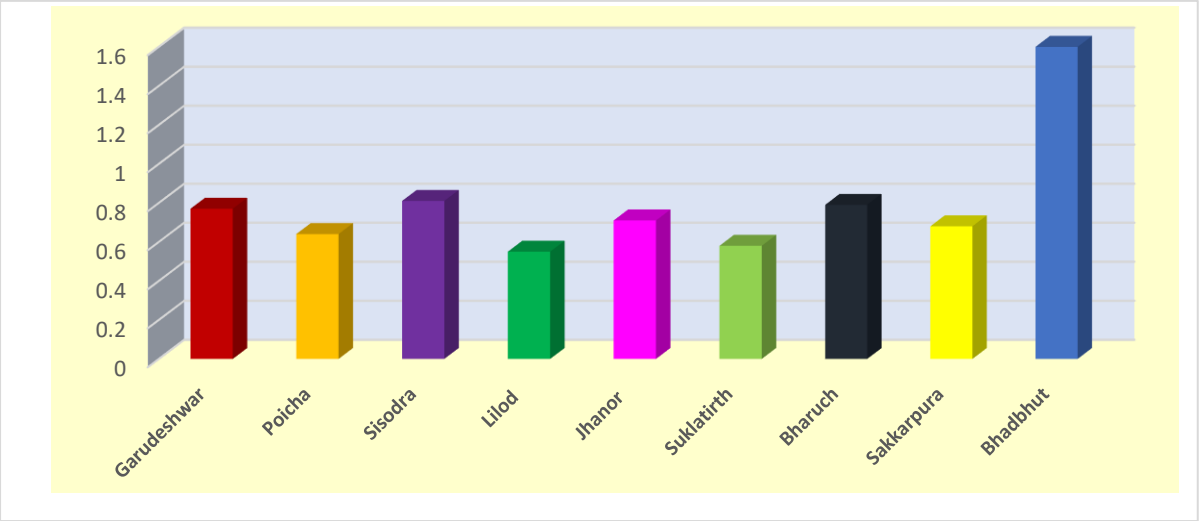


Figure 34: Diagram representing site wise CPUE value (Kg/ hr/person)

CPUE during post-monsoon period

During post-monsoon sampling CPUE value was calculated based on total fish catch per person in an hour. In the present post-monsoon sampling CPUE is recorded in each sampling sites (Fig. 35). higher value of CPUE (12.5 kg/hr/person) recorded from Bhadbhut site and lowest value (2.0 kg/hr/person) was recorded each from Garudeshwar site. Large sized fishes recorded from Bhadbhut support the higher CPUE value. Large sized fishes added more weight to the total catch by an individual which is trigger the CPUE value. Comparatively less CPUE value recorded from Garudeshwar and Poicha (2.7

kg/hr/person) sites mainly due to less species richness and smaller size of fishes. Remaining other sites showed medium CPUE value which are acceptable as per as aquatic habitat is concern.

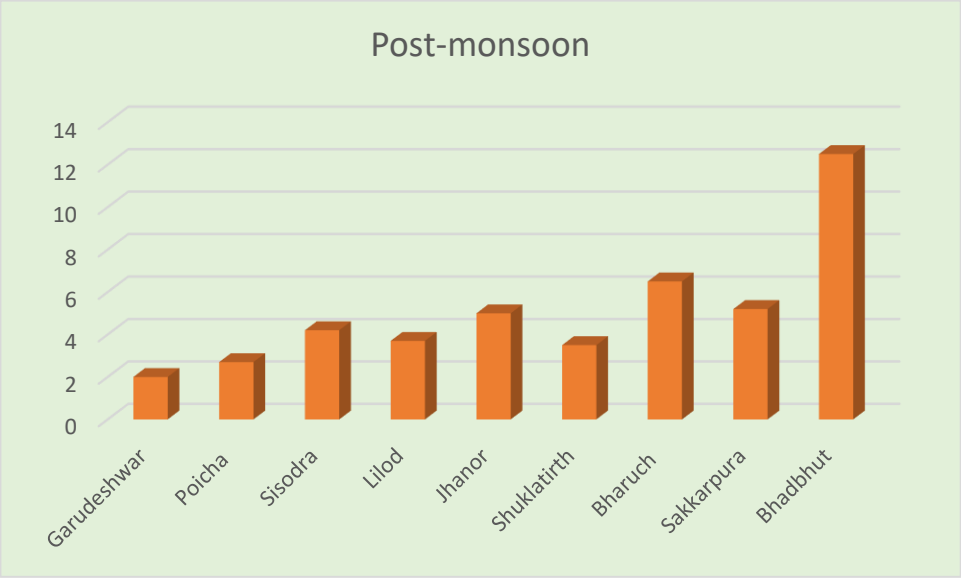


Fig 35. Diagram representing site wise value of CPUE

Table 8. Fish species occurrence at selected sites of river Narmada (Post-monsoon).

Sl. No.	Name of the species	Conservation status (IUCN)	Sampling sites								
			Garudeswar	Poicha	Sisodra	Lilod	Jhanor	Shuklatirth	Bharuch	Sakkarpura	Bhadbhut
	Family: Notopteridae										
1	*Notopterus notopteus*	LC	-	-	+	-	+	-	-	-	-
	Family: Dorosomatidae										
2.	*Tenualosa ilisha*	LC	-	-	-	-	-	-	-	+	+
3.	*Escualosa thoracata*	LC	-	-	-	-	-	-	+	+	+
	Family: Cyprinidae										
4.	*Amblypharyngodon mola*	LC	+	+	+	+	-	-	-	-	-
5.	*Cirrhinus mrigala*	LC	+	-	+	-	-	+	-	-	-
6.	*Labeo bata*	LC	-	-	+	-	-	-	-	-	-
7.	*Cirrhinus reba*	LC	+	+	+	-	+	-	-	-	+
8.	*Labeo boga*	LC	+	+	+	+	+	-	-	-	-
9.	*Labeo boggut*	LC	+	+	-	-	+	-	-	-	-
10.	*Labeo calbasu*	LC	+	-	+	-	+	-	-	-	-
11.	*Labeo gonius*	LC	-	-	+	-	-	-	-	-	-
-12.	*Labeo rohita*	LC	+	+	+	-	-	-	+	-	-
13.	*Osteobrama cotio*	LC	+	-	+	+	-	+	-	-	-
14.	*Osteochilus vittatus*	LC	+	-	-	-	-	-	-	-	-
15.	*Pethia conchonius*	LC	+	+	+	+	+	-	-	-	-
16.	*Puntius sophore*	LC	+	+	+	-	+	-	-	-	-
17.	*Salmophasia bacaila*	LC	+	+	-	+	-	+	-	-	-
18.	*Systomus sarana*	LC		+	+	-	-	-	-	-	-
19.	*Tor tor*	DD	+	+	+	-	-	-	-	-	-
	Family: Bagridae										
20.	*Mystus cavasius*	LC		+	+	+	+	+	-	-	-

21.	*Sperata aor*	LC	+	+	+	-	+	-	+	-	-
22.	*Sperata seenghala*	LC	+	-	+	-	-	+	-	-	-
	Family: Siluridae										
23.	*Ompok bimaculatus*	NT	+	+	+	-	-	-	+	-	-
24.	*Wallago attu*	VU	+	-	+	+	+	-	+	-	-
	Family: Schilbeidae										
25.	*Clupisoma garua*	LC	+	+	-	-	-	-	-	-	+
26.	*Eutropiichthys vacha*	LC	+	-	+	+	+	+	-	-	-
	Family: Ambassidae										
27.	*Chanda nama*	LC	+		+	+	+	-	-	-	-
	Family: Latidae										
28.	*Lates calcarifer*	LC	-	+	+	+	-	-	+	+	+
	Family: Scianeidae										
29.	*Otolithoides pama*	LC	-	-	-	-	-	+	+	+	+
30.	*Protonibea diacanthus*	NT	-	-	-	-	-	-	+	-	-
	Family: Scatophagidae										
31.	*Scatophagus argus*	LC	-	-	-	-	-	-	-	+	+
	Family: Nandidae										
32.	*Nandus nandus*	LC	+	-	-	-	-	-	-	-	+
	Family: Cichlidae										
33.	*Oreochromis niloticus* (Exo.)	LC	+	-	-	-	-	-	-	-	-
	Family: Mugilidae										
34.	*Liza parsia*	LC	-	-	-	-	-	-	-	+	+
35.	*Rhinomugil corsula*	LC	+	-	+	-	-	-	+	+	+
	Family: Palaemonidae										
36.	*Macrobrachium rosenbergii* (Shell fish)	LC	-	-	+	+	+		+		+
	Family: Oxudercidae										

37.	*Odontamblyopus rubicundus*	LC	-	-	-	-	-	-	-	+	+
	Family: Channidae										
38.	*Channa punctatus*	EN	-	+	+	-	-	-	+	-	-
39.	*Channa striatus*	LC	-	-	-	-	-	-	-	-	+
	Family: Mastacembelidae										+
40.	*Mastacembelus armatus*	LC	+	+	-	+	+	-	+	-	-
	Family: Soleidae										
41.	*Cynoglossus cynoglossus*	LC	-	-	-	-	-	-	-	+	+
	Family: Polynemidae										
42.	*Eleutheronema tetradactylum*	LC	-	-	-	-	-	-	+	-	+
	Family: Ritidae										
43.	*Rita rita*	LC	+	+	-	-	+	-	+	-	-

Remarks:

A total of 3352 individuals fishes belonging to 12 orders, 20 families, 36 genera and 47 fish species have been documented from the sampling sites of the river Narmada during pre-monsoon (June' 25) and post-monsoon (November'25) sampling (Table 9.). During pre-monsoon sampling 36 no. fish species have been documented and 42 species have been recorded during post-monsoon season. *Rhinomugil corsula, Labeo bata, Labeo gonius, Protonibea diacanthus, Osteochilus vittatus, Channa punctatus, Channa striatus and Cynoglossus cynoglossus* was recorded during post-monsoon season whereas *Labeo dyocheilus, Channa marulius* and *Parambassis ranga* were documented in pre-monsoon season, remaining species recorded in both the seasons.

As result obtained from the above study cyprinid was the major group (36.07%) followed by Bagridae (8.51%), Channidae (6.38%) and Sciaenidae (4.25%) respectively. Maximum species richness in both the season was recorded at Garudeshwar (n=30, 63.82%) followed by Sisodra (n= 29, 61.70%), Poicha (n=24, 51.06%) and Jhanor (n=21, 44.68%) respectively. Significantly it has been found that, species richness gradually decreased with the decrease of river elevation (Fig 36.).

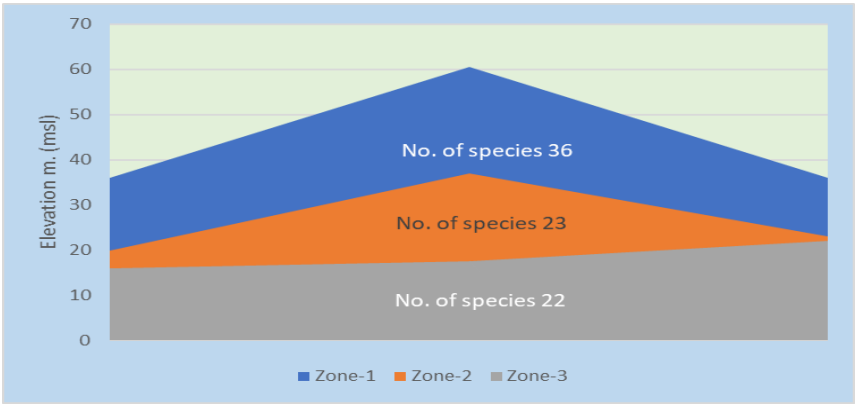


Fig 36. Graphical representation of species occurrence at different elevation.

(Zone 1 = Garudeshwar, Poicha, Sisodra; Zone 2 =Lilod, Jhanor, Shuklatirth, Zone 3 =Bharuch, Sakkarpura, Bhadbhut

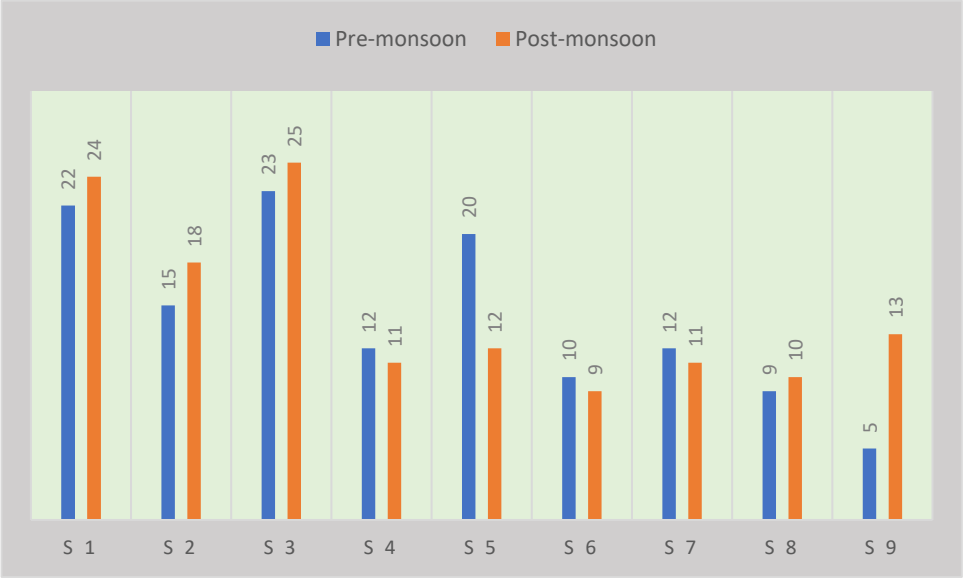


Fig 37. Season-wise species occurrence at different sampling stations.

In the stretch between Garudeshwar to Shuklatirth, the species composition was found dominated by *Labeo calbasu, Cirrhinus reba, Cirrhinus mrigala, Labeo bata, Labeo calbasu Labeo boga, Labeo boggut, Salmophasia bacaila, Clupisoma garua, Eutropiichthys vacha, Tor tor.* Among catfishes *Sperata aor, S. seenghala, R. rita, C. garua, E. Vacha* and *Mystus spp.* were the most important species available almost throughout the stretch except Sakkarpura and Bhadbhut which are located in tidal oscillation zone. Species occurrence observed in both the seasons indicating that not much variations were recorded in sampling sites. Maximum species (n=25) recorded during post monsoon season in Sisodra followed by Garudeshwar (n=24) (Fig. 37). In remaining sites species richness were almost same in both the seasons. Significantly a wide variety of small indigenous fish (SIF) (19.14%) diversity was observed in the upstream at Garudeshwar to Shuklatirth sites. These are *Amblypharyngodon mola, Cirrhinus reba, Chanda nama, Parambassis ranga, Nandus nandus, Osteobrama cotio, Puntius sophoe, Pethia conchonius, Systomus sarana.*

Further, fish species documented during sampling are categorized into 19 major fish groups. Catfishes (CTF) formed the major group with 8 fish species followed by BML (Barbs, Minnows and Loaches), minor and peninsular carp (n=6), Indian Major Carp (n=3), Air breathing fish, Clupids, Croaker, Mullet with 2 species each. Remaining group contains 1 species each. It is clearly indicating that the selected stretches of river Narmada inhabit rich ichthyofauna with diverse groups.

Catch Per Unit Effort (CPUE) was calculated in each sampling centre during pre-monsoon and post-monsoon season. In pre-monsoon sampling, higher value of CPUE (1.6 kg/hr/person) recorded from the Bhadbhut site, and the lowest value (0.55 kg/hr/person) was recorded from Lilod.

Significantly less fish diversity was recorded from Bhadbhut, but probably due to the huge hilsa catch triggered the CPUE value at the site. Significantly in post monsoon season CPUE value was higher than pre-monsoon season in all the sampling stations (Fig. 38). This was probably due to large sized fishes caught by the fishermen. In post monsoon sampling highest value of CPUE (12.5 kg/hr/person) was recorded from the Bhadbhut site, and the lowest value (2.0 kg/hr/person) was recorded from Garudeshwar. Large sized fishes recorded from Bhadbhut support the higher CPUE value. Large sized fishes added more weight to the total catch by an individual, which triggers the CPUE value. Comparatively less CPUE value recorded from Garudeshwar and Poicha (2.7 kg/hr/person) sites mainly due to smaller size of fish. The remaining sites showed medium to high CPUE value which are acceptable as per the aquatic habitat concern.

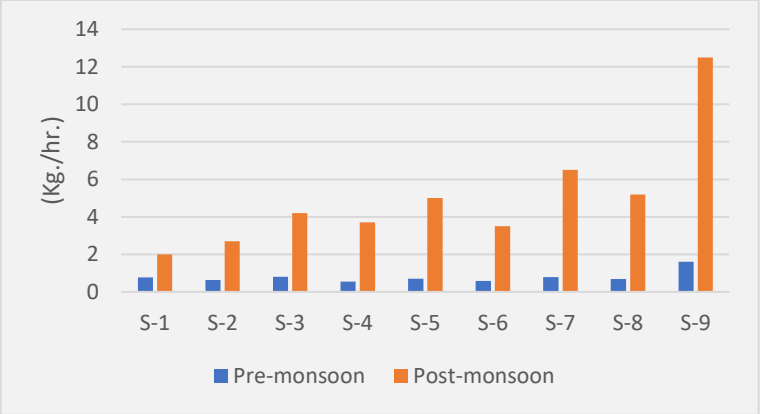


Fig. 38 Comparative value of CPUE in pre and post monsoon sampling.

Further, total fishes recorded during pre-monsoon and post-monsoon seasons are categorized into three important categories, i.e., Food fishes, major food fishes and ornamental fish. The existence of food fishes and potential ornamental fishes indicating acceptable habitat and aquatic ecological integrity that supports the intolerant species like ornamental fishes for surviving. In the present study, out of 47 fish species, 21 (44.68%) species were categorized as food fishes, 10 (21.27%) species were put under ornamental fishes, and 16 (34.04%) species regarded as major food fish (Fig 39.). Significantly all the ornamental fishes recorded from the upstream of the river from Garudeshwar to Shuklatirth sites.

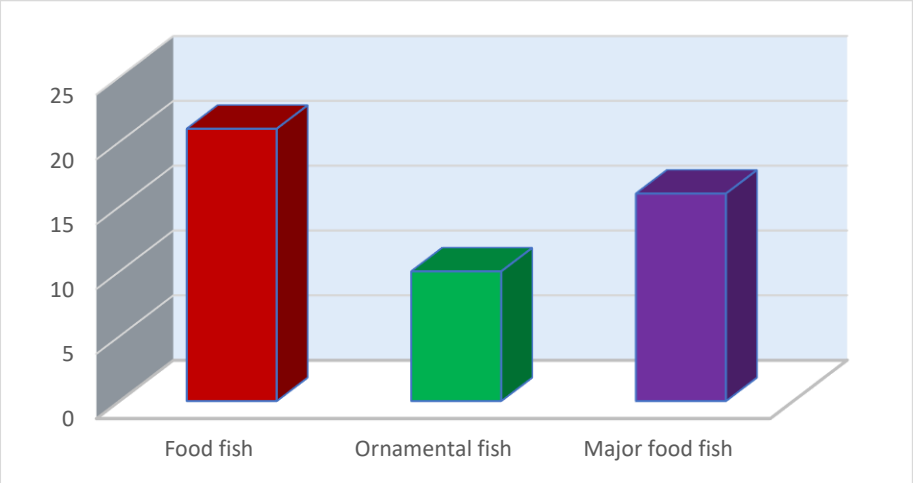


Fig 39. Diagrammatic representation of the categorization of fishes recorded during both the seasons.

Distribution of migratory fishes

In a word fish migration is relocation of fishes from one area to another. Many types of fish migrate on a regular basis from one habitat to another on time scale mainly due to feeding, spawning and seeking better habitat. Fish migrations involve movements of schools of fish on a scale and duration larger than those arising during normal daily activities. Some particular types of migration are *anadromous*, in which adult fish live in the sea and migrate into fresh water to spawn; and *catadromous*, in which adult fish live in fresh water and migrate into salt water to spawn. Another type of migration in which fish migrations occur wholly within fresh water is *Potamodromous.*

In the present study, in pre-monsoon and post-monsoon seasons, the migratory fish species mostly available in the stretch between Garudeshwar to Bhadbhut were *Tor tor and Tenualosa Ilisha* and *Lates calcarifer.* The stretch around Sisodra to Bhadbhut has been identified as hilsa fishing zone, and as such, there was no regular fishing activity in the upper stretches of the river Narmada. In general, catch of *T. Ilisha* is abundant at Bhadbhut and Bharuch area due to tidal oscillation zone, whereas according to fishermen', *T. Ilisha is* occasionally caught at Sisodra area also during the rainy season. In the stretch between Garudeshwar to Shuklatirth, the migratory species *Tor tor* was found to be dominant during the rainy season along with other fish species.

Fish species not encountered during the sampling

The following fish species were not encountered during the sampling period which are occassionally caught in the river Narmada as per fishermen perception.These are: *Chagunius chagunio, Bagarius bagarius, Macrognathus pancalus, Gudusia chapra, Jhonius coitor, Corica soborna, Gonialosa manmina,Crossocheilus latius, Labeo catla.* The fishes caught abundantly by the fishermen during summer and monsoon season.

Less abundant of fish species

Species belonging to the following genera under different families have been found to be quantitively less abundant as has been revealed in the present investigation during November 2025 (Table. 9)

Table 9. List of fish species recorded quantitatively less abundant

Family	Species
Cyprinidae	*Tor tor, Labeo bata, Ciirrhinus mrigala, Labeo calbasu., Labeo rohita, Labeo gonius, Systomus sarana , Osteochilus vittatus*
Bagridae	*Sperata seenghala*
Channidae	*Channa striatus*
Schilbeidae	*Clupisoma garua*
Polynemidae	*Eleutheronema tetradactylum*
Nandidae	*Nandus nandus*
Soleidae	*Cynoglossus cynoglossus*
Scatophagidae	*Scatophagus argus*
Ritidae	*Rita rita*
Siluridae	*Ompok bimaculatus*
Latidae	*Lates calcarifer*

It reveals that the Family Cyprinidae had the maximum (n=8) less abundant species followed by Bagridae, Cha nnidae, Schilbidae, polynemidae, Nandidae, Soleidae, Scatophagidae, Ritidae, Siluridae and Latidae with less abundant group respectivel

Table 10. Representative fish species documented from river Narmada during pre and post monsoon sampling period.

		Sampling stations																	
		Garudeshwar		Poicha		Sisodra		Lilod		Jhanor		Shuklatirth		Bharuch		Sakkarpura		Bhadbu\hut	
	Months	6	11	6	11	6	11	6	11	6	11	6	11	6	11	6	11	6	11
Family	Species																		
Cyprinidae	*Amblypharyngodon mola*	+	+	+	+	+	+		+	+	-	-	-	-	-	-	-	-	-
	Cirrhinus mrigala	+	+	+	-	+	+	+	-	-	-	+	+	-	-	-	-	-	-
	Cirrhinus reba	+	+	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	+
	Labeo bata	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Labeo boga	+	+	+	+		+	-	+	+	+	-	-	-	-	-	-	-	-
	Labeo boggut	-	+	+	+	+	-	-	-	+	+	-	-	-	-	-	-	-	-
	Labeo calbasu	-	+	+	-	+	+	-		+	+	-	-	-	-	-	-	-	-
	Labeo dyocheilus	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Labeo gonius	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Labeo rohita	+	+	-	+	+	+	-	-	+	-	-	-	-	+	-	-	-	-
	Osteobrama cotio	+	+	-	-	+	+	+	+	-	-	+	+	-	-	-	-	-	-
	Osteochilus vittatus	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Pethia conchonius	+	+	+	+	+	+	+	+	+	+	-	-	+	-	-	-	-	-
	Puntius sophore	-	+	+	+	+	+	-	-	+	+	-	-	+	-	-	-	-	-
	Salmophasia bacaila	+	+	+	+	-	-	+	+	-	-	+	+	-	-	-	-	-	-
	Systomus sarana	+	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Tor tor	-	+	-	+	-	+	+	-	+	-	-	-	-	-	-	-	-	-
Ambasside	*Chanda nama*	-	+	+	-	+	+	-	+	+	+	+	+	-	-	-	-	-	-
	Parambassis ranga	-	-	-	-	+	-	+		+	-	+	-	-	-	-	-	-	-
	Channa marulius	+	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-

Channidae	*Channa punctatus*	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	Channa striatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Schilbeidae	*Clupisoma garua*	+	+	+	+	+	-	-	-	+	-	-	-	-	-	+	-	-	+
	Eutropiichthys vacha	+	+	-	-	+	+	+	+	-	+	+	+	+	-	-	-	-	-
Soleidae	*Cynoglossus cynoglossus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+
		Garudeshwar		Poicha		Sisodra		Lilod		Jhanor		Shuklatirth		Bharuch		Sakkarpura		Bhadbut	
		6	11	6	11	6	11	6	11	6	11	6	11	6	11	6	11	6	11
Polynemidae	*Eleutheronema tetradactylum*	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+
Dorosomatidae	*Escualosa thoracata*	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+
	Tenualosa Ilisha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+
Latidae	*Lates calcarifer*	-	-	-	+	-	+	-	+	-	+	-	+	+	+	+	+	+	+
Mugilidae	*Liza parsia*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+		+
	Rhinomugil corsula	-	+	-	-	-	+	-	-	-	-	-	-	-	+	-	+		+
Mastacembelidae	*Mastacembelus armatus*	+	+	-	+	+	-	-	+	+	-	+	-	-	+	-	+	-	-
Bagridae	*Mystus bleekeri*	-	-	+	-	+	-	+	-	+	-	-	-	+	-	-	-	-	-
	Mystus cavasius	+	-	-	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-
	Sperata aor	+	+	-	+	+	+	-	-	+	+	-	-	+	+	-	-	-	-
	Sperata seenghala	+	+	+	-	+	+	-	-	+	-	+	+	-	-	+	-	-	-
Nandidae	*Nandus nandus*	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Notopteridae	*Notopterus notopteus*	+	-	-	-	+	+	-	-	+	+	+	-	+	-	-	-	-	-
Oxudercidae	*Odontamblyopus rubicundus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+
Siluridae	*Ompok bimaculatus*	-	-	+	+	+	+	+	-	-	-	-	-	-	+	+	-	-	-
	Wallago attu	+	+	-	-	+	+	+	+	+	+	-	-	+	-	-	-	-	-

Sciaenidae	*Otolithoides pama*	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+
	Protonibea diacanthus	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Ritidae	*Rita rita*	+	+	-	+	+	+	+	-	-	-	-	-	+	+	+	-	-	-
Scatophagidae	*Scatophagus argus*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	+
Cobitidae	*Lepidocephalichthys guntea*	+	-	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-	-
Cichlidae	*Oreochromis niloticus* (Exo.)	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palaemonidae	*Macrobrachium rosenbergii*	-	-	-	-	-	+	-	+	-	+	-	-	-	+	-	-	-	+

Index of Biotic Integrity (IBI)

The Index of Biotic Integrity (IBI) is a scientific tool used to assess the ecological health of aquatic systems. The multi-metric index of biotic integrity (IBI) method (Karr, 1981) used worldwide in stream or river to integrate information from individual, population assemblage and ecosystem levels into a single numerical indicator and quality rating for water bodies. This metrics was applied in the present study in selected stretches of river Narmada for assessing its quality in terms of fish assemblages and to varying levels of physical and chemical aquatic degradation.

The IBI was calculated for each site following the methods of Fausch *et al. (*1984), Hughes *et al. (*1998). The scoring criteria were developed as per the methods of Hughes *et al. (*1998). The qualitative evaluation of the IBI scores were done following Hughes *et al. (*1998), Ganesan and Hughes (1998) and Das (2006). The impaired IBI score was when the value was less than 60 % of the maximum observed. Since the highest metric values observed do not represent numerically disturbed condition, a marginally impaired score was one ranging between 60 % and 80 % of the highest score.

Modification of IBI for river Narmada (Below SSD, Garudeshwar to Bhadbhut)

Species richness

This metric is a common measure of biological diversity that generally declines with environmental degradation (Karr, 1981). Referring the original metric of Karr (1981) total number of species was replaced by native species and number of native families by Ganasan and Hughes (1998) and Das (2006). The number of native species used is a measure of biological diversity that typically decreases with increased degradation. The number of native families was used since it is a measure of biodiversity at the family level that also decreases as anthropogenic disturbance increases.

Species composition

In the present study the four metrics, number of darter species, number of sunfish species, number of sucker species and % green sunfish individuals were replaced by number of benthic species, number of water column species and % individuals as tolerant species. Karr *et al. (*1986) suggested these substitutes and they are common substitutes when IBI is modified for use outside the United States (Hughes and Oberdorff, 1999). Ganasan and Hughes (1998) and Das (2006) also used the modification for central Indian rivers and included both large and small benthic species in this metric, rather than separate them into separate darter and sucker substitute metric. Both

these two metrics are strongly responsive to change in water quality and habitat structure like siltation, turbidity, reduced oxygen content and toxic chemical. Water column species are active swimmer that typically feed on drifting and surface invertebrates or other fishes whereas benthic species are sensitive to siltation and benthic oxygen depletion because they feed and reproduce in benthic habitats (Ganasan and Hughes, 1998). The metric percent tolerant species was retained as the percentage of tolerant individual increase with increased physical and chemical degradation. The tolerant species are the last to disappear following a disturbance and the first to reappear as the system begins to recover. Several of them have accessory respiratory organs. The metric, number of intolerant species was retained as it declines with environmental degradation (Karr1981, 1986). This metric was also used in the Indian rivers (Ganasan and Hughes, 1998) and Das (2006). The degradation is associated with urban development but particularly sedimentation, turbidity, decreased dissolved oxygen and warming (Hughes and Oberdorff, 1999).

Trophic composition

Of the three metrics namely, percent of individual as omnivore and percent of individuals as top carnivores were retained and % of individual as insectivore (invertivore) was replaced with % of individuals as herbivores. In this study also as observed by Ganasan and Hughes (1998) and Das (2006) insectivore species and individuals were less common than herbivores in less polluted habitats of the estuary and more common in polluted habitats and were thus more sensitive than insectivore. Herbivores being sensitive to physical and chemical alteration in habitat are indicative of primary production status in the site.

Fish health and abundance

The original metrics ‘total number of individuals in the samples’ and % of individuals with disease or anomalies were retained. The new metric added by Ganasan and Hughes (1998) for Central Indian River and Das (2006) for river Hooghly was also retained % of individual as non-native, since exotic species are gradually becoming an important concern in Indian rivers. Non-native species are generally more successful where native species are depauperated or in anthropogenically altered systems (Ross, 1991). Total number of individuals is a gross measure of fish production and is lowest in highly disturbed system as well as in nutrient poor waters.

Table: 11. IBI at different selected sites of river Narmada

Site	Garudeshwar		Poicha		Sisodra		Lilod		Jhanor		Shuklatirth		Bharuch		Sakkarpura		Bhadbhut	
Month	6	11	6	11	6	11	6	11	6	11	6	11	6	11	6	11	6	11
Year	2025		2025		2025		2025		2025		2025		2025		2025		2025	
No. of Native sp.	21	23	15	18	24	23	11	10	20	11	9	7	15	9	6	11	6	13
No. of Native family	9	9	5	7	9	8	6	6	8	7	5	4	10	9	8	8	5	11
% of individual exotic	4.54	4.16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. of Benthic spp.	13	13	9	9	14	14	6	4	11	7	4	3	9	4	5	4	1	4
No. of Column spp.	7	8	5	6	8	8	3	4	7	3	3	2	5	4	4	4	4	6
No. of intolerant spp.	13	17	11	10	15	17	6	7	10	7	7	5	10	6	6	10	5	11
% of individual tolerant	40.9	33.3	26.6	33.3	33.3	30.4	45.4	60.0	45.0	27.2	22.2	28.5	40.0	33.3	50.0	0	0	18.1
% of individual omnivore	40.9	42.3	29.1	39.1	45.8	47.8	63.6	40.0	40.0	27.2	44.4	57.1	53.3	44.4	50.0	45.4	50.0	46.1
% of individual carnivore	40.9	40.9	26.6	27.7	41.6	34.7	36.3	40.0	45.0	54.5	55.5	42.8	46.6	55.5	66.6	66.6	16.6	46.1
% of individual herbivore	13.6	16.6	26.6	16.6	8.3	17.3	0	20.0	15.0	18.1	0	0	0	0	16.6	9.0	16.6	7.6
Total no. of individuals	373	264	309	184	491	168	215	147	137	113	54	52	138	67	34	36	90	142
Total no. of spp.	22	24	15	18	24	23	11	10	20	11	9	7	15	9	6	11	6	13
IBI score	**33**	**35**	**35**	**29**	**39**	**37**	**23**	**27**	**29**	**29**	**25**	**29**	**25**	**19**	**27**	**35**	**23**	**29**
IBI score (average)	**34**		**32**		**38**		**25**		**29**		**27**		**22**		**31**		**26**	
Integrity class	**A**		**MI**		**A**		**MI**		**MI**		**MI**		**MI**		**MI**		**MI**	

A= Acceptable: MI = Moderately Impaired

Table 12. Criteria for scoring of IBI metrics for river Narmada **(**Garudeshwar to Bhadbhut).

Category	**Metric**	**Scoring criteria**		
		5 (Best)	**3**	**1 (worst)**
Taxonomic richness	No. of Native spp.	> 23	11-23	< 11
	No. of Native family	> 10	8-10	< 8
Habitat composition	No. of Benthic spp.	> 13	6-13	< 6
	No. of Column spp.	> 7	4-7	< 4
	No. of intolerant spp.	> 16	6-16	< 6
	% of individual tolerant	< 19	19-30	> 30
Trophic composition	% of individual omnivore	< 30	30-45	> 45
	% of individual carnivore	> 53	40-53	< 40
	% of individual herbivore	> 20	13-20	< 13
Fish health and abundance	Total no. of individuals	> 350	150-350	< 150
	% of individual as non-native	0	1-5	> 5
	% individual with anomalies	_	_	_

Scores 5,3,1 assigned according to whether its values approximate, deviates somewhat from or deviates strongly from value of least disturbed site.

IBI assessment and grading of river stretch

Results

The IBI was calculated for each site following the methods of Fausch *et al. (*1984) and Hughes *et al. (*1993). We used the most desirable metric values as obtained at the least disturbed site *i.e.* Sisodra as estimates of the reference condition. The scoring criteria was developed for river Narmada (Table 12) as per the methods of Hughes *et al. (*1993).

In the present investigation, among the metric included in the index, all the metric changed. The number of native species and families in the reference site is significantly higher than that observed in the slight stressed zone. A comparison of the species composition revealed that the number of benthic species, the number of water column species and the number of intolerant species have reduced in sites where biotic integrity was found to be moderately impaired (Lilod, Jhanor, Shuklatirth, Bharuch and Bhadbhut). Whereas percentage of tolerant species have increased in these sites. The most common species at the disturbed sites were *Eutropiicththys vacha, Pethia conchonius, Mastacembelus armatus, Mystus cavasius, Rita rita, Otolithoides pama* and *Sperata aor.* The trophic compostion also showed alteration in the stressed sites (moderately impaired). Percent omnivores and carnivores increased and percent herbivores decreased. Fishes with disease or anomalies were not recorded during sampling. The index of fish assemblages decreased with distance downstream from undisturbed reference zone (Sisodra along Narmada River). Based on the modification of IBI Garudeshwar (S-1) and Sisodra (S-3) along river Narmada supported fish assemblages in acceptable condition (Table 11).

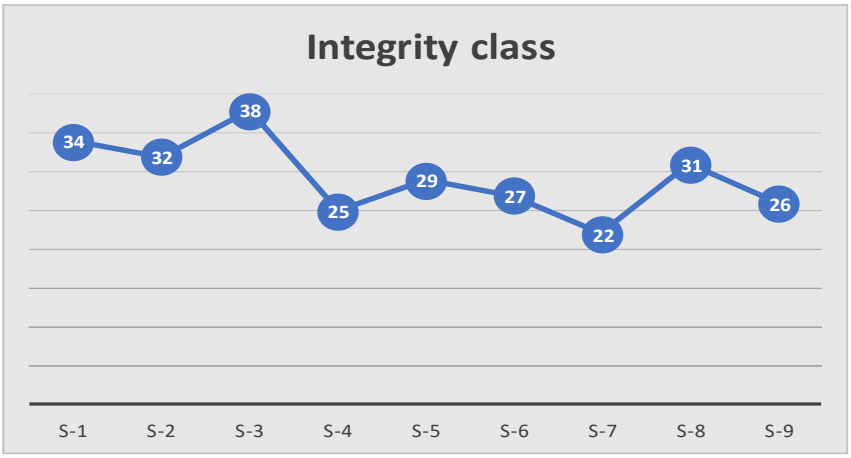


Fig. 40 Linear diagram representing integrity class of IBI at sampling sites
Value 34-38 = Acceptable; 22-32 = Moderately impaired

Remarks

From the present study, Sisodra was considered as the reference zone, being the least disturbed site with the highest fish diversity (Fig. 45). The remaining sampling sites along upstream and downstream to it recorded slight changes of IBI metrics. Garudeshwar and Sisodra were in the acceptable range. These sites thus reflected fewer disturbances with higher number of native species, intolerant, and herbivores. As such, environmental stress was minimal with the least effect on the fish assemblage. These sites can thus be inferred to support a healthy grade of fisheries. Significantly, one alien species, *Oreochromis niloticus* recorded from the Garudeshwar site in both seasons. The number of native species and native families is a measure of biological diversity and decreases with increasing anthropogenic disturbances (Karr, 1981). Whereas Poicha, Lilod, Shuklatirth, Bharuch, Sakkarpura and Bhadbhut were found to be moderately impaired. Though these sites were graded as moderately impaired as per IBI gradation, but all these sites are nearer to acceptable range which are significant as per as fish assemblage is concern. A little environmental stress at these sites. Sewage disposal, expulsion of waste on account of religious activities formed a source of major pollution at these sites. As such due to environmental stress, number of exotic (*viz. O. niloticus*) and tolerant species (*viz. R. rita, Channa*, *Aorichthys,* and *Mystus* species) had been recorded.

The decrease in number of benthic species and water column species is also indicative of deterioration of habitat quality. Both these metrics are strongly responsive to changes in water quality and habitat structure like siltation, turbidity, reduced oxygen content and toxic chemical. Water column species are active swimmers that feed on drifting and surface invertebrates or other fishes whereas benthic species are sensitive to siltation and benthic oxygen depletion because they feed and reproduce in benthic habitats (Ganasan and Hughes, 1998). Siltation and turbidity seem to be stressors in Bharuch, Lilod and Shuklatirth in the present study. Along with, the significant increase in the number of tolerant species and percent omnivores in the disturbed sites also indicate the deteriorated habitat in these sites. This is in agreement to the observation of Ganasan and Hughes (1998) who opined that tolerant fishes are opportunistic, invasive species that tend to be widely distributed and locally abundant, while intolerant fishes are more patchily distributed and not so abundant in anthropogenically stressed site. It is relevant to mention that though pollution to certain degree in stressed sites, water quality does not reflect significant contamination. Yet there is reduction in the IBI in Lilod and Bharuch. The possible reason could be the greater river width and presence of pools

adjacent to main channel respectively. In agreement to the opinion of Ganasan and Hughes (1998), it is felt that the metric scoring criteria require further evaluation, as do reference condition data from minimally disturbed sites. In the present investigation the site used as reference site might not be the ideal reference site as pristine sites in an ecoregion may not be always available as has been done in the investigation of Ganasan and Hughes (1998) and Das et al (2006).

In the present investigation, sampling sites were selected within a short longitudinal distance and did not cover all the climatic seasons for sampling, variations of environmental impact were little among the sampling sites, and these were also reflected in the IBI scores also. However, use of disturbed reference sites may be necessary for rehabilitating some of the worst conditions in an ecoregion; otherwise, in such water relation to natural conditions might be considered so unrealistic that nothing would be done and upstream reaches in better condition would continue to be degraded. Since the Sakkarpura and Bhadbhut sites are located in the tidal oscillation zone, therefore IBI scores may be varied from time to time, because of frequent visit of fishes with different trophic level. Overall, all sampling sites located in the study area are considered as acceptable and moderately impaired as per IBI scores with suitable ecological habitat and environmental flow.

Hydrological Assessment Using ADCP

An acoustic Doppler current profiler, or ADCP, is a device used worldwide to measure the speed and direction of currents throughout the water column by using sound waves. It provides information about how water in the rivers moves, and provides important information about the biological, chemical, and physical properties of the lotic water bodies.

During the post-monsoon sampling, an Acoustic Doppler Current Profiler (ADCP) survey was conducted along the lower stretch of the Narmada River, covering nine sites from Garudeshwar to Bhadbhut, representing an important transitional zone from regulated upstream reaches to the estuarine influence near the river mouth. The survey generated site-specific data on river width, discharge, flow velocity, and depth, which were further compared with available pre-monsoon depth and flow conditions to understand seasonal hydrological variability and its implications for river health and fisheries.

River Width and Channel Geometry

The river width showed a progressive downstream increase, reflecting channel expansion towards the estuarine zone. Width ranged from 213.7 m at Garudeshwar to 965.95 m at Bhadbhut, with notable widening at Bharuch (785.55 m) and Sakkarpura (589.9 m). This widening contributes to flow dispersion, reduced mean velocities, and enhanced lateral habitat diversity, which are critical for fish spawning, nursery grounds, and migratory pathways.

Discharge Characteristics

River discharge exhibited substantial spatial variation across sites. The lowest discharge (46.25 m^3/s) was recorded at Garudeshwar, indicating strong upstream regulation effects and reduced flow availability in the upper part of the lower stretch. Discharge increased downstream, reaching 693 m^3/s at Poicha, 1270 m^3/s at Bharuch, and peaking at 2095 m^3/s at Sakkarpura, before slightly declining at Bhadbhut (1430 m^3/s).
This increasing discharge trend downstream is attributed to tributary inflows, tidal backwater influence, and widening channel geometry. Compared to pre-monsoon flow velocities (0.32–1.30 m/s), present discharge conditions suggest enhanced post-monsoon flow connectivity, which is crucial for nutrient transport, sediment flushing, and maintenance of fish migration routes.

Flow Velocity Patterns

Maximum current velocities varied between 0.85 m/s (Jhanor) and 3.03 m/s (Bhadbhut), while mean velocities generally remained low to moderate (0.02–1.07 m/s) (Fig 16.). High maximum velocities at Bhadbhut and Garudeshwar indicate localized constrictions or tidal influence zones.

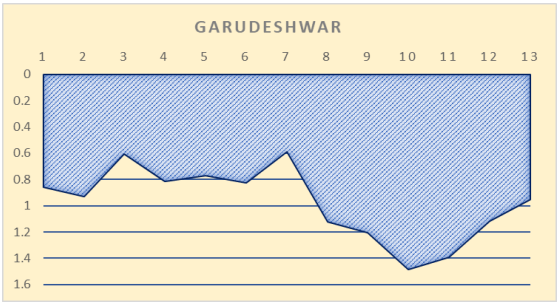
The overall low mean velocities at sites such as Lilod, Suklatirth, and Jhanor suggest the presence of low-energy habitats favourable for benthic and column-feeding fish species, whereas moderate to high velocities at Poicha, Sakkarpura, and Bharuch support migratory species and aid in preventing excessive sediment deposition.

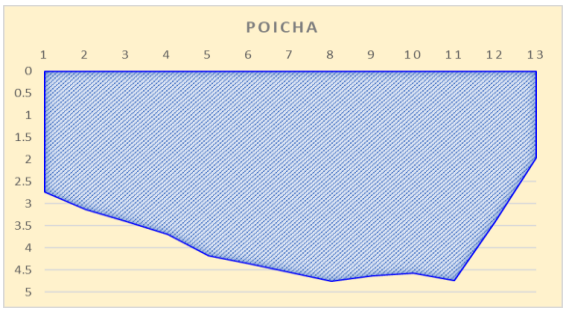
Depth Distribution and Comparison with Pre-monsoon Conditions

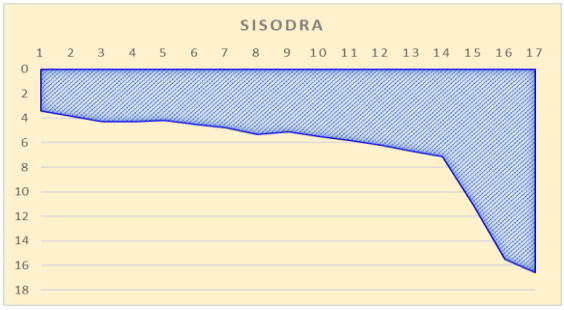
Maximum observed depths ranged from 1.56 m (Garudeshwar) to 17.0 m (Sisodara), while mean depths varied between 0.76 m (Garudeshwar) and 6.97 m (Jhanor) (Fig 15.). Deeper channel sections at Sisodara, Jhanor, and Lilod indicate the presence of pools that act as thermal refugia and resting zones for large-bodied fish, especially during lean periods. When compared with pre-monsoon depths, the present observations show a general reduction in depth at several locations (*e.g.,* Lilod: 9.6 m pre-monsoon vs. 4.93 m observed mean depth; Bharuch: 11.46 m vs. 4.29 m), indicating sediment redistribution and seasonal drawdown. Such depth reduction can directly affect fish refuge availability during lean seasons and intensify competition for space and oxygen (Table 13.).

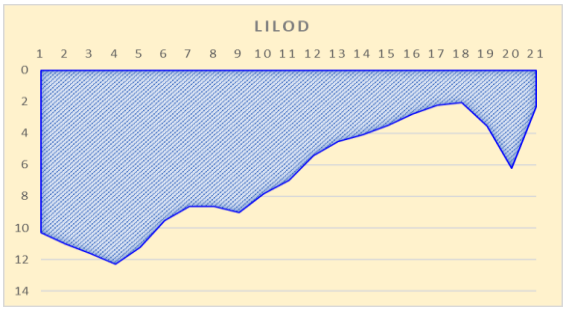
Table13: Hydrological parameters recorded from the selected sites of the river Narmada using ADCP.

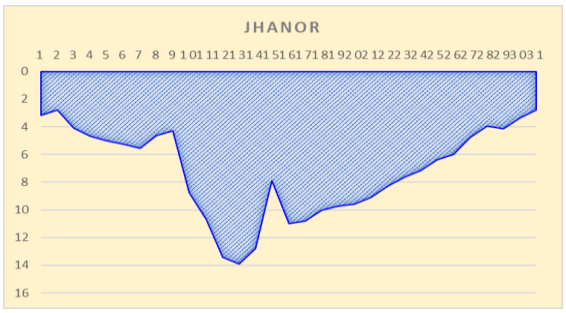
	Width	Discharge	Max. Vel	Mean Vel.	Max. Depth	Mean Depth
	(m)	(m^3/s)	(m/s)	(m/s)	(m)	(m)
Garudeshwar	213.70	46.25	2.69	0.17	1.56	0.76
Poicha	271.30	693.00	1.73	0.75	5.00	3.42
Sisodara	198.00	293.50	1.00	0.14	17.00	4.86
Lilod	242.50	150.00	1.77	0.02	12.30	4.93
Jhanor	461.70	540.00	0.85	0.17	15.45	6.97
Suklatirth	300.90	184.00	1.44	0.02	7.29	2.50
Bharuch	785.55	1270.00	1.49	0.36	6.50	4.29
Sakkarpura	589.90	2095.00	1.88	1.07	5.91	3.31
Bhadbhut	965.95	1430.00	3.03	0.23	9.81	4.13

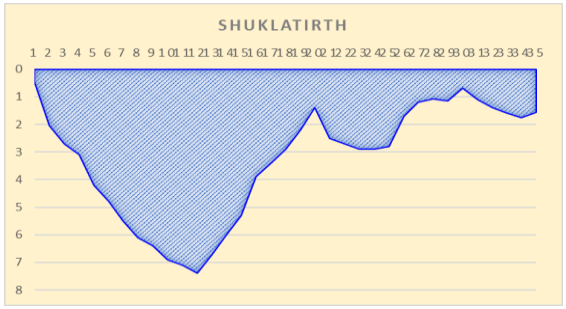

GARUDESHWAR
1 2 3 4 5 6 7 8 9 10 11 12 13
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

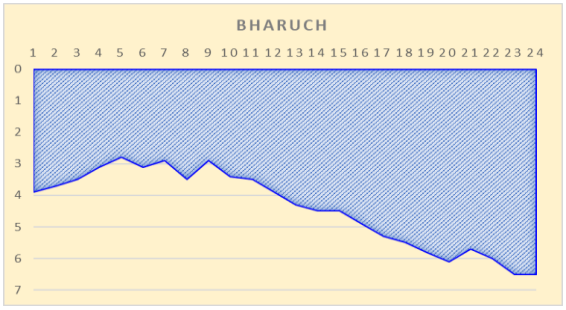

POICHA
1 2 3 4 5 6 7 8 9 10 11 12 13
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

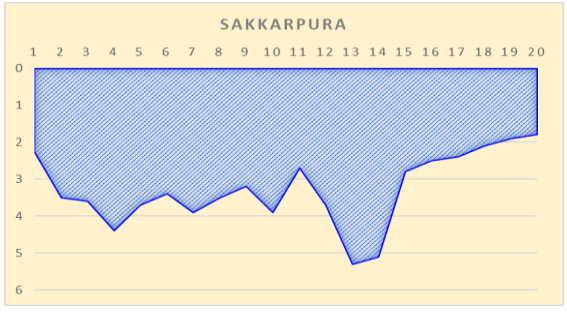

SISODRA
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
0
2
4
6
8
10
12
14
16
18


LILOD
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
0
2
4
6
8
10
12
14


JHANOR
0
2
4
6
8
10
12
14
16


SHUKLATIRTH
0
1
2
3
4
5
6
7
8


BHARUCH
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
0
1
2
3
4
5
6
7


SAKKARPURA
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
0
1
2
3
4
5
6

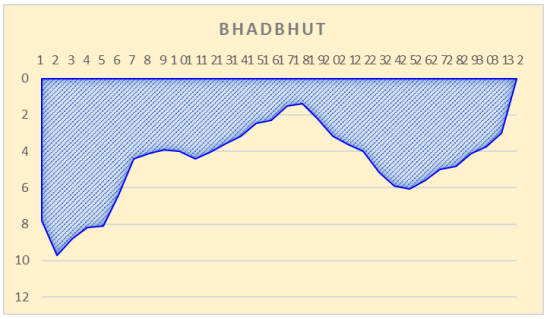
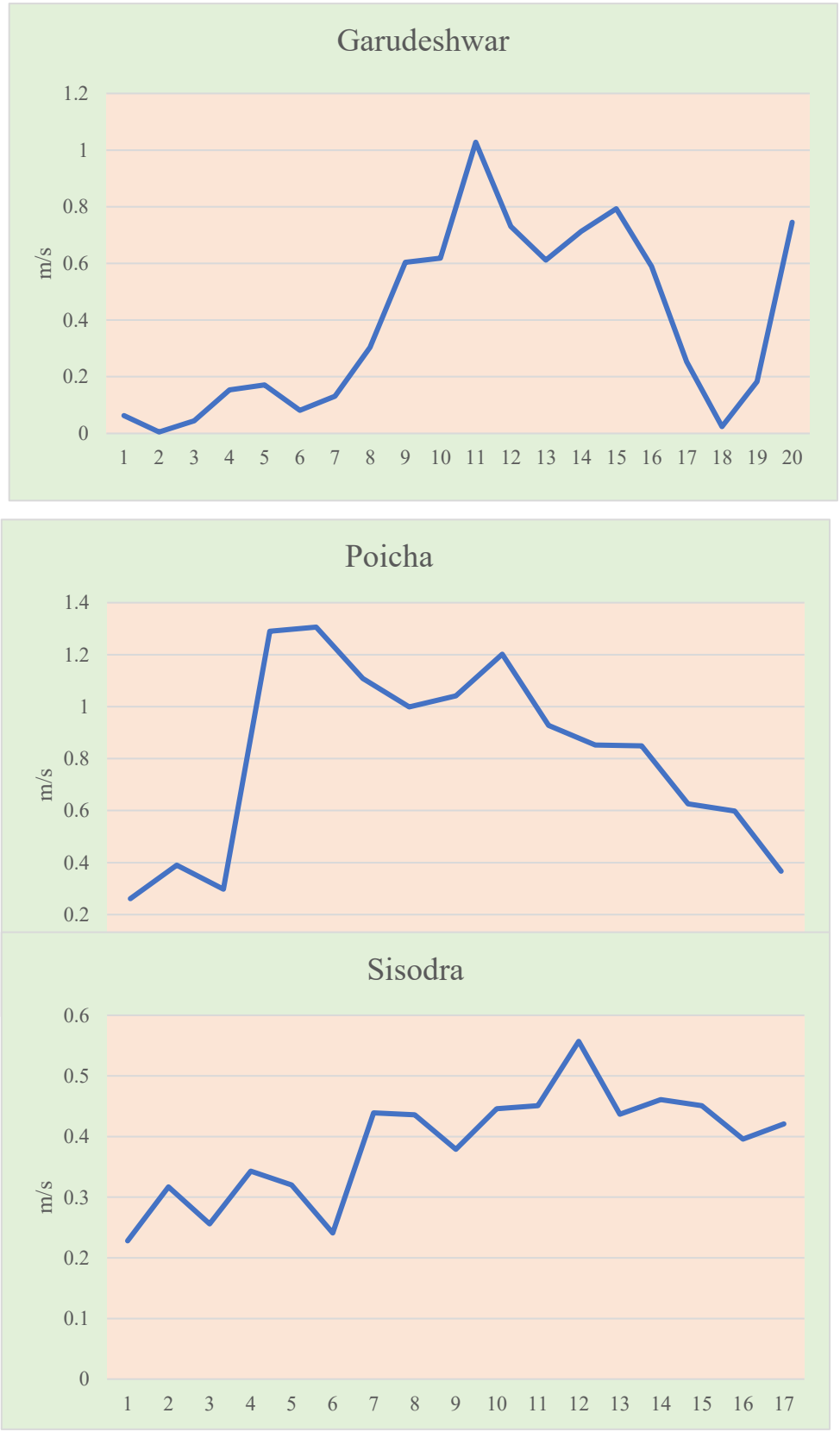
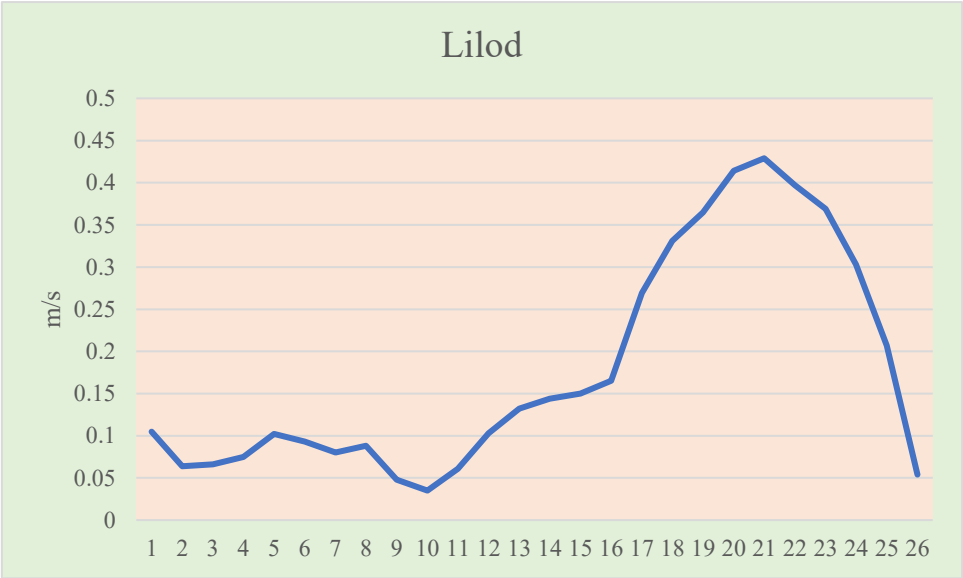
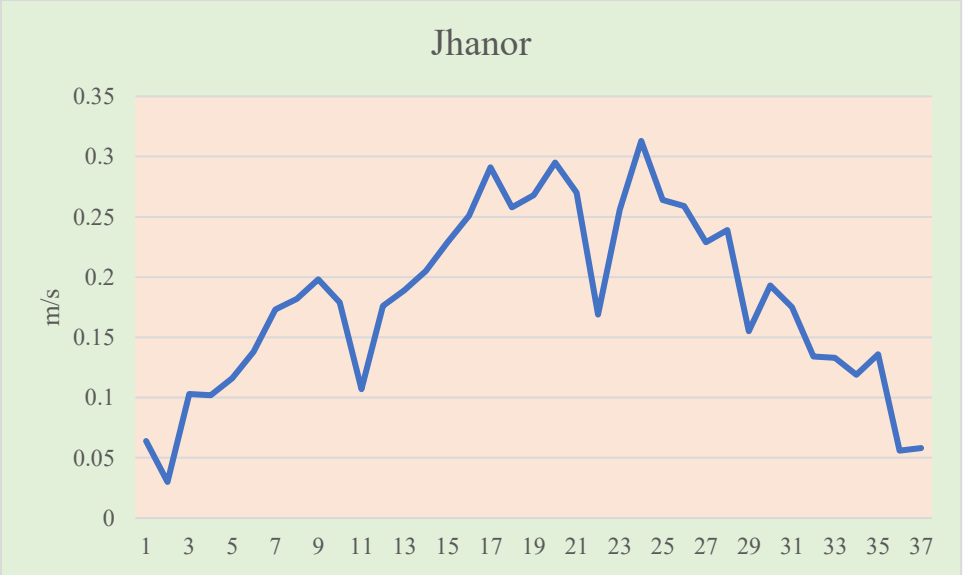

BHADBHUT
0
2
4
6
8
10
12

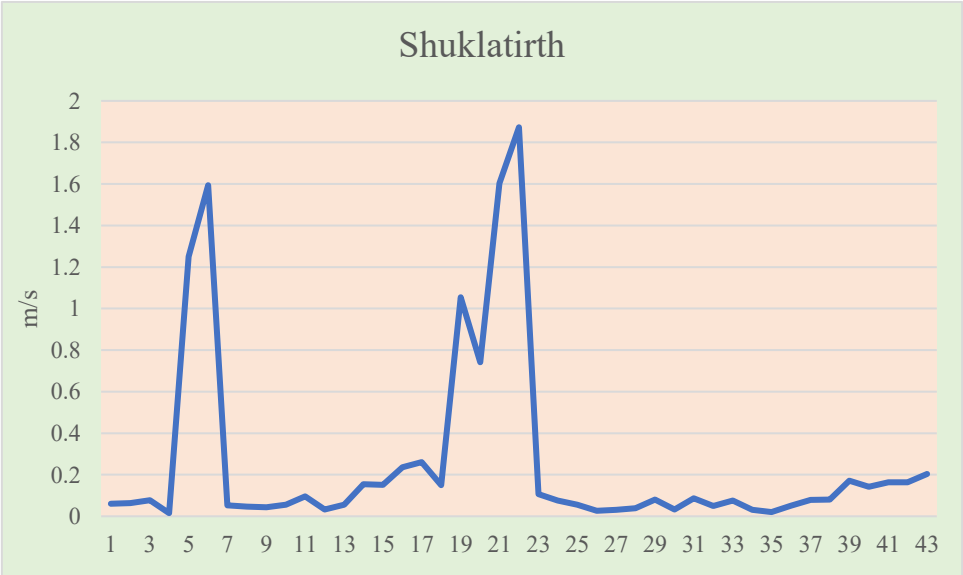
Fig 41. Graphical representation of site-wise cross-sectional depth (m.) measured by ADCP

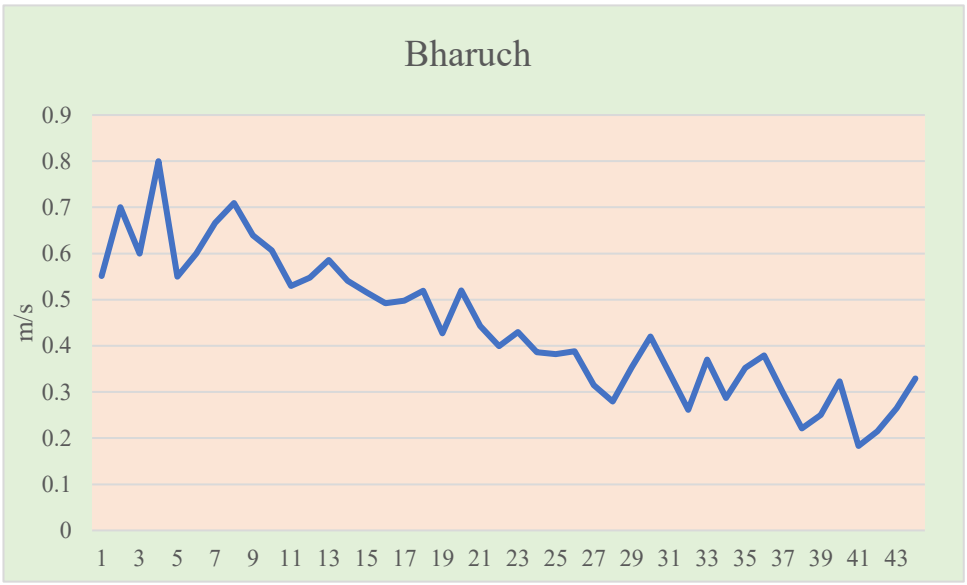
Fig 42. Diagrams representing site wise cross sectional water velocity measured by ADCP.

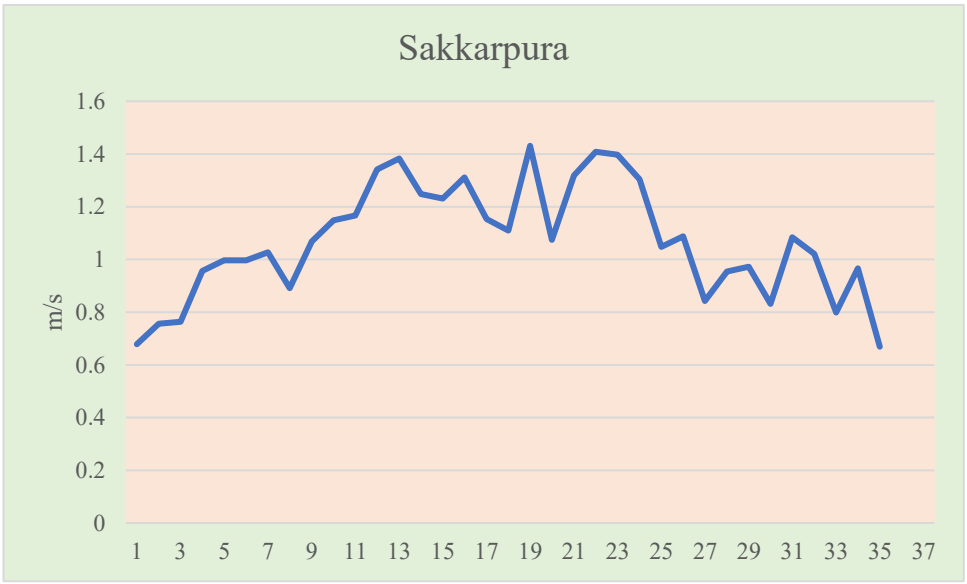


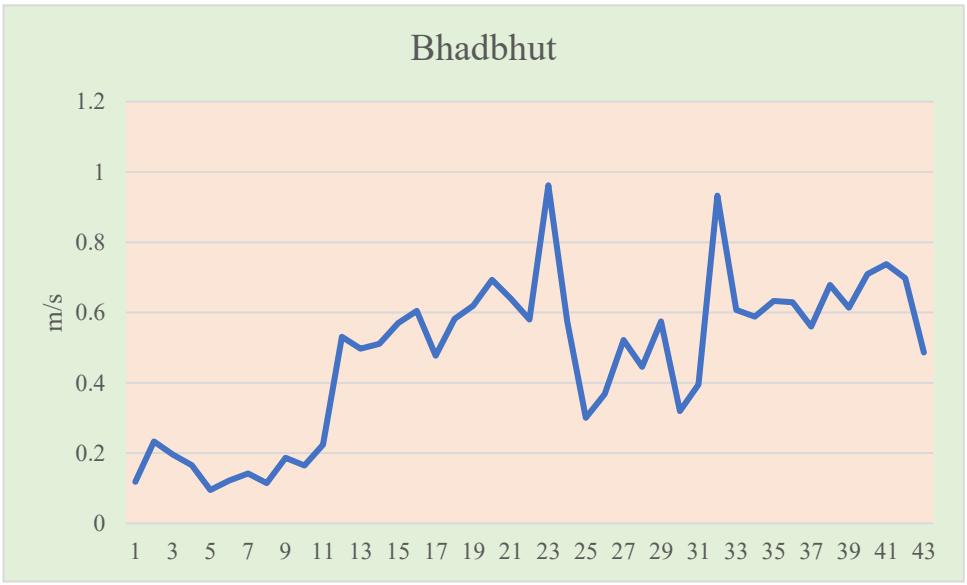

Lilod
m/s
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26


Jhanor
m/s
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37


Shuklatirth
m/s
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43


Bharuch
m/s
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43


Sakkarpura
m/s
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37


Bhadbhut
m/s
1.2
1
0.8
0.6
0.4
0.2
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43

Implications for River Health

The observed longitudinal gradient in width, discharge, and depth reflects a hydrologically dynamic but regulated river system. Reduced discharge at upstream sites such as Garudeshwar may impact longitudinal connectivity, whereas higher downstream discharge helps sustain estuarine productivity. However, sharp spatial variability in flow and depth suggests altered sediment dynamics, potentially affecting channel stability and habitat complexity.

Fisheries Perspective

From a fisheries standpoint, sections with moderate discharge (Poicha–Bharuch) and greater depth heterogeneity support better fish assemblage diversity, spawning grounds, and migratory movement. High-discharge zones such as Sakkarpura and Bhadbhut are particularly important for migratory fishes, providing hydraulic cues for upstream movement. Conversely, shallow and low-discharge zones upstream may pose barriers during critical life stages, especially for long-distance migratory species.

Water velocity and fish diversity

Water velocity in the river plays a crucial role in sustenance and fish diversity. It is a strong driver influencing habitat, spawning, and species assemblages. Natural variable flows from Dams favour generalist species. Diverse, heterogeneous habitats (e.g., rocky substrate with deep pools) generally support more species than a uniform, low-flow environment. Different fish species prefer specific flow requirements; for instance, some prefer fast-flowing, rocky environments while others prefer low-flowing environments. Higher spatial variation in flow, such as in rocky shallow stream habitats, typically supports higher species richness than deep uniform habitats. Ideal river water velocity varies widely from time to time, depending on ecological or engineering needs. A healthy river often flows between 0.3 m/s and 3.1 m/s. Moderate velocities are ideal for aquatic habitats, while rapid flow (> 2 m/s) is common in mountain streams, and lesser flow (< 0.5 m/s) is typical for low gradient rivers.

Table 14. Fish species assemblage in the sampling sites with respect to water velocity.

Sampling sites	Water velocity (m./sec.)		Important fishes	
	Maximum	Mean	No. of species	Major fish species
Garudeshwar	2.69	0.17	30	*Cirrhinus mrigala, Labeo boggut, Labeo calbasu, Labeo dyocheilus, Labeo rohita, Tor tor, Nandus nandus, Channa marulius, Clupisoma garua, Eutropiichthys vacha, Sperata aor, Sperata seenghala*
Poicha	1.73	0.75	23	*Labeo calbasu, Labeo boggut, Cirrhinus mrigala, Labeo boga, Labeo rohita, Tor tor, Clupisoma garua, Lates calcarifer, Sperata aor, Sperata seenghala, Ompok bimaculatus, Rita rita*
Sisodra	1.00	0.14	30	*Cirrhinus mrigala, Cirrhinus reba, Labeo boga, Labeo boggut, Labeo calbasu, Labeo gonius, Labeo rohita, Tor tor, Clupisoma garua, Eutropiichthys vacha, Lates calcarifer, Sperata aor, Sperata seenghala, Ompok bimaculatus, Wallago attu, Rita rita*
Lilod	1.77	0.02	16	*Cirrhinus mrigala, Labeo boga, Tor tor, Eutropiichthys vacha, Lates calcarifer, Ompok bimaculatus, Wallago attu, Rita rita,*
Jhanor	0.85	0.17	22	*Labeo boga, Labeo boggut, Labeo calbasu, Labeo rohita, Tor tor, Channa marulius, Clupisoma garua, Eutropiichthys vacha, Lates calcarifer, Sperata aor, Sperata seenghala , Wallago attu,*
Shuklatirth	1.44	0.02	12	*Cirrhinus mrigala, Eutropiichthys vacha, Lates calcarifer, Sperata seenghala, Otolithoides pama,*
Bharuch	1.49	0.36	16	*Labeo rohita, Eutropiichthys vacha, Eleutheronema tetradactylum, Lates calcarifer, Sperata aor, Ompok bimaculatus, Wallago attu, Otolithoides pama, Protonibea diacanthus,*

Sakkarpura	1.88	1.07	14	*Clupisoma garua, Tenualosa Ilisha, Lates calcarifer, Liza parsia, Otolithoides pama, Rita rita,*
Bhadbhut	3.03	0.23	13	*Cirrhinus reba, Channa striatus, Clupisoma garua, Eleutheronema tetradactylum, Tenualosa Ilisha, Lates calcarifer, Liza parsia, Otolithoides pama,*

During the study period, water velocity was measured in all the sampling sites. The maximum value (2.69 m/s) was recorded from the Garudeshwar site, and the minimum value (0.85 m/s) was recorded from Jhanor (Table. 14). In the present study, it has been observed that 63.8% species richness (n=30) was recorded from Garudeshwar and Sisodra sites, where water velocity varied from 1.0 to 2.69 (m./sec.) and mean velocity varied between 0.14 and 0.17 (m./sec.). In the Shuklatirth site, 25.5% of species richness (n=12) was recorded during the study period, where the maximum water velocity was recorded as 1.44 m/s, and the mean velocity was 0.02 m/s. which was a comparatively lower value of water velocity. Significantly maximum value of water velocity (3.03 m/s) was recorded from the Bhadbhut site, where the occurrence of fish species was significantly less (n=13). The above observations indicate that many aquatic species prefer higher velocity (2.0 to > 3.0 m/s), creating rapid and slow speed characterizing pools.

It is evident that water velocity in the rivers is not constant and varies based on slope, gradient, and channel roughness. During the exploration, water velocity recorded from all the sampling sites has been graded as moderate except Jhanor and Shuklatirth. As we know, moderate water velocities are ideal for aquatic habitats.

Major conclusions:

- The water and sediment quality (D.O, pH, Electrical conductivity, TDS, Salinity, Free CO_2, Total alkalinity, etc.) of the river Narmada, at the majority of the sites, had optimal water quality for fish and aquatic organisms. Physical parameters like water velocity and depth were also ascertained and found ideal for an aquatic habitat.

- In the present study, a total of 47 species of fish belonging to 20 families were recorded from the main channel of the river Narmada. The relative contribution of major groups of fishes, viz., carps, catfishes, ornamental, miscellaneous, and exotic fishes was 12.76%, 14.89%, 21.27%, 51.06 and 2.12 % respectively. It clearly indicates a diminishing presence of indigenous carp, catfish, an increase in miscellaneous, ornamental fishes, and the presence of invasive exotic fish species *Oreochromis niloticus.*

- A latest updated list of fish available in the main channel of the river Narmada is presented with clear, lively photographs and salient diagnostic characters for reference by workers interested in identifying available species.

- ADCP reading indicates that distinct spatial variations in hydrological conditions across the lower Narmada River persist. Comparison with pre-monsoon data indicates significant seasonal modulation of depth and flow, with clear implications for river health and fisheries sustainability. Maintaining ecological flow, especially in upstream sites like Garudeshwar, is essential to preserve habitat continuity, sediment balance, and fish migration pathways in the lower Narmada River system.

- Habitat profile of the selected sites has been portrayed during both seasons, and data indicate that overall acceptable conditions prevailed in each of the sampling sites.
- In the river Narmada from Garudeshwar to Bhadbhut, 9 sites were assessed in relation to their fish biotic integrity. Sisodra represented the reference site for IBI studies. It indicated that the stretches of Garudeshwar and Sisodra were in

acceptable condition in terms of fish assemblages; the remaining seven sites were moderately impaired, though the sites were nearer to acceptable condition.

- In general, it is assumed that the water velocity in the river was moderate and has diminished at two sites due to various anthropogenic activities in the form of hydraulic structures, water extraction, river channelling, sedimentation, and sand gravelling. This is also reflected in the diminished water velocity at Jhanor and Shuklatirth, altering the aquatic environment. This has definitely hampered the recruitment process of the carps, which require inundation of the floodplains for spawning. The decrease in major carp abundance in the river is evident, along with a significant rise in the exotic carp (n=1) because of favourable habitat for the latter. During the present investigation, there are no such conditions prevailing in the highest degree except water lifting from the river in one site, and it has reflected in fish diversity (n=47) and ecological integrity of the study area.
- The riverine fisheries offer the main economic activity to our fishermen, and it would be necessary to link the improvement of environmental flow with the biotic community, particularly fish diversity. It has been considered that fish and their presence with rich diversity in the river will ultimately indicate the level of ecological integrity.
- SSNL is committed to provide the time series hydrological discharge data with the river cross sections at all 9 sampling sites for estimation of fish based environmental flow. Final estimation will be made once these data are available to ICAR-CIFRI. This will support towards aquatic species restoration, livelihood improvement and nutritional security of those people associated with the river Narmada.

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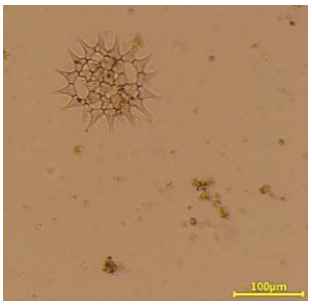
2. Fausch, K.D., Karr and Yant, P.R. 1984. Regional application of an index of biotic integrity based on stream fish communities. *Transactions of the American Fisheries Society*, 113:39-55.
3. Hughes, R.M., Kaufmann, P.R., Herlihy, A.T., Kincaid, T.M., Reynolds and Larsen, D.P.1998. A process for developing and evaluating indices of fish assemblages' integrity. *Canadian Journal of Fisheries and Aquatic Sciences*, 55.
4. Ganasan, V. and Hughes, R.M. 1998. Application of an index of biological integrity (IBI) to fish assemblages of the rivers Khan and Kshipra (Madhya Pradesh), India, Freshwater Biology, 40(2):361-384.
5. Hughes, R.M., Kaufmann, P.R., Herlihy, A.T., Kincaid, T.M., Reynolds and Larsen, D.P.1998. A process for developing and evaluating indices of fish assemblages' integrity. *Canadian Journal of Fisheries and Aquatic Sciences*, 55.
6. Ganasan, V. and Hughes, R.M. 1998. Application of an index of biological integrity (IBI) to fish assemblages of the rivers Khan and Kshipra (Madhya Pradesh), India, Freshwater Biology, 40(2):361-384.
7. Das, M.K. & Samanta, S. 2006. Application of an index of biotic integrity (IBI) to the fish assemblage of the tropical Hooghly estuary. *Indian Journal of Fisheries*. 53(1):47-57.

Annexure 1

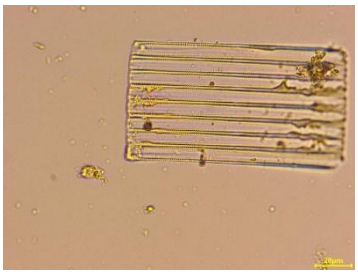
Commonly Recorded phytoplankton Taxa during the pre and post monsoon study



Pediastrum simplex

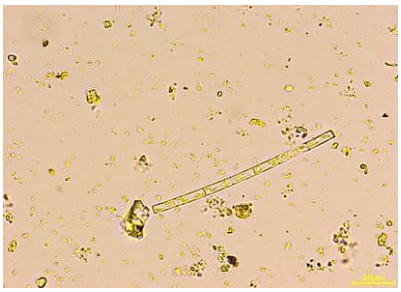
Closterium sp.

Coscinodiscus sp.

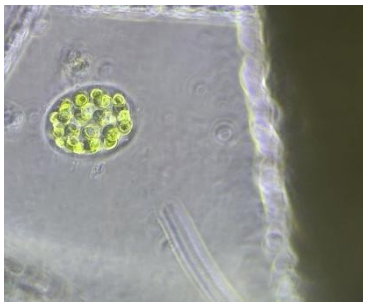


Fragilaria sp.

Ceratium sp.

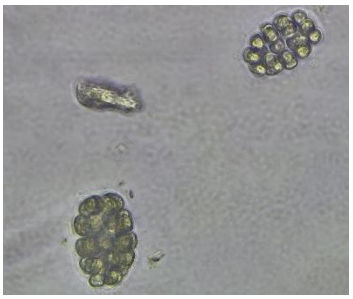


Spirogyra sp.



Eudorina sp.

Staurastrum sp.



Coelastrum sp.

Annexure 2

Commonly Recorded Zooplankton Taxa during the premonsoon study

Copepods

Mesocyclops sp.

Daphnia sp.

Acanthocyclops

Keratella sp.

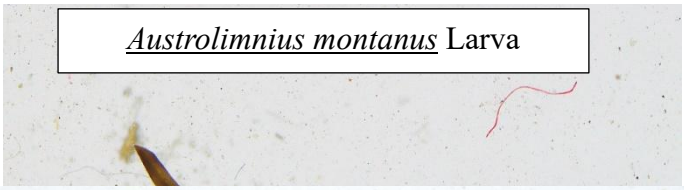
Annexure 3

Common Benthic Macroinvertebrates Identified during the pre and post monsoon study

Prawn larvae

Crab juvenile

Aulodrilus sp.



Austrolimnius montanus Larva

Thiara scabra

Syllidae sp.

Fish larvae

Gnorimosphaeroma sp.

Prostoma sp.

Tarebia lineata

Parreysia caerulea

Indoplanorbis exustus

Agabus binotatus

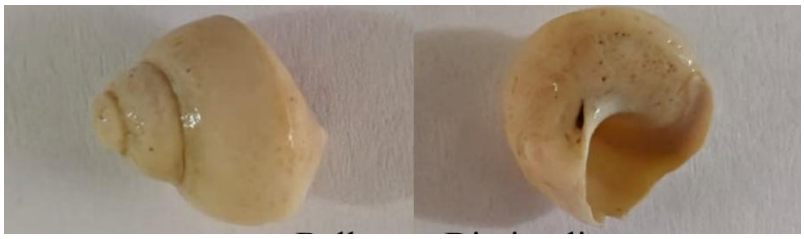
Tarebia granifera

Bellamya crassa

Thiara tuberculata

Corbicula striatella

Parreysia favidens



Bellamya dissimilis

Images of habitat profile (Pre-monsoon)

Site-I (Garudeshwar)

Elevation (msl.)	60.57 m.
Width of channel (wetted)	300 m.
Width of channel (Bank to bank)	800 m.
Depth (Av.)	3.5 m.
Water velocity	130 cm/sec.
Substrate composition	Boulders 25%, coarse sand 45%, gravels 10%, clay and others 20%.
Deep pools	2 nos. identified with average depth of 18.5 ft.
Riparian vegetation	Trees 45%, Herbs 15%, Shrubs 25%, grass land 15%
GPS Coordinates	N 21.887099, E 73.656058
Other information	Check dam constructed, Ritual activities by the local people were visualized, temple exist. No pollution sources were recorded.

Site-II (Poicha)

Elevation (msl.)	36 m.
Width of channel (wetted)	300 m.
Width of channel (Bank to bank)	800 m.
Depth (Av.)	3.26 m.
Water velocity	110 cm./sec.
Substrate composition	Coarse sand 25%, gravels 15%, cobbles 10% clay and others 50%.
Deep pools	1 no (depth 12 m.)
Riparian vegetation	Trees 40%, Herbs 20%, Shrubs 25%, grass land 15%
GPS Coordinates	N 21.975716, E 73.458628
Other information	Pollution source not recorded, bank soil erosion observed, instream cover not found.

Site-III (Sisodra)

levation (msl.)	37.3 m.
Width of channel (wetted)	200 m.
Width of channel (Bank to bank)	800 m.
Depth (Av.)	3.9 m.
Water velocity	75 cm./sec.
Substrate composition	Small gravels 15%, sand 35%, clay and others 50%
Deep pools	Not recorded
Riparian vegetation	Trees 35%, shrubs 15%, herbs 15%, grass land 25%
GPS Coordinates	N 21.913903, E 73.347048
Other information	Ritual activities visualized, sources of pollution not found.

Site-IV (Lilod)

Elevation (msl.)	29.5 m.
Width of channel (wetted)	500 m.
Width of channel (Bank to bank)	700 m.
Depth (Av.)	9.6 m.
Water velocity	85 cm./sec.
Substrate composition	Sandy clay and others 100%
Deep pools	Recorded (1 no. with 30 m. depth)
Riparian vegetation	Trees 40%, shrubs 10%, herbs 15%, grass land 35%

GPS Coordinates	N 21.878093, E 73.233343
Other information	Temple exist, no significant pollution discharge source identified.

Site-V (Jhanor)

Elevation (msl.)	20 m.
Width of channel (wetted)	450 m.
Width of channel (Bank to bank)	700 m.
Depth (Av.)	5.46 m.
Water velocity	32 cm. /sec.
Substrate composition	Sandy clay
Deep pools	Not recorded
Riparian vegetation	Trees 20%, shrubs 25%, herbs 15%, grass land 40%
GPS Coordinates	N 21.8388, E 73.134
Other information	Water lifting pump installed in the bank of the river, no pollution sources were found.

Site-VI (Shuklatirth)

Elevation (msl.)	36.9 m.
Width of channel (wetted)	400 m.
Width of channel (Bank to bank)	700 m.
Depth (Av.)	4.7 m.
Water velocity	47 cm. / sec.
Substrate composition	Sandy clay
Deep pools	Not recorded
Riparian vegetation	Trees 15%, shrubs 25%, herbs 20%, grass land and others 40%
GPS Coordinates	N 21.747727, E 73.123398

Other information	Ritual activities observed as the site considered as one of the holiest shrines.

Site-VII (Bharuch)

Elevation (msl.)	15.9 m.
Width of channel (wetted)	700 m.
Width of channel (Bank to bank)	1000 m.
Depth (Av.)	11.46 m.
Water velocity	35 cm./sec.
Substrate composition	Clay and organic materials
Deep pools	Not recorded
Riparian vegetation	Trees 20%, shrubs 25%, herbs 20%, grass land and others 35%

GPS Coordinates	N 21.690182, E 73.00644
Other information	Urban area, city sewage being discharged into the river, railway and road bridge constructed over the river.

Site-VIII (Sakkarpura)

Elevation (msl.)	14.8 m.
Width of channel (wetted)	500 m.
Width of channel (Bank to bank)	700 m.
Depth (Av.)	5.2 m.
Water velocity	45 cm./sec.
Substrate composition	Sandy clay
Deep pools	Not recorded
Riparian vegetation	Trees 25%, shrubs 15%, herbs 10%, grass land and others 50%

GPS Coordinates	N 21.682, E 73.907
Other information	Water lifting pump installed in the shoreline of the river, no instream cover was recorded.

Site-IX (Bhadbhut)

Elevation (msl.)	17.47 m.
Width of channel (wetted)	900 m.
Width of channel (Bank to bank)	1200 m.

Depth (Av.)	7.76 m.
Water velocity	56 cm./sec. (Synchronized with the tidal effect)
Substrate composition	Sandy clay
Deep pools	Not recorded
Riparian vegetation	Rich riparian vegetation (Trees, shrubs, herbs, grass land and others)
GPS Coordinates	N 21.680952, E 73.845297
Other information	Island formed in the middle of the river, Temples are located on the bank of the river, barrage under construction.

Images of habitat (post-monsoon)




Site-1 (Garudeshwar)

Site-2 (Poicha)




Site-3 (Sisodra)

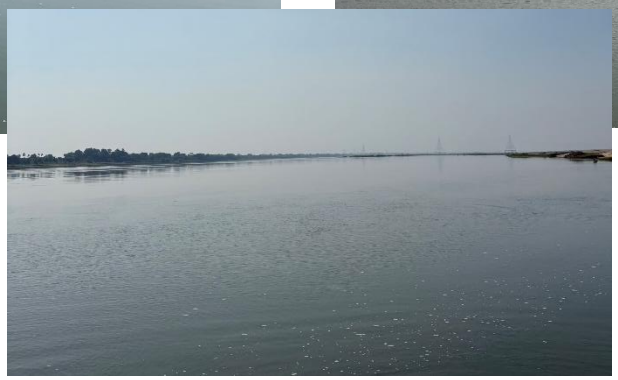



Site-4 (Lilod)

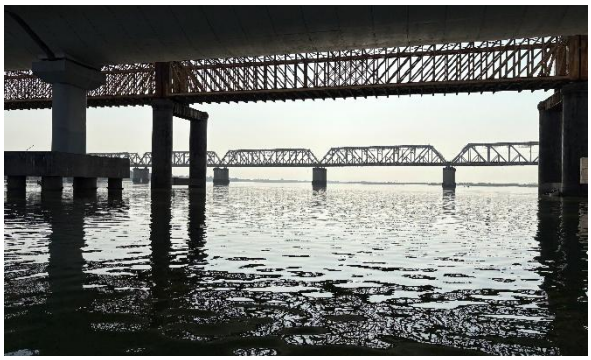



Site-5 (Jhanor)





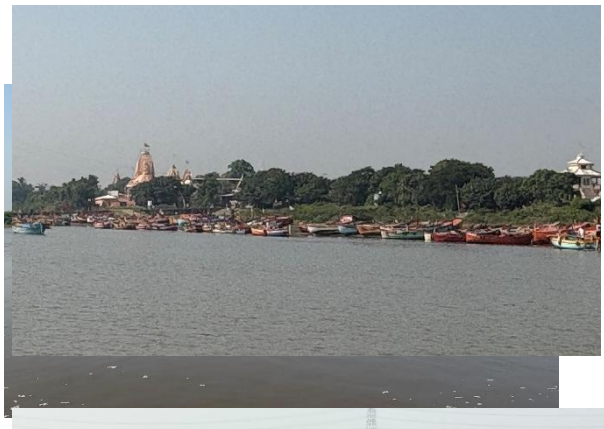
Site-6 (Shuklatirth)

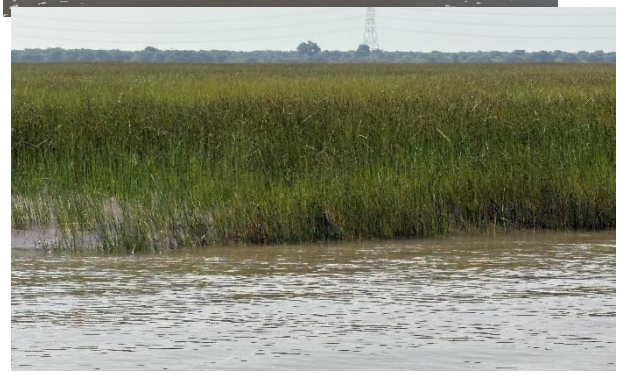


Site-7 (Bharuch)

Site-8

(Sakkarpura)





Site-9 (Bhadbhut)

Images of field activities