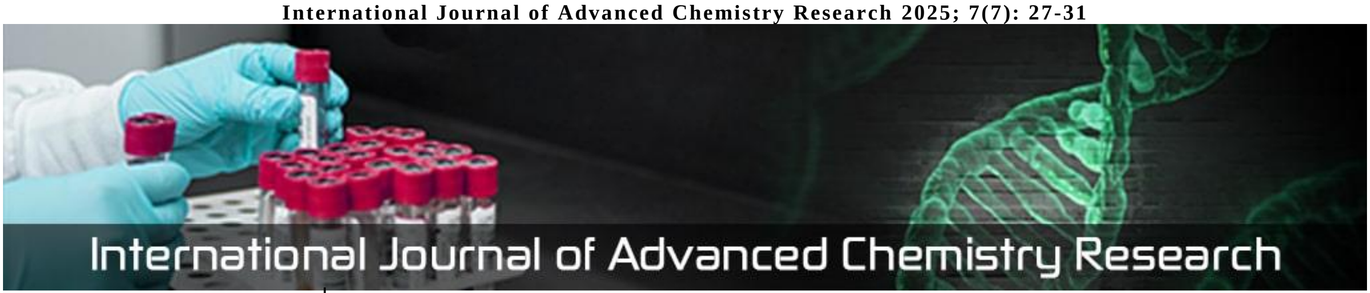

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Seasonal variation in water chemistry of mahseer (*Tor* spp.) breeding sites in the Narmada River, Jabalpur district

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Abstract
The present study assessed the physico-chemical characteristics of the Narmada River across four selected sites (T1-T4) within Jabalpur district over a 12-month period from April 2023 to March 2024. Monthly water samples were analyzed to evaluate seasonal variations and ecological stability using standard methodologies. The parameters examined included water temperature, pH, dissolved oxygen (DO), free carbon dioxide (CO_2), alkalinity, and ammonia (NH_3). Results indicated thermally stable conditions throughout the year, with temperature fluctuations remaining within a narrow range (27.48 °C to 29.39 °C). pH levels were consistently within a neutral to slightly alkaline range (7.58-7.94), favoring biological productivity and nutrient availability. DO levels remained above the critical threshold of 6.5 mg/l, supporting a healthy aquatic ecosystem conducive to the survival of sensitive species like Mahseer. Low CO_2 concentrations and stable alkalinity values reflected a well-buffered system, while ammonia levels were minimal (0.03-0.04 mg/l), indicating negligible anthropogenic pollution. The overall findings suggest that the studied stretch of the Narmada River maintains good water quality and ecological balance, although localized human activities may still pose risks. Continued monitoring is essential for the sustainable conservation of this important riverine habitat.

Keywords: Physico-chemical parameters, Narmada River, mahseer habitat, water quality assessment

Introduction
The Narmada River, with a total length of approximately 1,312 kilometers, is one of the major west-flowing rivers in India and ultimately drains into the Arabian Sea near Bharuch in Gujarat (CWC, 2015) [5]. Its extensive drainage basin spans an area of about 98,796 square kilometers, covering parts of Madhya Pradesh, Gujarat, and Maharashtra (NRSC, 2016) [9]. The basin plays a pivotal role in regional water balance, agriculture, and ecological stability. Among the significant aquatic fauna of the Narmada River is the Mahseer, a group of large freshwater cyprinid fishes belonging to the genus *Tor*. These fishes are widely distributed across rivers and streams of South and Southeast Asia and are renowned for their ecological, cultural, and economic importance, particularly in sport fishing and subsistence fisheries. In India, notable species such as *Tor tor*, *Tor putitora*, and *Tor khudree* are reported from several major river systems, including the Ganges, Yamuna, Narmada, and Cauvery.
Mahseer are highly sensitive to environmental changes and are considered reliable bio-indicators of riverine ecosystem health. Their reproductive success depends on specific physico-chemical conditions, such as clean, well-oxygenated water, gravelly or rocky substrates, and moderate to fast-flowing currents (Ogale, 2002; Nautiyal, 1994) [12, 10]. Consequently, evaluating and monitoring the water quality of their breeding habitats-especially in ecologically critical rivers like the Narmada-is essential for species conservation and sustainable management.
Water quality assessment in aquatic ecosystems generally involves two complementary approaches: physico-chemical and biological. Physico-chemical analysis provides insights into the presence and concentration of various substances or pollutants, while biological methods reflect their cumulative effects on aquatic life. When both sets of data are integrated, a more comprehensive and holistic understanding of the ecological status and

pollution impacts of a water body can be achieved (Saini *et al*., 2015) [15]. Despite its ecological and socio-economic importance, comprehensive studies on the water quality of the Narmada River remain limited. Recent investigations, such as those conducted by Gupta *et al*. (2017) [8], have employed multiple water quality indices including the Weighted Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index (NSFWQI), and the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI)-to assess the river's suitability for human and environmental use.

Although the Narmada River near Jabalpur has historically provided ideal conditions for Mahseer breeding, recent anthropogenic activities such as dam construction, habitat fragmentation, and unregulated sand mining have negatively impacted its ecological integrity. Nevertheless, certain river stretches characterized by slower flow rates and shallower depths continue to offer favorable conditions for Mahseer spawning (Tiwari *et al*., 2024) [16].

Material and Methodology

The present investigation was carried out between April 2023 and March 2024, focusing on a selected 20-kilometre stretch of the Narmada River within the Jabalpur district of Madhya Pradesh. Four sampling sites-Bedhaghat (T_1), Tilwaraghat (T_2), Gwarighat (T_3), and Lametaghat (T_4)-were systematically chosen to represent ecologically and geographically distinct locations along this river segment.

Bedhaghat (T_1), located at 23.1306° N latitude and 79.8024° E longitude, defines the upstream boundary of the study area and is known for its relatively undisturbed riverine conditions. Progressing downstream, Tilwaraghat (T_2) is situated at 23.1079° N and 79.8758° E, followed by Gwarighat (T_3) at 23.1100° N and 79.9277° E-both of which experience moderate anthropogenic influence. The final site, Lametaghat (T_4), positioned at 23.1118° N and 79.8356° E, marks the downstream limit of the study area and is characterized by a combination of religious, recreational, and urban activities. The selection of these sites was guided by their ecological relevance, gradient along the river continuum, and potential suitability as Mahseer breeding habitats.

Sample Collection and Water Quality Analysis

To evaluate the physico-chemical characteristics of the Narmada River across the selected study sites, a set of standard water quality parameters was periodically monitored from April 2023 to March 2024. Water samples were collected fortnightly from each of the four designated sites-Bedhaghat (T_1), Tilwaraghat (T_2), Gwarighat (T_3), and Lametaghat (T_4)-using clean, labeled plastic bottles. Immediately after collection, the samples were transported to the laboratory for analysis. All physico-chemical analyses were carried out following the Standard Methods for the Examination of Water and Wastewater as prescribed by the American Public Health Association (APHA, 2012) [2]. The parameters analyzed and corresponding methodologies are outlined below

- **Water Temperature:** Water temperature was measured in situ at the time of sampling using a digital thermometer. This parameter is critical as it influences the metabolic activity of aquatic organisms, the solubility of gases, and the rate of chemical reactions in the aquatic environment (APHA, 2012) [2].
- **PH:** The pH of water samples was determined using a portable digital pH meter, which was calibrated before each use with standard buffer solutions (pH 4.0, 7.0, and 9.2). PH is an essential parameter that indicates the acidic or alkaline nature of water and plays a significant role in the survival and reproduction of aquatic organisms (APHA, 2012) [2].
- **Dissolved Oxygen (DO):** Dissolved oxygen was estimated by the Winkler titration method, which involves fixing the oxygen in the sample with manganese sulfate and alkaline iodide-azide reagents, followed by acidification and titration with sodium thiosulfate. DO levels reflect the oxygenation status of the water, which is vital for the survival of aquatic fauna (APHA, 2012) [2].
- **Free Carbon Dioxide (CO_2):** Free carbon dioxide was quantified by titrating the water sample with standard sodium hydroxide (NaOH), using phenolphthalein as an indicator. The appearance of a permanent pink coloration marked the endpoint. CO_2 concentration is a key indicator of carbon dynamics and buffering capacity in freshwater ecosystems (APHA, 2012) [2].
- **Alkalinity:** Alkalinity, representing the water's capacity to neutralize acids, was measured by titration with standard sulfuric acid (H_2SO_4), using phenolphthalein and methyl orange as indicators. Results were expressed in mg/L as calcium carbonate ($CaCO_3$). This parameter plays a role in pH regulation and aquatic productivity (APHA, 2012) [2].
- **Ammonia (NH_3):** Ammonia concentration was measured using the Nesslerization method. The water sample was treated with Nessler's reagent, resulting in a yellow to brown coloration depending on the ammonia level. The intensity of color was then measured using a spectrophotometer at 425 nm. Elevated ammonia levels are indicative of organic pollution and can be toxic to aquatic life (APHA, 2012) [2].

Results & Discussion

The physico-chemical parameters of the Narmada River were monitored monthly across four sampling sites (T1-T4) over a 12-month period (April 2023 to March 2024), and their mean values with standard deviations were analyzed to identify seasonal trends and ecological stability.

Water temperature (Table 1) varied from 27.48 °C in July to 29.39 °C in April, with monthly averages ranging between 27.84 ± 0.63 °C and 29.02 ± 0.31 °C. The narrow range and low standard deviations (<1 °C) indicate stable thermal conditions throughout the year. Such consistency supports the metabolic activities and survival of freshwater fish, particularly ectothermic species that are highly sensitive to ambient temperature fluctuations (Boyd, 1982; Wetzel, 2001) [4, 17].

The pH levels (Table 2) remained relatively stable, ranging from 7.58 to 7.94. This neutral to slightly alkaline range is considered optimal for enzymatic activity, nutrient availability, and overall aquatic productivity. Additionally, these pH conditions help mitigate the toxicity of un-ionized ammonia, which tends to increase with higher pH levels (Emerson *et al*., 1975) [6]. Dissolved oxygen (Table 3) levels were consistently above 6.5 mg/l throughout the study period, ensuring suitable conditions for the sustenance of aquatic organisms, including sensitive species such as Mahseer. The values remained well within the range considered safe for most freshwater biota. Free carbon dioxide concentrations (Table 4) were low and exhibited minimal variability, ranging from 0.21 to 0.29 mg/l, with standard deviations between ±0.0132 and ±0.0308 mg/l. This stability reflects a well-balanced interplay between photosynthesis and respiration within the aquatic ecosystem (Goldman & Horne, 1983) [7]. When considered alongside the stable pH, these values suggest a strong buffering capacity in the river system.

Alkalinity (Table 5) displayed more variability compared to other parameters, with values ranging from 130.13 to 150.84 mg/l. The highest average alkalinity was recorded in February (144.97±2.73 mg/l), while the largest fluctuation occurred in August (±7.62 mg/l). These variations may be influenced by seasonal runoff, sediment transport, or bicarbonate input during the dry season (APHA, 2012) [2]. Ammonia (NH_3) concentrations (Table 6) remained consistently low throughout the study period, ranging from 0.03 to 0.04 mg/l with minimal variation (±0.01 mg/l). These levels fall within the safe range for freshwater organisms and indicate efficient nitrogen cycling. The absence of elevated ammonia levels further suggests minimal contamination from domestic or agricultural sources, pointing to a well-maintained and ecologically balanced river stretch (Randall & Tsui, 2002) [14].

Table 1: Temperature range of experimental site of Narmada River water

Month	Temperature T_1 (°C)	Temperature T_2 (°C)	Temperature T_3 (°C)	Temperature T_4 (°C)	Mean ± SD (°C)
Apr	28.84	29.39	28.7	29.17	29.02±0.31
May	27.8	29.26	27.65	28.34	28.26±0.73
Jun	29.1	28.69	27.23	28.74	28.44±0.83
Jul	27.51	28.79	27.48	27.58	27.84±0.63
Aug	27.96	29.03	28.74	27.55	28.32±0.68
Sep	28.91	28.44	27.93	28.99	28.57±0.49
Oct	28.45	28.92	27.42	29.18	28.49±0.78
Nov	27.74	27.82	27.43	27.98	27.74±0.23
Dec	28.53	27.83	27.8	27.35	27.88±0.49
Jan	28.81	27.95	27.61	29.14	28.38±0.72
Feb	29.09	29.32	27.78	28.63	28.70±0.68
Mar	28	29.03	28.49	28.03	28.39±0.48

Table 2: pH range of experimental site of Narmada River water

Month	pH (T_1)	pH (T_2)	pH (T_3)	pH (T_4)	Mean ± SD (pH)
Apr	7.66	7.52	7.87	7.86	7.73±0.17
May	7.75	7.69	7.87	7.84	7.79±0.08
Jun	7.62	7.68	7.83	7.8	7.73±0.10
Jul	7.9	7.55	7.88	7.85	7.80±0.16
Aug	7.7	7.62	7.81	7.85	7.74±0.10
Sep	7.73	7.62	7.82	7.71	7.72±0.08
Oct	7.69	7.53	7.82	7.77	7.70±0.13
Nov	7.62	7.69	7.88	7.79	7.74±0.11
Dec	7.79	7.57	7.86	7.85	7.77±0.14
Jan	7.69	7.69	7.85	7.72	7.74±0.08
Feb	7.77	7.64	7.8	7.87	7.77±0.10
Mar	7.89	7.57	7.86	7.75	7.77±0.14

Table 3: Dissolved oxygen range of experimental site of Narmada River water

Month	Dissolved oxygen (mg/l) (T_1)	Dissolved oxygen (mg/l) (T_2)	Dissolved oxygen (mg/l) (T_3)	Dissolved oxygen (mg/l) (T_4)	Mean ± SD (DO)
Apr	6.85	7.18	7.07	6.84	6.98±0.17
May	7.01	7.13	7.07	6.64	6.96±0.22
Jun	6.84	6.97	6.96	7.09	6.96±0.10
Jul	6.75	7.12	6.56	6.81	6.81±0.23
Aug	6.63	6.83	6.75	7.11	6.83±0.20
Sep	6.78	7.24	6.45	7.17	6.91±0.37
Oct	6.9	7.25	7.09	7.03	7.07±0.15
Nov	6.89	6.95	6.87	6.87	6.90±0.04
Dec	7.08	7.02	6.53	6.69	6.83±0.26
Jan	6.99	6.91	6.43	7.27	6.90±0.35
Feb	6.85	6.97	6.97	7.09	6.97±0.10
Mar	6.66	6.96	6.98	6.92	6.88±0.15

Table 4: CO_2 range of experimental site of Narmada River water

Month	CO_2 (mg/l) (T_1)	CO_2 (mg/l) (T_2)	CO_2 (mg/l) (T_3)	CO_2 (mg/l) (T_4)	(Mean ± SD)
Apr	0.26	0.23	0.26	0.25	0.25±0.0132
May	0.23	0.22	0.28	0.26	0.25±0.0260
Jun	0.25	0.23	0.28	0.26	0.26±0.0208
Jul	0.23	0.25	0.29	0.24	0.25±0.0255
Aug	0.25	0.23	0.27	0.25	0.25±0.0173
Sep	0.23	0.23	0.29	0.24	0.25±0.0273
Oct	0.25	0.24	0.26	0.25	0.25±0.0082
Nov	0.26	0.22	0.27	0.25	0.25±0.0192
Dec	0.22	0.23	0.28	0.25	0.25±0.0251
Jan	0.23	0.24	0.28	0.24	0.25±0.0212
Feb	0.23	0.23	0.26	0.25	0.24±0.0132
Mar	0.21	0.24	0.28	0.24	0.24±0.0308

Table 5: Alkalinity range of experimental site of Narmada River water

Month	Alkalinity (mg/l) (T_1)	Alkalinity (mg/l) (T_2)	Alkalinity (mg/l) (T_3)	Alkalinity (mg/l) (T_4)	(Mean ± SD)
Apr	137.78	132.4	142.55	142.62	138.84±4.47
May	141.69	143.53	131.22	144.4	140.21±5.46
Jun	134.24	135.37	141.45	139.88	137.24±3.44
Jul	135.27	130.13	137.82	139.47	135.67±3.67
Aug	136.19	132.19	148.28	150.84	141.38±7.62
Sep	135.03	133.13	145.78	145.62	139.39±5.94
Oct	134.19	135.96	139.56	147.98	139.42±5.61
Nov	139.19	145.28	130.26	145.23	139.74±6.68
Dec	139.66	149.07	139.34	142	142.52±4.22
Jan	136.58	132.89	144.19	144.84	139.63±5.13
Feb	140.14	146.56	145.36	145.83	144.97±2.73
Mar	142.66	135.33	140.71	149.24	141.99±5.79

Table 6: Ammonia range of experimental site of Narmada River water

Month	Ammonia (mg/l) (T_1)	Ammonia (mg/l) (T_2)	Ammonia (mg/l) (T_3)	Ammonia (mg/l) (T_4)	Mean ± SD
Apr	0.04	0.03	0.03	0.05	0.04±0.01
May	0.04	0.03	0.04	0.05	0.04±0.01
Jun	0.03	0.04	0.05	0.03	0.04±0.01
Jul	0.03	0.03	0.04	0.04	0.04±0.01
Aug	0.04	0.03	0.04	0.03	0.04±0.01
Sep	0.04	0.02	0.05	0.02	0.03±0.01
Oct	0.03	0.03	0.05	0.03	0.04±0.01
Nov	0.04	0.03	0.04	0.02	0.03±0.01
Dec	0.03	0.04	0.03	0.03	0.03±0.00
Jan	0.03	0.03	0.05	0.02	0.03±0.01
Feb	0.04	0.04	0.03	0.03	0.04±0.01
Mar	0.03	0.04	0.03	0.05	0.04±0.01

The physicochemical characteristics of the Narmada River provide important insights into the hydro chemical dynamics of the region, reflecting the combined influence of natural factors and anthropogenic activities. These parameters are governed by the area's underlying geology, climatic conditions, and, increasingly, by human-induced impacts such as the discharge of untreated or partially treated wastewater. Several studies have examined the quality of both river water and incoming sewage to assess their effects on overall water chemistry. Notably, Arora *et al*. (1974) [3] and Agrawal *et al*. (1984) [1] investigated the influence of domestic and industrial effluents on the Narmada River, emphasizing the detrimental impacts of wastewater discharges on aquatic ecosystems.

Conclusion

The comprehensive assessment of physico-chemical parameters across the Narmada River in Jabalpur district reveals a stable and ecologically supportive aquatic environment throughout the year. Key indicators such as temperature, pH, and dissolved oxygen remained within optimal ranges for freshwater biodiversity, including Mahseer, a sensitive and ecologically significant fish species. The low and consistent levels of free carbon dioxide and ammonia, alongside moderate alkalinity, further highlight the river's resilience and effective buffering capacity. While the current water quality appears favourable, earlier studies have pointed to the potential risks from domestic and industrial effluent discharge. Therefore, despite the positive findings, there remains a need for vigilant water quality monitoring and implementation of conservation measures to mitigate the impact of anthropogenic activities and safeguard the ecological integrity of the river system.

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