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# APPRAISAL OF WATER QUALITY STATUS OF CHHAPARWADI-II RESERVOIR IN RAJKOT DISTRICT (GUJARAT) THROUGH WEIGHTED ARITHMETIC INDEX APPROACH

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**ABSTRACT**

The present study aimed to assess the surface water quality of the Chhaparwadi-II Dam, located (lies between 21.88 N, 70.62 E) in Jetpur Taluka, Rajkot District, Gujarat, through a detailed physico-chemical and statistical evaluation during the pre- and post-monsoon seasons of 2024, which play a crucial role in determining water quality. A total of 9 water samples were collected following Central Water Commission (CWC) protocols and analyzed for key physico-chemical parameters. Total 22 water quality parameters (WQPs) were measured, and Weighted Arithmetic Water Quality Index (WQI) method was employed to interpret the overall water quality status. The computed WQI values of 40.80 (pre-monsoon) and 29.22 (post-monsoon) classified the reservoir water under the "good" water quality category (represents class–II condition), indicating suitability for domestic and agricultural use. Seasonal variations were observed due to factors such as evaporation, surface runoff, and dilution effects, influencing parameters like pH, EC, TDS, alkalinity, and bicarbonate. The results revealed that post-monsoon conditions exhibited better water quality owing to increased dilution and sedimentation processes. The study underscores the need for regular monitoring and integrated watershed management to sustain surface water resources in semi-arid regions like Saurashtra, where human activities and climate variability threaten water quality. The findings enhance understanding of seasonal water quality dynamics and support local authorities in developing sustainable management strategies for ensuring long-term water security in the region.
***Keywords*****:** Water Quality Index (WQI), pH, EC, TDS, alkalinity.

## Introduction

Water is one of the most essential natural resources, indispensable for sustaining all forms of life and supporting ecological balance, agricultural productivity, and industrial development (Shiklomanov, 1998). Freshwater constitutes only about 2.5% of the total global water resources, of which less than 1% is available for direct human use (Gleick, 2003). Despite this limited availability, the demand for freshwater has increased manifold due to rapid population growth, urbanization, and intensive agricultural and industrial activities (UN-Water, 2021). Consequently, maintaining the quality of surface water has become a major environmental and public health challenge worldwide. Surface water resources such as rivers, lakes, and reservoirs serve as primary sources for domestic, industrial, and agricultural use. However, these water bodies are under severe stress due to anthropogenic activities, including untreated sewage discharge, agricultural runoff containing fertilizers and pesticides, and industrial effluents (UNEP, 2022). The degradation of surface water quality has far-reaching consequences on aquatic ecosystems, drinking water security, and sustainable agricultural productivity (Mishra and Bhatt, 2008). In developing countries like India, the problem is more pronounced, where surface water bodies receive both point and non-point source pollutants without adequate treatment (CWC, 2020). The Saurashtra region of Gujarat, located in the semi-arid western part of India, is characterized by limited natural freshwater availability, erratic rainfall, and high evapotranspiration rates (GWRDC, 2020). To overcome these constraints, several reservoirs and check dams, including the Chhaparwadi-II Dam, were constructed to store monsoon runoff and ensure irrigation and drinking water supply (NWRWS, 2024). However, increasing urbanization, expansion of agricultural areas, and improper waste disposal have led to gradual deterioration in the water quality of many reservoirs in this region (Patel *et al.*, 2019). Studies have indicated rising levels of total dissolved solids (TDS), electrical conductivity (EC), bicarbonates, and nutrients in many surface water bodies across Saurashtra, primarily due to agricultural runoff and wastewater intrusion (Solanki and Patel, 2018; GPCB, 2023). The deterioration of surface water quality in such semi-arid ecosystems is a major concern, as it directly impacts irrigation sustainability, soil health, and crop productivity. The seasonal fluctuation in rainfall and reservoir storage further influences the spatial and temporal variation of physico-chemical characteristics of water. Therefore, it is vital to assess the current status of these parameters to understand the suitability of surface water for agricultural and domestic purposes. Given this background, the present study focuses on the assessment of physico-chemical characteristics of surface water in the Chhaparwadi-II reservoir.

## Materials and Methods

### Elucidation of Study area

The study was carried out fir the Chhaparwadi-II Dam located in Jetpur Taluka of Rajkot district, Gujarat, India. The reservoir (Chhaparwadi-II Dam) is an earthen-/gravity-type structure constructed for irrigation purposes and serves several villages in the Jetpur region (Figure 1). The dam has a recorded full reservoir level (FRL) / high flood level of 100.44 m and lower safe level of 98.38 m above msl (NWRWS, 2024). The Saurashtra peninsula’s climate is monsoon-dominated and the reservoir plays a key role in regulating irrigation water supply for the surrounding semi - arid agricultural zone. Given its significance in local water supply and irrigation, the reservoir was selected as a “trend station” for seasonal water-quality sampling (pre- and post-monsoon) in the Bhadar River Basin study area.” According to the Narmada, Water Resources, Water Supply and Kalpsar Department (NWRWS), the dam has a gross storage capacity of 15.27 million cubic metres (MCM) and a live storage of 16.62 MCM, with a high flood level (HFL) of 100.44 m and a lower level of 98.38 m above mean sea level (NWRWS, 2024; India-WRIS, 2024). Hydrologically, the dam falls within the West Flowing Rivers of Saurashtra and Luni Basin system, which comprises short rivers draining the Saurashtra plateau toward the Arabian Sea (CWC, 2019). The surrounding catchment experiences variable rainfall, generally between 600-800 mm annually, influencing the seasonal variation in inflow and water quality (GWRDC, 2020). The Chhaparwadi-II reservoir plays a significant role in regional water management by supporting agriculture and mitigating seasonal droughts in the semi-arid tracts of Rajkot district. The area’s agricultural pattern is dominated by cotton, groundnut, and pulses, which depend largely on reservoir-fed irrigation (DoA Gujarat, 2023).

**Table 1:** The salient feature of the Chhaparwadi-II dam is tabulated below:-

| **1.0** | **Name of Project** | **Chhaparwadi-II Irrigation Scheme** |
|---|---|---|
| **2.0** | **Location** | |
| | a. River | Chhaparwadi |
| | b. Nearest Village | Jetpur |
| | c. Taluka | Jetpur |
| | d. District | Rajkot |
| | e. State | Gujarat |
| | f. Location of Dam | Lat. 21°-53'-00"N, Long. 70°-37'-05"E |
| **3.0** | **HYDROLOGY** | |
| **A** | **Catchment Area** | **Sq. km.** |
| | i. Total catchment area at Dam site | 375.43 |
| | ii. Intercepted catchment area | 90.62 |
| | iii. Net catchment area | 284.81 - |

| | | | |
|---|---|---|---|
| | iv. Nature of catchment area | Fan shaped in hard trap region | |
| | v. Average annual rainfall | 615.00 mm | |
| | vi. Maximum rainfall | 1290.00 mm | |
| | vii. Total population affected | 1500 Souls | |
| | viii. No of houses under submergence submergence | 88 Nos | |
| | ix. Maximum water level | 100.44 m. | |
| | x. Maximum flood discharge 3542.00 M*/Sec | 3542.00 m$^3$/Sec | |
| | xi. Observed maximum flood discharge | 2230.00 m$^3$/sec. (Depth 6.10 m) | |
| | xii. Design discharge of spiliway | 2925.00 m$^3$/sec<br>(Revised 5067 m$^3$/sec)<br>M°/Sec | |
| | xiii. Maximum flood discharge as per 1979 | 5143.00 m$^3$/sec. | |
| | xiv. Maximum flood discharge as per 1983 | 6219.00 m$^3$/sec. | |
| **4.0** | **Reservoir** | | |
| | i. H.F.L. R.L | 98.38 m | |
| | ii. F.R.L. R.L. | 98.38 m | |
| | iii. Cenal Sill R. L. (O S.L.) | 90.78 m | |
| | iv. Top of Dam R.L | 100.82 m | |
| | v. Capacity at outlet | 2.11 M cum. | |
| | vi. Live Reservoir Capacity 16.77 M.cum. | 16.77 M. cum. | |
| | Vii. Gross Reservoir Capacity | 18.89 M.cum. | |
| | | | (NWRWS, 2024; Flood Control Cell, Rajkot- 2025) |

## Methodology

### Surface Water Samples Collection Task

The water sample collection was planned for both the pre- and post-monsoon periods of 2024. The dam site was selected as a trend monitoring station, and the integrated sampling method was followed according to the guidelines of the Central Water Commission (CWC, 2020). During the pre-monsoon season, samples were collected three times (once each month) from March to May 2024, while during the post-monsoon season; sampling was conducted twice a month from September to November 2024 (Figure 2). In total, 9 water samples were collected. For laboratory analysis, the samples were filtered using Whatman filter papers No. 45 and 42 to remove foreign particles. This filtration process was carried out to prevent clogging of the analyzer's thin tubes or nebulizer during testing.

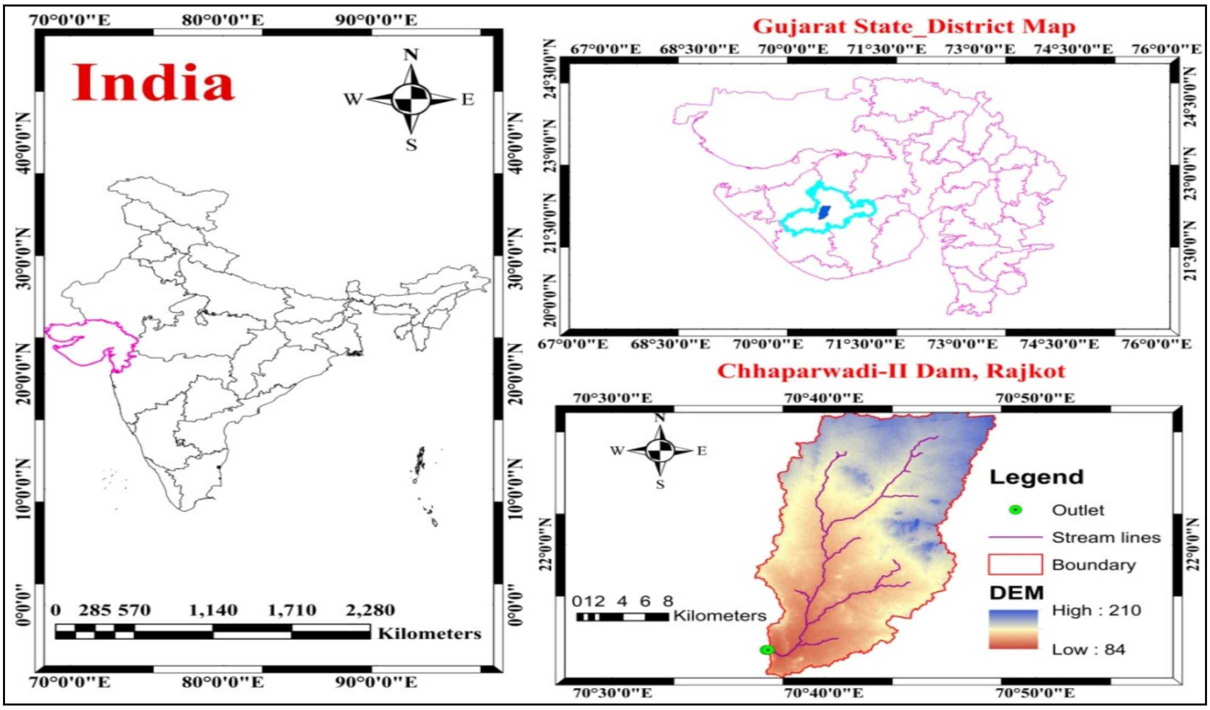


**Fig 1 :** Location map conducted research work

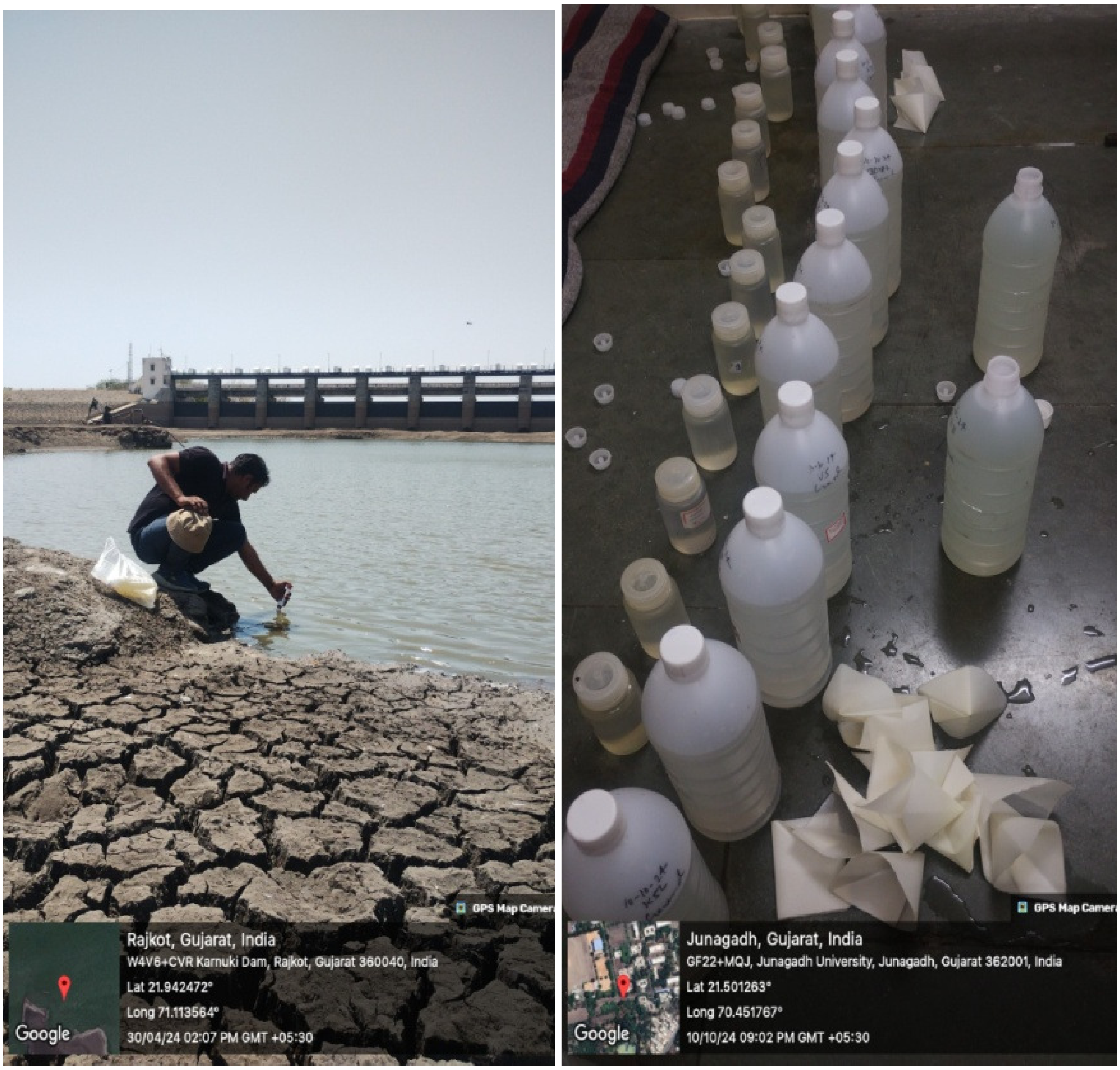


**Fig. 2 :** Water sample collection

**Determination of Physiochemical Parameters**

The determination of physicochemical parameters of collected water samples involves the analysis of key indicators such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness, alkalinity, and major cations and anions. These parameters help assess the suitability of water for domestic, agricultural, and industrial use (Trivedy and Goel, 1986; APHA, 2017). Standard methods for water and wastewater examination ensure accuracy and comparability across samples (BIS, 2012; WHO, 2022). Total 22 water quality parameters enlisted in table 2, were measured.

**Table 2** Standard guideline to determine the water quality parameters (Kumar *et al.* 2025)

| Sr. No. | Parameters | Method | Instrumentation | Reference |
|---|---|---|---|---|
| **Primary Parameters** | | | | |
| 1 | pH | Electrode method | Model No. BLE-9908, Gaby Digital Water Quality Tester | Sorensen (1909), EPA (1993) |
| 2 | Electrical Conductivity (EC) | Electrode method | | Kohlrausch (1879), ASTM D:1125-23 |
| 3 | Total Dissolve Solids (TDS) | Electrode method | | Rhoades (1976) |
| 4 | Temperature | Thermometric | | EPA (1974) |
| 5 | Carbonate ($CO_3$) | Titration | Glassware | BIS (2023), APHA (2017) |
| 6 | Bi-carbonate ($HCO_3$) | Titration | Glassware | BIS (2023), APHA (2017) |
| 7 | Calcium (Ca) | Complexometric method | Glassware | BIS (2009), APHA (2017) |
| 8 | Magnesium (mg) | Complexometric method | Glassware | BIS (2009), APHA (2017) |
| 9 | Sodium (Na) | Flame Photometer | Model No. CL-378, Elico Company, Telangana, India | BIS (1993), Jackson (1973) |
| 10 | Potassium (K) | Flame Photometer | | BIS (1993), Jackson (1973) |
| 11 | Total Suspended Solids (TSS) | Filtration and Gravity method | Hot Air Oven | BIS (1985) |
| 12 | Total Alkalinity (TA) | Derived Parameters | | Gran (1952) |
| 13 | Sodium Adsorption Ratio (SAR) | | | Richards (1954) |
| 14 | Potassium Adsorption Ratio (PAR) | | | Richards (1954) |
| 15 | Magnesium Adsorption Ratio (MAR) | | | Szabolcs and Darab (1964) |
| 16 | Residual Sodium Content (RSC) | | | Eaton (1950) |
| 17 | Total Hardness (TH) | | | Clark (1865) |
| 18 | Soluble Sodium Percentage (SSP) | | | Wilcox (1955) |
| 19 | Exchangeable Sodium Percentage (ESP) | | | Richards (1954) |
| 20 | Percent Sodium (SP) | | | Wilcox (1995) |
| 21 | Permeability Index (PI) | | | Doneen (1962), Domenico and Schwartz (1990) |
| 22 | Kelly's Ratio (KR) or ESR | | | Kelly (1963) |

**Weighted Arithmetic-Water Quality Index (WA-WQI)**

In the present study, all water quality parameters excluding trace and heavy metals-were considered for calculating the Water Quality Index (WQI). The WQI was determined based on the standard permissible limits for drinking water quality prescribed by the Bureau of Indian Standards (BIS, 2012), the World Health Organization (WHO, 1992), and the Indian Council of Medical Research (ICMR, 1975). The Weighted Arithmetic Index method proposed by Brown *et al.* (1972) was employed to assess the WQI of the water samples. The procedure for WQI determination involves the following steps.

**Weightage factor ($W_i$)**

Firstly, there is need to assigned weight ($w_i$) of the individual parameter in according to its significance in the drinking water quality (table 4). This weightage is completely based on the standard value of individual parameter reported by distinct agencies such as BIS (2012), WHO (1992), ICMR (1975) etc. The weightage factor is calculated by following formula:

$$W_i = w_i / \sum_{i=1}^{n} w_i \text{ or } k/s_i \quad (1)$$

$$w_i = \frac{k}{s_i} \quad (2)$$

Where,

$W_i$= Relative weight,

$w_i$= Weight of each parameter and

n = Number of parameters

$s_i$= Permissible or standard value of individuals parameter,

$k = 1/\sum s_i$.

**Calculation of quality rating / sub index ($q_n$)**

Quality rating is calculated by the following equation:

$$(Sub\ Index)q_n = \frac{Measured\ value\ (m_i) - Ideal\ value\ (v_i)}{Standard\ value\ (s_i) - Ideal\ value\ (v_i)} \times 100 \quad (3)$$

(Let there be n water quality parameters and quality rating or sub index ($q_n$) corresponding to $n^{th}$ parameter is a number in the polluted water with respect to its standard permissible value).

Where,

$q_n$ = Quality rating for the $n^{th}$ Water quality parameter.

$v_i$= All the parameter has zero '0' ideal value except pH = 7 and Dissolve Oxygen 14.6 mg/L (Dhanush *et. al.* 2024, Kumar *et al.* 2025).

**WQI calculation**

For measuring the WQI, sub-index is first calculated for each parameter using the following equation:

$$Sl_i = q_n \times W_i \quad (4)$$

Where,

$SI_i$ =Sub-index of $i^{th}$ parameter,

$q_n$=Sub rating based on concentration of $i^{th}$ and

n = Number of parameters.

The overall water quality-index (WQI) was figured by adding together each sub-index value of each groundwater sample as follows (Pandey *et. al.* 2020):

$$WQI = \sum Sl_i \quad (5)$$

Computed WQI values were classified into 5 categories mentioned in given below table-3.

**Table 3 :** The assigned unit weight of each parameter, and Pre and Post monsoon WQI value

| **Parameters** | **$s_i$** | **$1/s_i$** | **$W_i$=k/$s_i$** | **Sub-Index Value** | |
|---|---|---|---|---|---|
| | | | | **Pre-monsoon WQI** | **Post- monsoon WQI** |
| EC | 3000 | 0.00 | 0.00 | 0.01 | 0.00 |
| TDS | 2000 | 0.00 | 0.00 | 0.01 | 0.01 |
| pH | 8.50 | 0.12 | 0.05 | 3.57 | 4.87 |
| K | 12 | 0.08 | 0.04 | 1.20 | 0.59 |
| Na | 200 | 0.01 | 0.00 | 0.07 | 0.07 |
| $CO_3$ | 400 | 0.00 | 0.00 | 0.02 | 0.01 |
| TA | 600 | 0.00 | 0.00 | 0.05 | 0.03 |
| $HCO_3$ | 600 | 0.00 | 0.00 | 0.06 | 0.04 |
| Ca Hardness | 300 | 0.00 | 0.00 | 0.15 | 0.15 |
| TH | 600 | 0.00 | 0.00 | 0.07 | 0.08 |
| Mg Hardness | 500 | 0.00 | 0.00 | 0.04 | 0.06 |
| $Mg^+$ ion | 100 | 0.01 | 0.00 | 0.25 | 0.35 |
| $Ca^+$ ion | 200 | 0.01 | 0.00 | 0.14 | 0.13 |
| SAR | 30 | 0.03 | 0.01 | 0.33 | 0.29 |
| PAR | 1 | 1.00 | 0.43 | 17.89 | 8.47 |
| MAR | 100 | 0.01 | 0.00 | 0.13 | 0.17 |
| RSC | 200 | 0.01 | 0.00 | 0.39 | 0.16 |
| ESP | 100 | 0.01 | 0.00 | 0.11 | 0.10 |
| SSP | 50 | 0.02 | 0.01 | 0.45 | 0.39 |
| %Na | 100 | 0.01 | 0.00 | 0.12 | 0.10 |
| PI | 100 | 0.01 | 0.00 | 0.15 | 0.13 |
| KR | 1 | 1.00 | 0.43 | 15.58 | 13.04 |
| $\sum 1/s_i$ | | 2.3281 | $\sum W_i$ = 1.00 | WQI ($\sum SI_i$) = 40.80 | WQI ($\sum SI_i$) = 29.22 |
| K = $1/\sum(1/s_i)$ | | 0.4295 | *All parameters value in mg/L except pH and EC* | | |

**Table 4 :** Description of acceptance degree of water

| Classes | Range of WQI | Acceptance degree of Water |
|---|---|---|
| Class – 1 | 0-25 | Excellent |
| Class – 2 | 26-50 | Good |
| Class – 3 | 51-70 | Poor |
| Class – 4 | 71-90 | Very poor |
| Class - 5 | >100 | Not consumable |
| | | Brown *et. al.* (1972) |

## Results and Discussion

### Evaluation of Quality Parameters of the Reservoir Water

The physico-chemical and irrigation water quality characteristics of the Chhaparwadi-II Dam were analyzed for both pre-monsoon and post-monsoon seasons of 2024, and the results are summarized in Table 5. The variation in water quality parameters reflects the influence of seasonal hydrological conditions, agricultural runoff, and evaporation rates typical of the semi-arid Saurashtra region of Gujarat.

The Electrical Conductivity (EC) of water represents the total concentration of dissolved ionic species and serves as a key indicator of salinity and overall water quality. Figure 3a illustrates the temporal variation of EC (µS/cm) in the Chhaparwadi-II Dam during the pre- and post-monsoon seasons of 2024. The EC values ranged between approximately 770.5 µS/cm (September 2024) and 1306 µS/cm (November 2024), showing noticeable seasonal fluctuations. During the pre-monsoon period (March–May 2024), EC values gradually increased from around 1013 µS/cm to 1143 µS/cm, indicating progressive concentration of dissolved salts due to evaporation losses and reduced inflow. In contrast, a significant reduction was observed during the early post-monsoon period (September 2024), corresponding to rainfall-induced dilution of the reservoir water. However, the EC again increased by November 2024, likely due to accumulation of salts from agricultural runoff and reduced water volume toward the end of the monsoon. The linear regression equation shows a slight positive slope, indicating a minor increasing trend in EC across the sampling months. Although the low $R^2$ value (0.047) suggests weak correlation over time, the general pattern reflects seasonal salinity dynamics typical of semi-arid reservoirs in the Saurashtra region.

**Table 5 :** Findings of pre and post-monsoon water quality parameters

| Pre-Monsoon - 2024 | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site Code** | **Month of sampling** | **EC (uS/cm)** | **TDS (ppm)** | **pH** | **K (mg/l)** | **Na (mg/l)** | **CO3 (mg/l)** | **TA (mg/l)** | **HCO3 (mg/l)** | **Ca Hard. (mg/l)** | **TH (mg/l)** | **Mg Hard. (mg/l)** |
| | **Mar. 2024** | 1013 | 506 | 7.9 | 2.1 | 49.2 | 60 | 380 | 463.6 | 330 | 600 | 270 |
| | **Apr. 2024** | 1050 | 525 | 8.11 | 4.7 | 67.25 | 70 | 430 | 524.6 | 325 | 570 | 245 |
| | **May, 2024** | 1143 | 571 | 8.18 | 5.3 | 87.7 | 50 | 400 | 488 | 320 | 540 | 220 |
| | **Max** | 1143 | 571 | 8.18 | 5.3 | 87.7 | 70 | 430 | 524.6 | 330 | 600 | 270 |
| | **Min** | 1013 | 506 | 7.9 | 2.1 | 49.2 | 50 | 380 | 463.6 | 320 | 540 | 220 |
| | **Mean ± SD** | 1068.67±66.98 | 534.00±33.42 | 8.06±0.15 | 4.03±1.70 | 68.05±19.26 | 60.00±10.00 | 403.33±25.17 | 492.07±30.70 | 325.00±5.00 | 570.00±30.00 | 245.00±25.00 |
| | **Mean** | 1068.67 | 534.00 | 8.06 | 4.03 | 68.05 | 60.00 | 403.33 | 492.07 | 325.00 | 570.00 | 245.00 |
| | **SD** | 66.98 | 33.42 | 0.15 | 1.70 | 19.26 | 10.00 | 25.17 | 30.70 | 5.00 | 30.00 | 25.00 |
| **MOD** | | **Mg ion (mg/l)** | **Ca ion (mg/l)** | **SAR** | **PAR** | **MAR** | **RSC** | **ESP** | **SSP** | **%Na** | **PI** | **KR** |
| | **Mar. 2024** | 64.8 | 132.13 | 4.96 | 0.21 | 32.90 | 326.67 | 19.82 | 19.99 | 20.67 | 28.74 | 0.25 |
| | **Apr. 2024** | 58.8 | 130.13 | 6.92 | 0.48 | 31.12 | 405.67 | 25.78 | 26.25 | 27.58 | 35.19 | 0.36 |
| | **May, 2024** | 52.8 | 128.13 | 9.22 | 0.56 | 29.18 | 357.07 | 32.02 | 32.65 | 33.95 | 40.87 | 0.48 |
| | **Max** | 64.8 | 132.13 | 9.22 | 0.56 | 32.90 | 405.67 | 32.02 | 32.65 | 33.95 | 40.87 | 0.48 |
| | **Min** | 52.8 | 128.13 | 4.96 | 0.21 | 29.18 | 326.67 | 19.82 | 19.99 | 20.67 | 28.74 | 0.25 |
| | **Mean ± SD** | 58.80±6.00 | 130.13±2.00 | 7.03±2.13 | 0.42±0.18 | 31.07±1.86 | 363.14±39.85 | 25.87±6.10 | 26.30±6.33 | 27.40±6.64 | 34.93±6.07 | 0.36±0.12 |
| | **Mean** | 58.8 | 130.13 | 7.03 | 0.42 | 31.07 | 363.14 | 25.87 | 26.30 | 27.40 | 34.93 | 0.36 |
| | **SD** | 6 | 2.00 | 2.13 | 0.18 | 1.86 | 39.85 | 6.10 | 6.33 | 6.64 | 6.07 | 0.12 |
| **Post-Monsoon - 2024** | | | | | | | | | | | | |
| **Site Code** | **Month of sampling** | **EC (uS/cm)** | **TDS (ppm)** | **pH** | **K (mg/l)** | **Na (mg/l)** | **CO3 (mg/l)** | **TA (mg/l)** | **HCO3 (mg/l)** | **Ca Hard. (mg/l)** | **TH (mg/l)** | **Mg Hard. (mg/l)** |
| | **Sept. 2024** | 770.5 | 385 | 8.54 | 1.7 | 55.35 | 45 | 290 | 353.8 | 340 | 600 | 260 |
| | **Oct. 2024** | 934 | 466.5 | 8.285 | 2.05 | 44.9 | 15 | 215 | 262.3 | 265 | 615 | 350 |
| | **Nov. 2024** | 1306 | 653 | 8.56 | 1.9 | 80.5 | 40 | 330 | 402.6 | 290 | 820 | 530 |
| | **Max** | 1306 | 653 | 8.56 | 2.05 | 80.5 | 45 | 330 | 402.6 | 340 | 820 | 530 |
| | **Min** | 770.5 | 385 | 8.285 | 1.7 | 44.9 | 15 | 215 | 262.3 | 265 | 600 | 260 |
| | **Mean ± SD** | 1003.50±274.43 | 517.75±91.18 | 8.26±0.26 | 2.96±1.60 | 64.15±17.34 | 46.67±18.89 | 340.83±79.40 | 415.82±96.87 | 311.67±28.40 | 624.17±99.62 | 312.50±115.23 |
| | **Mean** | 1003.50 | 501.50 | 8.46 | 1.88 | 60.25 | 33.33 | 278.33 | 339.57 | 298.33 | 678.33 | 380.00 |
| | **SD** | 274.43 | 137.39 | 0.15 | 0.18 | 18.30 | 16.07 | 58.38 | 71.22 | 38.19 | 122.92 | 137.48 |
| **MOD** | | **Mg ion (mg/l)** | **Ca ion (mg/l)** | **SAR** | **PAR** | **MAR** | **RSC** | **ESP** | **SSP** | **%Na** | **PI** | **KR** |
| | **Sept. 2024** | 62.4 | 136.14 | 5.55 | 0.17 | 31.44 | 200.26 | 21.42 | 21.56 | 22.10 | 28.94 | 0.28 |
| | **Oct. 2024** | 84 | 106.11 | 4.86 | 0.21 | 41.75 | 87.19 | 20.02 | 20.20 | 20.90 | 27.12 | 0.27 |
| | **Nov. 2024** | 127.2 | 116.12 | 7.30 | 0.17 | 52.28 | 199.28 | 24.71 | 24.86 | 25.30 | 31.06 | 0.33 |
| | **Max** | 127.2 | 136.14 | 7.30 | 0.21 | 52.28 | 200.26 | 24.71 | 24.86 | 25.30 | 31.06 | 0.33 |
| | **Min** | 62.4 | 106.11 | 4.86 | 0.17 | 31.44 | 87.19 | 20.02 | 20.20 | 20.90 | 27.12 | 0.27 |
| | **Mean ± SD** | 75.00±27.65 | 124.79±11.37 | 6.47±1.68 | 0.30±0.17 | 36.45±8.92 | 262.69±120.13 | 23.96±4.65 | 24.25±4.83 | 25.08±5.12 | 31.99±5.17 | 0.33±0.09 |
| | **Mean** | 91.20 | 119.45 | 5.90 | 0.19 | 41.82 | 162.25 | 22.05 | 22.21 | 22.76 | 29.04 | 0.29 |
| | **SD** | 32.99 | 15.29 | 1.26 | 0.02 | 10.42 | 65.00 | 2.41 | 2.39 | 2.27 | 1.97 | 0.03 |

**Table 6 :** Annual variations in water quality parameters (WQPs)

| WQPs | Max. | Min. | WQPs | Max. | Min. |
|---|---|---|---|---|---|
| EC (uS/cm) | 1306.00 | 770.50 | Mg ion (mg/l) | 127.20 | 52.80 |
| TDS (ppm) | 653.00 | 385.00 | Ca ion (mg/l) | 136.14 | 106.11 |
| pH | 8.56 | 7.90 | SAR | 9.22 | 4.86 |
| K (mg/l) | 5.30 | 1.70 | PAR | 0.56 | 0.17 |
| Na (mg/l) | 87.70 | 44.90 | MAR | 52.28 | 29.18 |
| $CO_3$ (mg/l) | 70.00 | 15.00 | RSC | 405.67 | 87.19 |
| TA (mg/l) | 430.00 | 215.00 | ESP | 32.02 | 19.82 |
| $HCO_3$ (mg/l) | 524.60 | 262.30 | SSP | 32.65 | 19.99 |
| Ca Hard. (mg/l) | 340.00 | 265.00 | %Na | 33.95 | 20.67 |
| TH (mg/l) | 820.00 | 540.00 | PI | 40.87 | 27.12 |
| Mg Hard. (mg/l) | 530.00 | 220.00 | KR | 0.48 | 0.25 |

According to Ayers and Westcot (1985), irrigation water with EC values below 1500 µS/cm is generally safe for most crops, implying that the Chhaparwadi-II Dam water remains within permissible limits for agricultural use throughout the year. Similar seasonal variations have been observed in other semi-arid watersheds, where evaporation and anthropogenic inputs significantly affect ionic concentration (Vasanthavigar *et al.*, 2010; Singh *et al.*, 2015). Overall, the observed trend in EC suggests that monsoon recharge plays a vital role in maintaining the water quality of the dam. However, continuous monitoring is recommended, as prolonged accumulation of salts due to evaporation and agricultural return flow could deteriorate water quality in the long term.

The Total Dissolved Solids (TDS) in the Chhaparwadi-II Dam during 2024 varied from 385 mg/L (September) to 653 mg/L (May), indicating moderate mineralization of surface water. The pre-monsoon period (March–May) showed a gradual rise in TDS due to evaporation losses and limited inflow, which led to increased ionic concentration. Conversely, a decline in TDS during early post-monsoon (September) resulted from rainwater dilution**,** followed by a rise in November, likely caused by agricultural runoff and sediment input from the surrounding catchment. This variation reflects seasonal influences on reservoir chemistry typical of semi-arid regions like Saurashtra. The regression analysis indicates a slight but consistent increasing trend (Figure 3b). According to BIS (2012) and WHO (2011) standards, TDS below 500 mg/L is desirable, and up to 1000 mg/L is permissible for domestic and irrigation purposes. Therefore, the recorded values remain within acceptable limits, suggesting that the dam water is moderately suitable for multiple uses. However, a gradual rise in post-monsoon TDS warrants continuous monitoring to prevent long-term salinity buildup. Similar seasonal fluctuations have been reported in other semi-arid basins of India (Subramani *et al.*, 2005; Vasanthavigar *et al.*, 2010), emphasizing the need for sustainable surface water management.

The pH of surface water in the Chhaparwadi-II Dam ranged between 7.9 and 8.56 during 2024, signifying a slightly alkaline character throughout the study period. As shown in Figure 3c, the pH exhibited a gradual rise from 7.9 in March to 8.56 in November, with a strong correlation ($R^2 = 0.764$). The increased alkalinity during the post-monsoon season may result from the dissolution of carbonate and bicarbonate minerals, agricultural runoff, and enhanced photosynthetic activity, which consumes $CO_2$ and increases hydroxyl ion concentration. The pre-monsoon rise in pH is likely influenced by evaporation and reduced dilution, leading to ionic concentration (Kumar *et al.,* 2020). According to BIS (2012) and WHO (2011), the desirable pH range for drinking water is 6.5–8.5, beyond which biological and chemical processes may be affected. Most observed values lie within permissible limits, indicating stable buffering capacity and minimal acidic input. Similar findings have been reported by Ramakrishnaiah *et al.,* (2009) in Tumkur, Karnataka, and Tiwari and Mishra (2019) in central India, who attributed high pH to carbonate weathering and nutrient enrichment from catchment runoff.

The graphical representation of sodium ($Na^+$) concentration in surface water samples of Chhaparwadi-II Dam from March to November 2024 (Figure 3e) shows a gradual variation between pre- and post-monsoon periods. The sodium concentration ranged between 44.90 and 87.70 mg/L, with a regression equation and a weak correlation ($R^2 = 0.031$), indicating minimal seasonal influence. The highest $Na^+$ content was observed during May (pre-monsoon), possibly due to evaporation and reduced inflow, while a slight dilution occurred in the post-monsoon months. Elevated sodium levels can affect soil permeability and crop yield when used for irrigation (Ayers and Westcot, 1985). The observed concentrations fall within the permissible limits prescribed by BIS (2012) and WHO (2022), suggesting that the dam water is moderately suitable for irrigation but requires monitoring to prevent sodicity hazards.

The Total Alkalinity (TA) of water in the Chhaparwadi-II Dam exhibited a clear declining trend from pre- to post-monsoon seasons during 2024. The coefficient of determination ($R^2$) = 0.457 shows a moderate negative correlation, suggesting that TA values decreased with progressing months. The mean alkalinity values were higher (approximately 403.3 mg/L) in the pre-monsoon period compared to post-monsoon (266.67 mg/L). This reduction can be attributed to the dilution of ions and decreased bicarbonate concentrations caused by heavy monsoonal inflows (Figure 3h) and surface runoff (Kumar and Gupta, 2020). Elevated pre-monsoon alkalinity levels are generally associated with enhanced evaporation and increased mineral dissolution from carbonate-rich lithology in semi-arid regions like Saurashtra (Mehta *et al.,* 2019). Such seasonal fluctuations are common in dam reservoirs influenced by catchment lithology and hydrological recharge (Patel *et al.,* 2022). While all observed TA values remained within permissible limits for drinking water, maintaining a balance is crucial for ecosystem stability and irrigation suitability.

The variation in Total Hardness (TH) of water in the Chhaparwadi-II Dam from March to November 2024 shows a noticeable seasonal trend (Figure 3m). The TH values ranged between approximately 540.0 mg/L and 820.0 mg/L, with $R^2$ = 0.482, indicating a moderate positive correlation between time and hardness levels. Higher TH during the post-monsoon season (November 2024) may result from the dissolution of calcium and magnesium salts due to runoff and soil leaching (Singh *et al*., 2020). Pre-monsoon hardness was relatively lower, possibly due to evaporation concentrating dissolved ions in stagnant water. According to BIS (2012) and WHO (2022) standards, the observed TH values classify the water as "hard to very hard," which may cause scaling in pipelines and reduce soap efficiency but is not harmful to health. Such findings emphasize the need for continuous monitoring to ensure sustainable domestic and irrigation usage.

The Sodium Adsorption Ratio (SAR) of water in the Chhaparwadi-II Dam ranged between 4.86 and 9.22 during 2024, showing minor fluctuations between the pre- and post-monsoon periods. The $R^2$ = 0.003 indicates a very weak positive correlation (Figure 3.n), suggesting negligible temporal variation in SAR. The mean SAR value slightly decreased from 7.03 in the pre-monsoon to 5.90 in the post-monsoon season, primarily due to dilution effects and the influx of rainwater reducing sodium concentration relative to calcium and magnesium ions (Singh *et al*., 2019). Such post-monsoon reductions are common in reservoirs influenced by monsoonal recharge, which enhances cation exchange and reduces salinity stress (Sharma *et al*., 2021). The SAR values observed in both seasons fall within the safe limit (<10), indicating that the dam water is suitable for irrigation purposes (Richards, 1954; Ayers and Westcot, 1985).

The Potassium Adsorption Ratio (PAR) in Chhaparwadi-II Dam water varied between 0.12 and 0.52 during 2024, showing a declining trend from pre- to post-monsoon seasons. The regression ($R^2$ = 0.186) indicates a weak negative correlation, implying that PAR decreased slightly with time. The mean PAR value reduced from 0.45 (pre-monsoon) to 0.18 (post-monsoon), attributed to rainfall-induced dilution and reduced evaporative concentration during the monsoon period (Bhardwaj *et al*., 2020). Elevated PAR values before the monsoon may result from evaporative enrichment and fertilizer runoff containing potassium salts (Sahu *et al*., 2019). Overall, the recorded PAR values remained within acceptable limits for irrigation water, indicating minimal risk of potassium-induced soil structure deterioration (Ayers and Westcot, 1985; Richards, 1954).

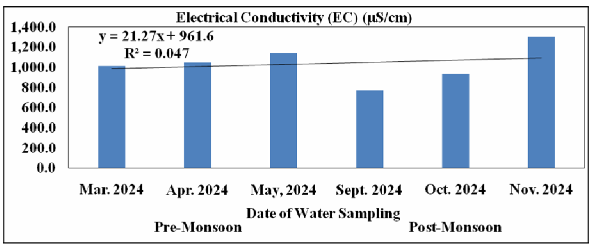


**Figure a**

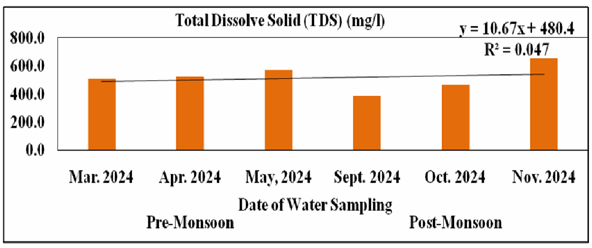


**Figure b**

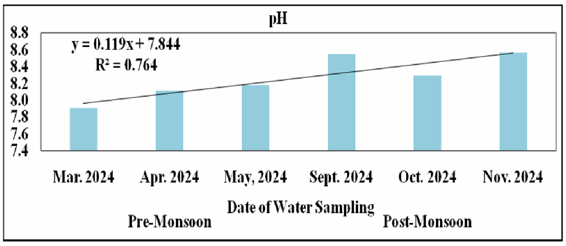


Figure c

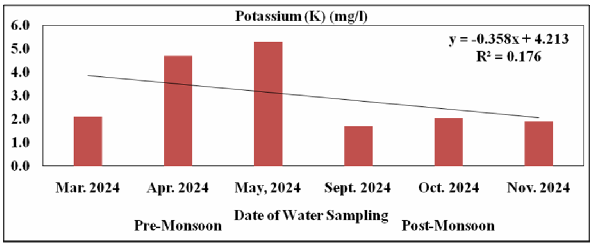


Figure d

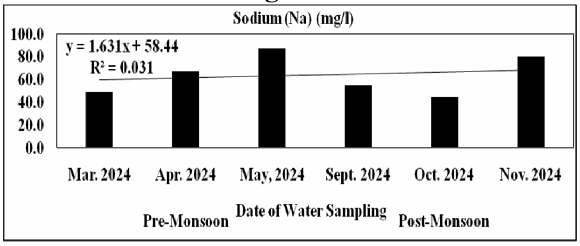


Figure e

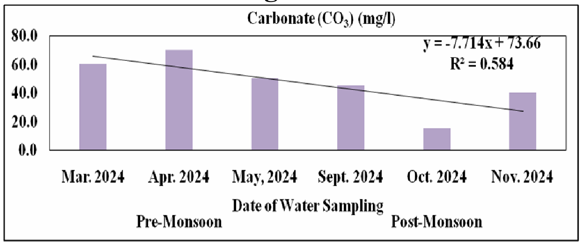


Figure f

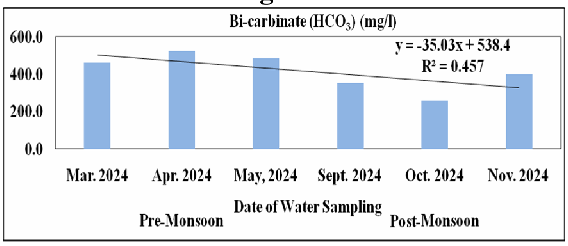


Figure g

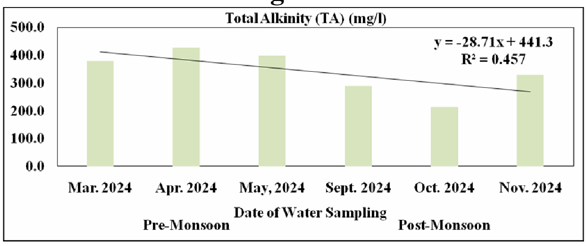


Figure h

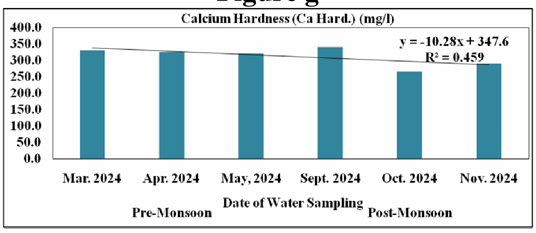


Figure i

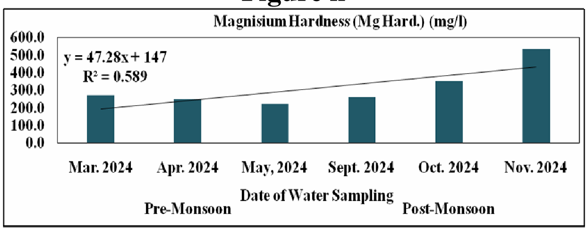


Figure j

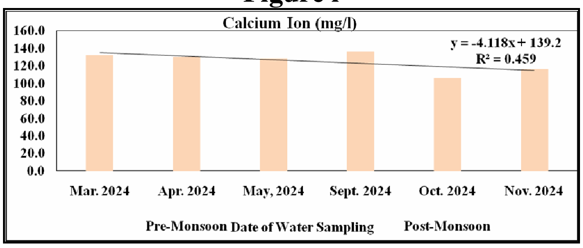


Figure k

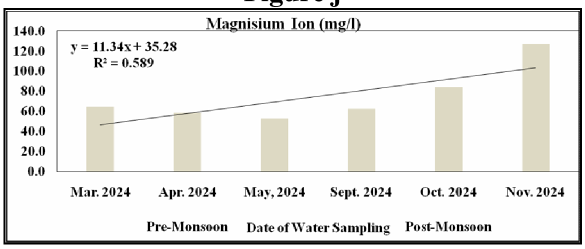


Figure l

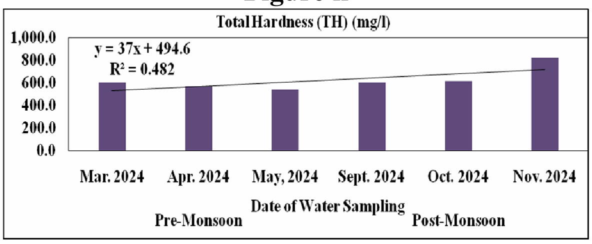


Figure m

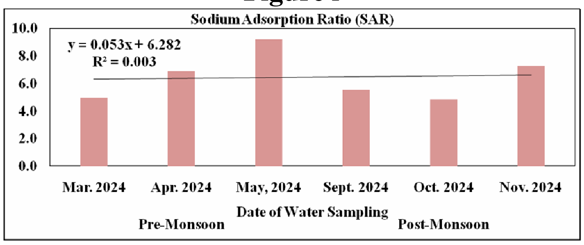


Figure n

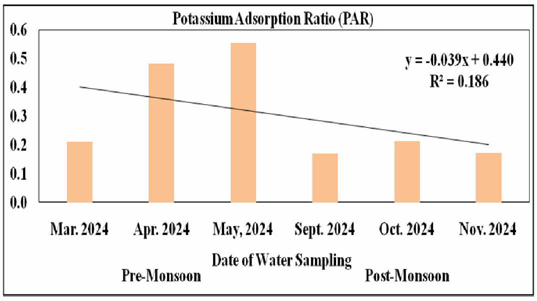


**Figure o**

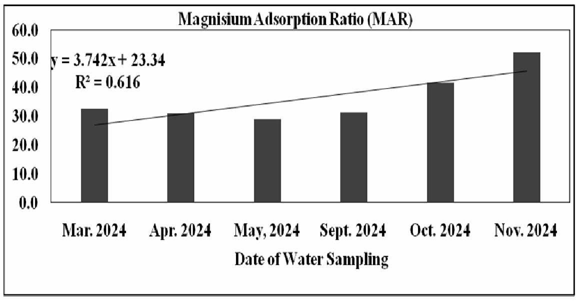


**Figure p**

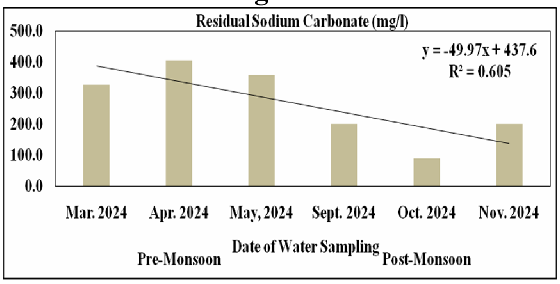


**Figure q**

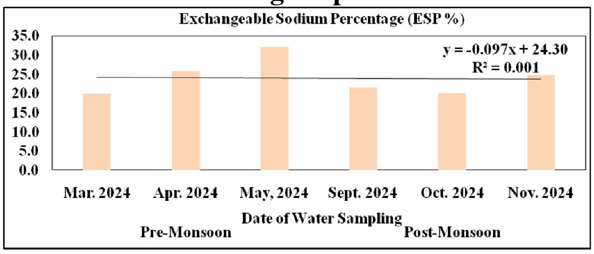


**Figure r**

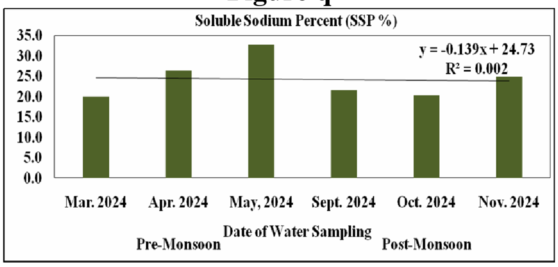


**Figure s**

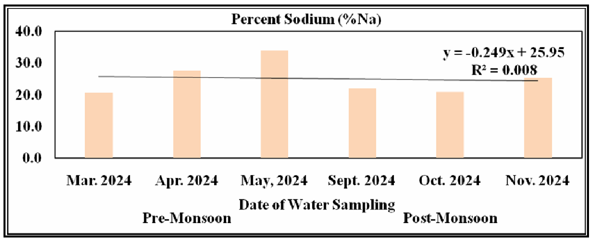


**Figure t**

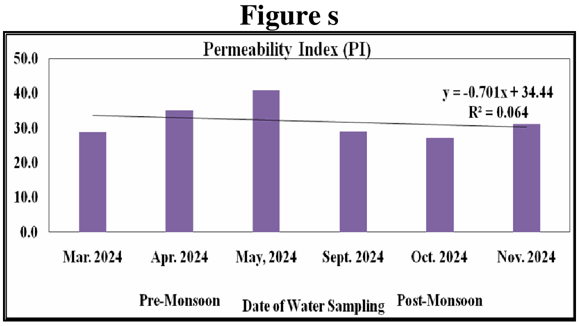


**Figure u**

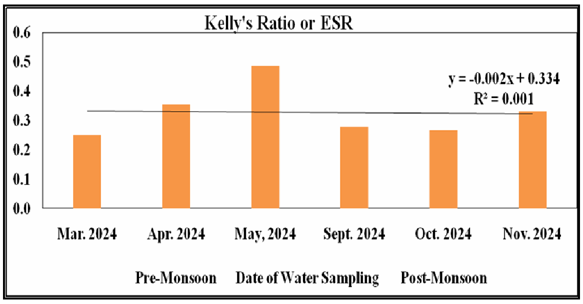


**Figure v**

**Fig. 3 (a-v) :** Graphical representation of physiochemical water quality parameters

The Magnesium Adsorption Ratio (MAR) exhibited notable seasonal variation, ranging from 29.18 mg/L to 52.28 mg/L during 2024. The trend line ($R^2$ = 0.62) indicated a gradual increase in MAR from pre- to post-monsoon seasons (Figure 3p). This rise suggests enhanced weathering of magnesium-rich basaltic formations and subsequent mineral dissolution during surface runoff in the monsoon period (Jain *et al.*, 2022). The post-monsoon increase might also result from irrigation return flow and domestic effluent infiltration**,** enriching the water with magnesium ions (Rao *et al.*, 2020). Elevated MAR values beyond safe limits can adversely affect soil structure and crop productivity, but in the present case, the values remained within the permissible limit for irrigation use (Todd and Mays, 2005; WHO, 2017). The findings emphasize that lithological influence and anthropogenic inputs together control the ionic composition of the dam water.

The Residual Sodium Carbonate (RSC) concentration exhibited a distinct declining trend from March (326.67 mg/L) to November (87.19 mg/L) 2024, as shown by the regression equation ($R^2$ = 0.61)**.**

Higher RSC values during the pre-monsoon period can be attributed to evaporation-induced concentration and dominance of carbonate and bicarbonate ions over calcium and magnesium, resulting in increased alkalinity (Sundaray *et al.*, 2020). Conversely, post-monsoon dilution and leaching of bicarbonates reduced RSC levels (Figure 3q) improving the water's suitability for irrigation (Singh *et al.*, 2022). Elevated RSC levels can adversely affect soil permeability and cause sodium accumulation in root zones, but the observed post-monsoon decline suggests improved hydrochemical balance due to rainfall recharge (Adimalla and Wu, 2019; Ayers and Westcot, 1985).

The Permeability Index (PI) of the collected water samples showed slight variation across the study period, ranging from 27.8 to 40.5%, with a weak decreasing trend ($R^2 = 0.06$). The relatively higher PI during the pre-monsoon months (April-May 2024) indicates increased sodium and bicarbonate concentrations, which can temporarily affect soil permeability (Ravikumar *et al.*, 2011). In contrast, the post-monsoon values showed marginal improvement due to dilution (Figure 3u) and recharge effects that reduce ionic concentrations and enhance soil structure stability (Sharma and Patel, 2021). According to Doneen's classification, most samples fall within the Class II category, signifying water of moderate suitability for irrigation (Doneen, 1964). A decline in PI after monsoon suggests the beneficial influence of rainwater percolation in maintaining soil permeability and reducing sodium hazard (Kumar *et al.*, 2023).

The Kelly's Ratio (KR) values for the collected water samples fluctuated between 0.25 and 0.48, indicating that all samples were below the critical limit of 1.0, which signifies suitability for irrigation use (Kelly, 1940). The regression trend suggests a very weak negative relationship over time, implying stable sodium and calcium, magnesium proportions throughout the study period (Figure 3v). The higher KR values during the pre-monsoon months (April-May 2024) reflect greater evaporative concentration and reduced groundwater recharge, which enhances sodium dominance in irrigation return flow and soil leaching (Singh *et al.*, 2020). Conversely, post-monsoon values (September-November 2024) decreased slightly, likely due to dilution effects from rainfall and surface recharge, improving ionic balance in the water (Kumar *et al.*, 2022). The findings indicate that the water remains suitable for irrigation, as KR < 1 denotes low sodium hazard and minimal risk of soil alkalinity development (Subramani *et al.*, 2005).

## Seasonal Hydrochemical Inferences for Sustainable Water Quality Management

The comprehensive assessment of the physico-chemical and irrigation water quality parameters in the Chhaparwadi-II dam for pre- and post-monsoon 2024 reveals significant temporal variations influenced by hydrological and anthropogenic factors. The pH values ranged between slightly alkaline limits, reflecting the dominance of bicarbonate ions and carbonate equilibrium within the aquatic system, which is ideal for sustaining aquatic biota and agricultural usability (Singh *et al.*, 2020). Electrical Conductivity (EC) and Total Dissolved Solids (TDS) exhibited higher values during the pre-monsoon season due to increased evaporation, low recharge, and the accumulation of dissolved salts, whereas dilution from rainfall reduced concentrations post-monsoon (Kumar *et al.*, 2022). Sodium ($Na^+$) and Potassium ($K^+$) showed spatial and seasonal variations, with higher values during the dry months, indicating potential agricultural runoff and ion exchange from soil minerals (Subramani *et al.*, 2005). Total Hardness (TH) and Total Alkalinity (TA) displayed contrasting patterns-TH increased post-monsoon owing to the leaching of calcium and magnesium from recharge zones, while TA declined due to dilution effects (Karanth, 1997). Similarly, the Magnesium Adsorption Ratio (MAR) showed an increasing post-monsoon trend, signifying enhanced contribution from carbonate and silicate mineral weathering (Ravikumar and Somashekar, 2010). Sodium Adsorption Ratio (SAR) and Kelly's Ratio (KR) remained within permissible limits, indicating the suitability of the water for irrigation with minimal sodium hazard (Richards, 1954). The decline in Residual Sodium Carbonate (RSC) and Permeability Index (PI) post-monsoon suggests improved water infiltration capacity and reduced alkalinity hazard (Paliwal, 1972).

## Evaluation of Water Quality Index (WQI)

The Water Quality Index (WQI) of the Chhaparwadi-II Dam was assessed using the Weighted Arithmetic Index Method proposed by Brown *et al.* (1972), which provides a comprehensive representation of overall water quality by integrating multiple physicochemical parameters into a single numerical value. The WQI was calculated separately for pre- and post-monsoon seasons to evaluate temporal variations in water quality conditions. The computed WQI values were 40.80 for the pre-monsoon and 29.22 for the post-monsoon period (as shown in Table 3). According to the WA-WQI classification system, water quality values ranging between 26-50 fall under the "Good" category (Class – II), indicating that the dam water is suitable for domestic and irrigation purposes with only minor treatment required. These results imply that the Chhaparwadi-II reservoir maintained a good water quality status throughout the year, with a slightly better condition observed during the post-monsoon period likely due to the dilution effect of rainfall and surface runoff**.** Hence, the WQI findings confirm that the reservoir water remains within acceptable limits for most beneficial uses, reflecting effective natural and anthropogenic balance in the catchment area.

## Conclusions

The present study on the Chhaparwadi-II Dam revealed that the overall surface water quality remains within the good category during both pre- and post-monsoon seasons, with WQI values of 40.80 and 29.22, respectively. Most physicochemical parameters were found within permissible limits, indicating minimal pollution influence. Slight seasonal variations were observed due to runoff dilution and evaporation effects. Overall, the water is suitable for domestic, irrigation, and aquatic life purposes, reflecting effective natural purification and sustainable watershed management within the dam's catchment area. Continuous monitoring is recommended to maintain its long-term quality.

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**Conflict of Interest**

The author declares that there is no conflict of interest associated with the publication of this research work.

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