

Assessment of Water Quality in Sindhudurg District, Maharashtra State, India

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ABSTRACT

This research paper provides a comprehensive assessment of the groundwater and surface water quality in the Sindhudurg district of Maharashtra, India. Situated along the southern Konkan coast, the district faces unique hydrogeochemical challenges due to its proximity to the Arabian Sea and heavy monsoon precipitation. The study synthesizes data from multiple investigative campaigns focusing on physico-chemical parameters, trace metal concentrations, and seasonal variations between pre-monsoon and post-monsoon periods. Analytical results indicate that the dominant hydrochemical facies is Ca–Mg–HCO₃, reflecting the influence of rock-water interactions. Water Quality Index (WQI) assessments reveal that approximately 95% to 96% of groundwater samples in the inland regions are of excellent to good quality for drinking purposes. However, coastal aquifers exhibit localized saline intrusion and elevated concentrations of trace elements like Iron (Fe) and Manganese (Mn), with some locations in the Malvan area exceeding safe health risk thresholds. Irrigation suitability analysis, utilizing indices such as Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), and Soluble Sodium Percentage (SSP), generally confirms the water's fitness for agriculture, though high-salinity hotspots near the coast remain a concern. This report concludes with recommendations for regular seasonal monitoring and targeted management of coastal water resources to ensure long-term sustainability.

Keyword: - Water Quality Index, Groundwater, Irrigation Suitability, Hydrogeochemistry.

1. INTRODUCTION

Water is a fundamental natural resource essential for life, health, and economic development. In the coastal district of Sindhudurg, Maharashtra, the assessment of water quality is of paramount importance due to the region's reliance on groundwater for domestic consumption and agriculture. The district is characterized by a high dependence on dug wells, bore wells, and local reservoirs to meet its water demands [1].

The primary pollutants of concern in Sindhudurg include high dissolved solids and chloride concentrations in coastal tracts, which indicate saltwater ingress from the Arabian Sea [2], [3]. Additionally, the presence of trace elements such as Iron, Manganese, and Chromium in certain coastal areas poses potential health risks to the local population [4]. Seasonal variations, driven by the intense Indian monsoon, significantly influence the hydro geochemistry of the region, leading to fluctuations in ionic concentrations and the overall Water Quality Index [5].

The scope of this research encompasses a detailed evaluation of physico-chemical parameters, the application of various water qualities and irrigation indices, and the use of multivariate statistical techniques to identify the sources of contamination. By comparing local findings with standards prescribed by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS), this paper aims to provide a clear picture of the current water quality status and provide actionable recommendations for regional planners [4].

2. STUDY AREA

2.1 Geographic Location and Coordinates

Sindhudurg district is the southernmost part of the Konkan coastal strip in Maharashtra. It is situated between 15°17'N to 16°40'N latitude and 73°19'E to 74°13'E longitude. The district is bordered by the Ratnagiri district to the north, the Arabian Sea to the west, the State of Goa to the south, and the Belgaum and Kolhapur districts to the east. The total geographical area of the district is approximately 5,087 sq. km [6].

2.2 Physiography

Physiographically, the district is divided into three distinct sections:

- i. Khalati: The low-lying coastal strip.
- ii. Valati: The undulating tract adjacent to the coast.

iii. Sahyadri Hills: The high-altitude mountainous region forming the eastern boundary.

The landscape is characterized by lateritic plateaus and rugged terrain, which significantly influence the drainage patterns and groundwater movement [7].

2.3 Climate and Rainfall

The district experiences a tropical climate dominated by the southwest monsoon. The annual rainfall range is substantial, typically between 2,000 mm and 3,000 mm. Mean monthly temperatures vary from a minimum of approximately 16°C to a maximum of 33°C. The heavy precipitation during the monsoon months (June to September) serves as the primary source of recharge for both surface water bodies and groundwater aquifers [1], [8].

2.4 Soil and Geology

The soil formation in Sindhudurg is primarily controlled by the climate and the underlying geology. Most soils are derived from lateritic rocks, which are widespread across the district. These soils are generally acidic and rich in iron and aluminum oxides. The regional geology includes various formations such as the Deccan Traps, Kaladgis, and Dharwar, with laterite being the most prominent surface formation [9].

3. METHODOLOGY

3.1 Sampling Techniques

Research studies in the district typically employ seasonal sampling to capture the temporal variability of water quality. Here collected 22 representative groundwater samples during the pre-monsoon and post-monsoon seasons of 2023. Samples are usually collected from diverse sources, including dug wells, bore wells, hand pumps, and surface reservoirs like the Palnekond reservoir in Sawantwadi [5].

3.2 Parameters Tested

The collected water samples are analyzed for a comprehensive suite of parameters:

Physico-chemical: pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), and Alkalinity [10].

Major Cations: Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), and Potassium (K^+).

Major Anions: Bicarbonate (HCO_3^-), Chloride (Cl^-), Sulfate (SO_4^{2-}), Nitrate (NO_3^-), and Carbonate (CO_3^{2-}).

Trace Metals and Other Elements: Iron (Fe), Manganese (Mn), Zinc (Zn), Copper (Cu), Chromium (Cr), Boron (B), and Fluoride (F^-) [11].

3.3 Water Quality Index (WQI)

The Water Quality Index is a widely used tool to simplify complex water quality data into a single numerical value that describes the overall status. The general formula for WQI calculation involves assigning weights (w_i) to each parameter based on its relative importance to health and the environment, and calculating a sub-index (q_i) for each parameter compared to its standard limit Eq 1 :

$$\text{WQI} = \sum (q_i \cdot w_i) / \sum (w_i) \quad (1)$$

Results are typically categorized as Excellent (<50), Good (50-100), Poor (100-200), Very Poor (200-300), and Unsuitable (>300) [12], [13].

3.4 Irrigation Indices

To evaluate the suitability of water for agricultural use, several indices are calculated:

i. Sodium Adsorption Ratio (SAR): Measures the sodality risk to soil Eq 2.

ii. Soluble Sodium Percentage (SSP): Calculated as the ratio of sodium to the total cations [14].

iii. Magnesium Adsorption Ratio (MAR): Evaluates the effect of magnesium on soil structure [15].

3.5 Multivariate Statistics and GIS

Advanced analytical techniques such as Principal Component Analysis (PCA), Factor Analysis, and Cluster Analysis (HCA) are applied to identify hydro geochemical processes and potential pollution sources [16]. Geographical Information Systems (GIS), particularly QGIS, are used to create spatial distribution maps of various parameters using Inverse Distance Weighting (IDW) interpolation [17], [18].

4. RESULTS AND DISCUSSIONS

4.1 Physico-chemical Parameters

The groundwater in Sindhudurg generally exhibits a freshwater character, though coastal samples show significant deviations. The following ranges have been reported in the coastal tracts [3]:

- pH: 6.19 to 8.66 (Mean: 7.15), indicating slightly acidic to alkaline nature.
- Electrical Conductivity (EC): 170 to 9,420 $\mu\text{S}/\text{cm}$ (Mean: 686.45 $\mu\text{S}/\text{cm}$). High values ($>750 \mu\text{S}/\text{cm}$) are primarily restricted to coastal wells [3].
- Total Dissolved Solids (TDS): 77 to 4,667 mg/L (Mean: 335.86 mg/L).
- Total Hardness: 78.56 to 2,038.71 mg/L (Mean: 310.36 mg/L).

A summary of the observed physico-chemical ranges and mean values is presented in Table 1.

Table 1: Summary of physico-chemical parameters in the coastal tracts of Sindhudurg

Parameter	Minimum	Maximum	Mean	Unit
pH	6.19	8.66	7.15	-
Electrical Conductivity (EC)	170	9,420	686.45	$\mu\text{S}/\text{cm}$
Total Dissolved Solids (TDS)	77	4,667	335.86	mg/L
Total Hardness	78.56	2,038.71	310.36	mg/L

4.2 Major Ion Chemistry and Hydro chemical Facies

The dominant order of cations is typically $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$, while for anions, it is $\text{HCO}_3 > \text{Cl} > \text{SO}_4 > \text{NO}_3$. Analysis using Piper diagrams reveals that the majority of groundwater samples fall into the Ca-Mg-HCO_3 facies, which is characteristic of recharge areas where silicate weathering and carbonate dissolution are the primary processes. However, coastal samples frequently transition toward Na-Cl or Ca-Mg-Cl facies, indicating the influence of seawater mixing. The concentration of Ca+Mg accounts for approximately 65.51% of total cations in the pre-monsoon season and 63.84% in the post-monsoon season.

4.3 Seasonal Variations

Marked seasonal shifts are observed in the district's water quality:

- Dilution Effect: Many studies report a slight reduction in the concentration of major ions during the post-monsoon season due to the massive influx of rainwater.
- Pollution Indices: The Pollution Index of Groundwater (PIG) indicates that while most samples (approx. 82-88%) show insignificant pollution across seasons, there are local increases in TDS, Mg, and Cl during the post-monsoon due to leaching and anthropogenic activities.
- Surface Water: Reservoirs and ponds, such as those in Vaibhavwadi and Sawantwadi, show significant fluctuations in dissolved oxygen (DO) and biochemical oxygen demand (BOD) linked to seasonal runoff.

The seasonal fluctuations in major ionic concentrations are visualized in Figure 1.

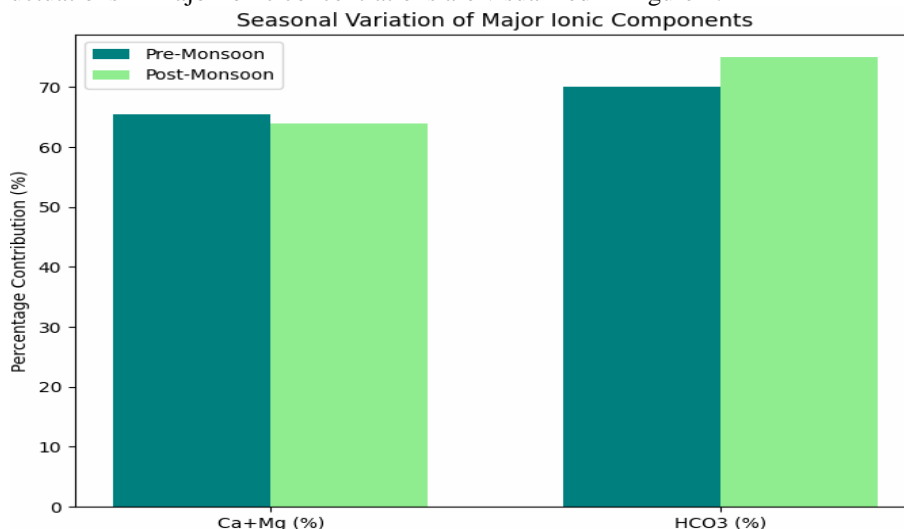


Figure 1: Seasonal variation of major ions between pre-monsoon and post-monsoon periods.

4.4 Suitability for Drinking

According to WQI assessments, the groundwater quality is remarkably high in inland Sindhudurg. Study found that 95.45% of samples were in the 'excellent' category, with the remaining 4.55% being 'good'. Naidu et al. (2021) similarly found that 96% of samples met the WHO and BIS standards for drinking.

The spatial distribution of WQI categories throughout the district is illustrated in Figure 2.

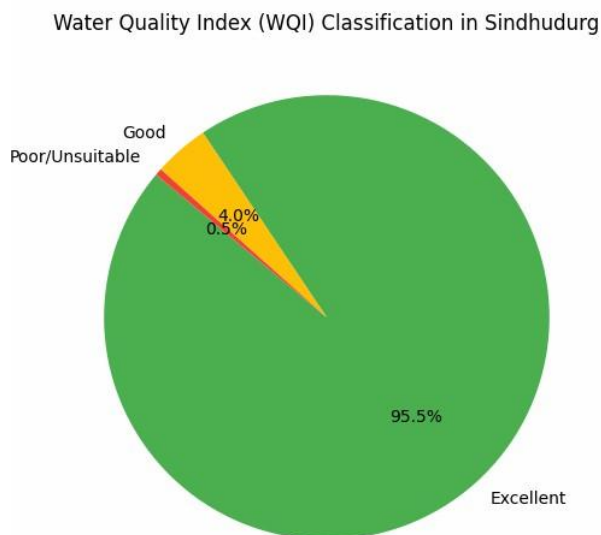


Figure 2: Spatial distribution of Water Quality Index (WQI) categories in Sindhudurg district.

However, trace metal analysis in Malvan paints a more concerning picture. Mean concentrations of Iron (1.39 mg/L) and Manganese (1.148 mg/L) were found to exceed permissible limits. The Hazard Index (HI) for non-carcinogenic risks was reported to be greater than 1 in some locations, particularly for Chromium (Cr), which also flagged a potential cancer risk in that specific dataset. (Table 2)

Table 2 summarizes the WQI classifications reported across different studies in the region.

Study Area / Dataset	WQI Category Distribution	Key Findings
Kudal region groundwater	95.45% Excellent, 4.55% Good	Predominantly high-quality groundwater
Northern coastal Sindhudurg	~96% within WHO/BIS drinking limits	Majority of samples meet standard criteria
Palnekond reservoir	Calculated based on standard parameters	Surface water quality monitored seasonally

4.5 Suitability for Irrigation

The assessment of irrigation suitability yields generally positive results:

- **SAR:** Values ranging from 0.24 to 11.39 indicate a low sodium hazard for most samples.
- **RSC:** Values between -34 and 1.14 meq/L suggest that the water is safe for irrigation with respect to residual carbonate.
- **SSP:** Values range from 7.21% to 65.73%, with most samples falling into the excellent to good category.
- **US Salinity Diagram:** Most groundwater samples plot in the C1-S1 and C2-S1 categories, signifying low to medium salinity and low sodium hazard. Exceptions occur in coastal wells where high salinity (C3 and C4 categories) makes the water unsuitable for irrigation without proper management.

4.6 Trace Metals and Health Risks

The proximity to the Arabian Sea and industrial/anthropogenic activities contribute to trace metal presence. In coastal Malvan, seasonal means for trace elements include:

- Iron (Fe): 1.39 mg/L
- Manganese (Mn): 1.148 mg/L
- Zinc (Zn): 0.166 mg/L
- Copper (Cu): 0.046 mg/L
- Fluoride (F): 0.509 mg/L

A comparison of these concentrations against standard limits is shown in Figure 3.

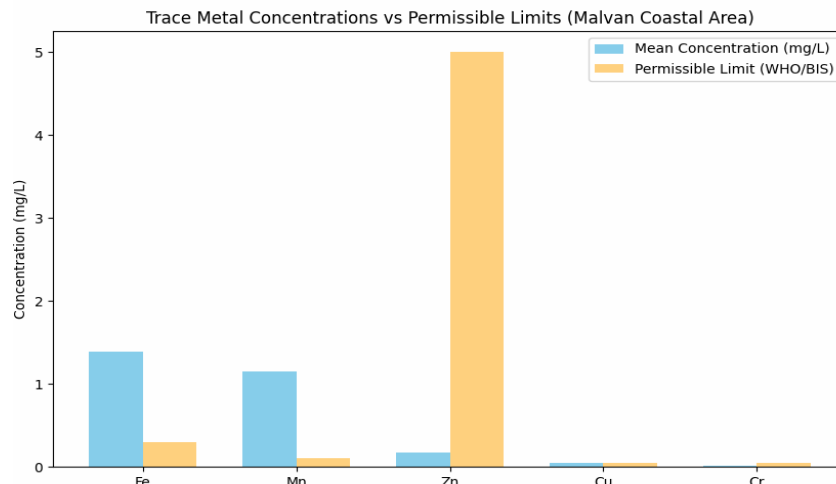


Figure 3: Comparison of trace metal concentrations (Fe, Mn, Zn, Cu, Cr) in Sindhudurg coastal samples with standard limits. Health risk assessments for elements like Boron and Fluoride indicate that while most samples are within safe limits, some locations exceed desirable WHO levels, particularly impacting vulnerable groups like infants and children

5. CONCLUSIONS

The water quality in Sindhudurg District, Maharashtra, is predominantly of high standard, particularly in the inland regions. The integration of various indices and statistical methods has provided the following key insights:

1. **General Status:** Approximately 95% of the district's groundwater is suitable for drinking and irrigation based on WQI and agricultural indices. The dominant hydrochemical facies is Ca–Mg–HCO₃.
2. **Coastal Risks:** Coastal areas, especially in Malvan and other low-lying tracts, are vulnerable to saline intrusion and trace metal contamination (Fe, Mn, Cr). These areas exhibit elevated EC and TDS values, often exceeding permissible standards.
3. **Seasonal Dynamics:** The monsoon plays a critical role in replenishing aquifers and diluting chemical concentrations, although it can also introduce anthropogenic pollutants through surface runoff.
4. **Health Implications:** While the overall risk is low, localized hotspots for trace metals and fluoride require attention due to potential non-carcinogenic and carcinogenic risks identified in specific coastal studies.

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