Integrated Assessment of Physicochemical Water Quality of Ambikapur City, India Using Arithmetic Mean Water Quality Index and Pollution Indices

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ABSTRACT:
Water quality evaluation is essential for protecting ecological balance and public health, particularly in metropolitan areas that are subjected to more anthropogenic stressors. Because of worldwide health concerns like the COVID-19 pandemic, it is now more important than ever to regularly analyse the physico-chemical and microbiological properties of drinking water. This study evaluates the quality of freshwater resources in Ambikapur City, Chhattisgarh, Utilizing the Arithmetic Mean Method and the Integration Pollution Index (IPI), water samples from various urban sources were analyzed to determine key physicochemical characteristics. The calculated Water Quality Indices (WQIs) provide a comprehensive overview of pollution levels and potential contamination sources, offering a clear picture of the aquatic ecosystem's health. The findings serve as a foundation for implementing effective water management policies and underscore the necessity of routine water monitoring to ensure hygienic and safe water supply for urban populations. The Ambikapur urban area's WQI of 51.91 places it in the "FAIR" category, meaning it can be used for industrial and irrigation purposes.

KEYWORDS:
Water Quality, Physico-Chemical Parameters, Urbanization, Water Pollution, Community Health, Sustainability.

INTRODUCTION AND BACKGROUND

The rapid pace of urbanization and industrialization in India has placed enormous stress on its water resources, resulting in the widespread contamination and degradation of water quality, particularly in urban regions (Ramachandra et al., 2014; Bassi & Kumar, 2017). An estimated 70% of India's surface water and a substantial proportion of its groundwater reserves are polluted with biological, toxic, organic, and inorganic contaminants, illustrating the severity of the country's water crisis (Sahil & Bhardwaj, 2021). Per capita water availability continues to decline, driven by population growth, increased consumption, and diminishing supplies of clean water (N et al., 2020). In many Indian cities, the pollution of bodies of water has gotten worse due to unmanaged runoff from agricultural areas and the release of untreated household and industrial wastewater (Bassi & Kumar, 2017).

This escalating pollution poses critical threats to human health and ecological systems. Contaminated water can harbor pathogens and chemical toxins, promote vector-borne diseases, and destabilize aquatic ecosystems (Mukherjee & Paramanik, 2024). Even in relatively developed Indian cities, sewage treatment facilities typically cover only 70–80% of the wastewater generated, leaving smaller towns and villages even more vulnerable to widespread sewage pollution. Given this, the index for water quality (WQI) becomes a crucial instrument for assessing and effectively conveying the condition of water resources. The decision-makers and everyone else can now easily obtain water quality assessments thanks to WQIs, which simplify complex data from several physicochemical and biological factors into a single numerical value (Bassi & Kumar, 2017). These indices provide an integrated evaluation of water quality, accounting for spatial and temporal variability, and are instrumental in guiding water management and pollution mitigation efforts.

A variety of factors, including pH level, turbidity, total solids dissolved, and heavy metal concentrations, are used to calculate physico-chemical indices, while biological indices consider species diversity, indicator organisms, and ecological health (Joshi et al., 2009). Such indices allow for efficient monitoring of water quality trends, even at low contaminant concentrations, and are frequently compared to both national and international standards (Tyagi et al., 2020; Iwegbue et al., 2022). These methodologies facilitate the identification of pollution levels and potential contamination sources, thereby offering actionable insights for sustainable water resource management. Table 1 summarizes the key water quality parameters and their permissible limits based on BIS and WHO guidelines. The following are the main objectives of this study:

1. To determine the physico-chemical properties of water used for drinking taken from several locations around the Ambikapur city wards/Urban setup.
2. To calculate the Water Quality Index (WQI) using the Arithmetic Mean Method and the Integrated Pollution Index (IPI) Approach.

Table 1. Water Quality Parameters with Their Guideline Values as per the BIS and WHO

S.No.	Operational Parameters	BIS (Permissible Limit)	WHO Standards (Permissible Limit)
1	pH	8.5	7-8.5
2	Conductivity	300	300
3	Turbidity	5	5
4	TDS	500	300
5	Alkalinity	200	100
6	Total Hardness	200	300
7	Chloride	200	200
8	Fluoride	1	1
9	Nitrate	45	100
10	Calcium	75	75
11	Magnesium	30	50
12	Iron	1	0.3
13	Sulphate	200	200

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LITERATURE REVIEW

Water Quality Indices (WQIs) are instrumental in assessing the overall quality of water resources by condensing complex data from multiple parameters into a single, interpretable value. Initially introduced in the early 1970s, WQIs were developed to provide a simplified depiction of the quality of water at a particular place; time by calculating a single number across an array of test results (Kilonzo et al., 2019; Vishnu Radhan et al., 2015). By aggregating key physicochemical and sometimes biological parameters, WQIs serve as valuable tools for communicating the status of water bodies to policymakers, researchers, and the general public (Al-Janabi et al., 2021). The use of statistical and mathematical techniques in the development of WQIs allows for the combination of multiple water quality indicators, such as pH level, Hardness, Alkalinity, total amount of solids in the water, and concentrations of specific pollutants, into a single index that depicts the condition of aquatic environments (Draşovean et al., 2019). However, despite their utility, WQIs come with inherent limitations. One of the primary criticisms is their location-specific design; each index is often tailored to particular regions or water types and may be disproportionately sensitive to certain parameters or the weights assigned to them (Ahmed et al., 2022). As such, while WQIs provide a useful overview, they may not always capture localized or context-specific variations in water quality.

Numerous studies have highlighted both the strengths and shortcomings of WQIs. Gupta et al. (2019) emphasized that the selection of parameters, weighting factors, and regional standards all influence the resulting index value. In their evaluation of Moulvi Bandh in Ambikapur, they reported an overall WQI of 57.60, indicating moderate pollution based on comparisons with WHO, BIS, and EPA guidelines. In a subsequent research project, Gupta et al. (2020) evaluated human pressures on communal water bodies in Joda Talab using the Integration Pollution Index (IPI). With multiple parameters beyond the recommended standard limits, their findings demonstrated the impact of both direct and indirect pollution sources and highlighted the region's persistent aquatic environmental stress.

While WQIs remain a crucial component of water quality monitoring programs, their limitations necessitate careful interpretation and, where possible, supplementation with more granular analyses and localized assessments to ensure effective water management and public health protection.

MATERIAL AND METHODOLOGIES

3.1 Study Area Description: Ambikapur, Chhattisgarh

Ambikapur is the Surguja district headquarters, is a significant urban center where residents rely on both surface water and groundwater (aquifers) for their drinking water needs. The Ambikapur Municipal Corporation governs an area of approximately 35,360 square kilometers, encompassing both urban and peri-urban regions. Ambikapur geographic coordinates are 23°12′N latitude and 83°2′E longitude. The city is located 623 metres (2,078 feet) above the mean level of the sea on average. This topographical positioning, coupled with increasing anthropogenic pressures, makes the city a pertinent site for evaluating urban water quality and its implications for public health and sustainable water resource management.

Table 2: The description and geographical coordinates of each sampling stations

S.no.	Locations	Source	Lat and long	Sites
1	Ring bandh, New Bus Stand	Pond Water	23°07'07"N 83°11'07"E	Site-I
2	Godhanpur	Pond Water	23°08'42"N 83°11'41"E	Site-II
3	Gandhinagar	Tap Water	23°08'42"N 83°10'28"E	Site-III
4	Namnakala	Tap Water	23°07'24"N 83°10'54"E	Site-IV
5	Bhagwanpur,	Well Water	23°08'50"N 83°09'49"E	Site-V
6	Bauripara	Well Water	23°07'40"N 83°12'03"E	Site-VI
7	Gangapur	Borewell	23°07'01"N 83°10'25"E	Site - VII
8	Subhashnagar	Borewell	23°09'11"N 83°09'50"E	Site - VIII

3.2 Water Quality Assessment Methods: Arithmetic Mean and Integration Pollution Index

Both the Integration Pollution Index (IPI) and the Arithmetic Mean Method are popular methods for evaluating water quality, and each has unique analytical benefits. Based on a weighted average framework, the Arithmetic Water Quality Index, or AWQI, technique calculates different sub-indices by dividing the measured values of specific water quality parameters by the respective standard limits (Mukherjee & Paramanik, 2023). By using a weighted average, which is determined by the relative importance of each parameter, this method combines the sub-indexes into an all-encompassing unitless score. This allows for simplified interpretation of complex data, facilitating the identification of temporal variations or spatial comparisons across different water bodies.

In contrast, the IPI approach employs statistical techniques to evaluate water quality by incorporating the collective influence and interactions among multiple parameters. This method provides a more comprehensive assessment of pollution levels, particularly in areas affected by mixed pollutant sources. Both methods are helpful tools for environmental monitoring, offering data on water quality dynamics and supporting evidence-based decision- making for water resource management. (Al-Janabi et al., 2021)

3.3 Arithmetic Mean Water Quality Index (AWQI/AMWQI) Method

This method was used to calculate the water body's WQI (Brown et al., 1970).

Where,

$$\boxed{Q_n = 100[V_n - V_{io}] / [S_n - V_{io}]}$$

Vn = is the nth parameter value of a certain sample site.

Sn = is the nth parameter standard allowable value.

Vio = is the nth parameter ideal value. ("0" for every other value and “7.0” and “14.6” mg/L, for pH and DO respectively).

To determine the unit weight, Wn

$$\boxed{W_n = K/S_n}$$

Wn = is the nth variable unit weight.

Sn = is the standard value of variable n.

K = proportionality constant.

The quality rating was linearly integrated with the weight assigned to each unit to determine the general WQI.

$$\boxed{WQI = \Sigma\,(Q_n . W_n) / \Sigma\, W_n}$$

Table 3: Utilisation of water bodies classified according to WQI

WQI	Status	Possible uses
0-25	Excellent	Industrial, agricultural, drinking
26-50	Good	Households, agricultural, industrial
51-75	Fair	Industrial, irrigation
76-100	Poor	Only in Irrigation
101-150	Very poor	Limited irrigation use
Above 150	Unfit for drinking	Before irrigation, proper treatment is necessary.

3.4 Integration Pollution Index method

Using the values gathered from the three sampling locations, the "Integration Pollution Index" has been determined for each parameter. The results are displayed below, where, Cb is parameter's value for each sample, Co for equivalent water quality standard value, and m for number of variables under monitoring.

$$IPI = \frac{1}{m}\sum_{b=0}^{m}\frac{cb}{co}(b = 1, 2, \ldots, m)$$

The water quality was evaluated using the Integration Pollution Index, with human pressure (the influence of the local people and the rapid urbanisation of the surrounding region) serving as the foundation for the evaluation. Our research sheds insight on how point and non-point pollution sources contribute to anthropogenic stress.

RESEARCH FINDINGS AND DISCUSSIONS

Table 4 displays the physico-chemical analysis of the water sources, while Table 5 displays the mean value of each parameter as well as the WQI value overall.

Table. 4 Physicochemical Characteristics of Drinking Water in Ambikapur

Parameters	Unit Table	Borewell Water	Pond Water	Tap Water	Well Water
Turbidity	N.T. U	11.715	19.23	3.555	15.71
pH	pH Scale	8.105	7.76	6.35	7.15
Conductivity	µs/cm	704.5	1088.1	704.5	807.5
Total Alkalinity	mg/l	107.315	336.17	107.225	118.135
Chlorides	mg/l	57.875	135.5	33.585	66.5
Nitrates	mg/l	0.65	22	0.365	4
Total Hardness (as CaCO3)	mg/l	176.44	283.1	149.76	110.2
Calcium (as Ca)	mg/l	28.895	49.78	27.125	26.98
Magnesium (as Mg)	mg/l	23.21	38.545	20.965	10.39
Iron	mg/l	0.385	0.66	0.145	0.27
Fluorides	mg/l	0.41	0.28	0.1	0.125
Sulphates	mg/l	8.4	27.495	6.005	21.4
Total Dissolved Solids	mg/l	404	489	85	278

Table 5: Water Quality Index parameters as analyzed from different sites

Parameters	**Unit Table**	**Mean Values**	S_n	$1/S_n$	**K**	W_n	Q_n	$W_n * Q_n$
Turbidity	N.T. U	12.5525	5	0.2	0.41462	0.08292	251.05	20.8179
pH	pH Scale	7.34125	8.5	0.11765	0.4275	0.05029	86.3676	4.34374
Conductivity	µs/cm	826.15	300	0.00333	0.4275	0.00142	275.383	0.39242
Total Alkalinity	mg/l	167.211	200	0.005	0.4275	0.00214	83.6056	0.17871
Chlorides	mg/l	73.365	200	0.005	0.4275	0.00214	36.6825	0.07841
Nitrates	mg/l	6.75375	45	0.02222	0.4275	0.0095	15.0083	0.14258
Total Hardness (as CaCO3)	mg/l	179.875	200	0.005	0.4275	0.00214	89.9375	0.19224
Calcium (as Ca)	mg/l	33.195	75	0.01333	0.4275	0.0057	44.26	0.25228
Magnesium (as Mg)	mg/l	23.2775	30	0.03333	0.4275	0.01425	77.5917	1.10567
Iron	mg/l	0.365	1	1	0.4275	0.4275	36.5	15.6036
Fluorides	mg/l	0.22875	1	1	0.4275	0.4275	22.875	9.77897
Sulphates	mg/l	15.825	200	0.005	0.4275	0.00214	7.9125	0.01691
Total Dissolved Solids	mg/l	314	500	0.002	0.4275	0.00085	62.8	0.05369
				∑ = **2.41187**		∑ = **1.02849**		∑ = **52.957 1**

$$WQI = \sum Q_n . W_n / \sum W_n$$

$$\boxed{\mathbf{WQI = 51.91}}$$

For the examined water bodies and sources in the Ambikapur urban region, the WQI is **51.91**. According to standard WQI classification systems, this value indicates that the water falls into the "**FAIR**" category—suitable for irrigation and industrial applications, but unsuitable for direct consumption or domestic use without prior treatment.

Table. 6 Observed WQI values of different Water Sources

Source of Water	WQI	Status	Possible Uses
Borewell water	58.61	Fair	Irrigation and industrial
Pond Water	78.54	Poor	Irrigation
Well Water	47.37	Good	Domestic, irrigation and industrial
Tap Water	21.39	Excellent	Drinking, irrigation and industrial

Table 6 shows the WQI values of different water sources used for consumption in the urban setup of Ambikapur. From the table it can be concluded that the Tap water supply source (by Municipal Corporation) is having Excellent water quality and the Pond water has least water quality.

Table. 7 Values that were recorded at various locations together alongside their IPI values

S.N.	Parameter	Mean values	Standard values	IPI
1	**Turbidity (N.T.U)**	12.5525	5	2.69
2	**pH**	7.34125	8.5	0.92
3	**Conductivity (µs/cm)**	826.15	300	2.96
4	**Alkalinity(mg/L)**	167.211	200	0.90
5	**Chlorides(mg/L)**	73.365	200	0.39
6	**Nitrates(mg/L)**	6.75375	45	0.16
7	**Total hardness(mg/L)**	179.875	200	0.96
8	**Calcium(mg/L)**	33.195	75	0.47
9	**Magnesium(mg/L)**	23.2775	30	0.83
10	**Iron(mg/L)**	0.365	1	0.39
11	**Fluorides(mg/L)**	0.22875	1	0.24
12	**Sulphates(mg/L)**	15.825	200	0.085
13	**Total dissolved solids (mg/L)**	314	500	0.67

Pollution Integration Index (IPI) Analysis

Each water sample's IPI was determined by comparing each water quality parameter to its corresponding standard threshold value. This method enables a systematic assessment of the cumulative pollution burden present in each sample. From the table it is observed that anthropogenic activities are responsible for higher Turbidity (2.69) and Conductivity (2.96), while have least impact on sulphates (0.085). The IPI is a helpful analytical method for identifying and ranking the specific elements that most significantly affect the decline in water quality. Anthropogenic activities including industrial effluents, improper disposal of solid and liquid waste, and agricultural runoff mostly affect these variables. By highlighting the most critical pollutants, the IPI facilitates targeted mitigation strategies and supports the prioritization of remedial interventions for sustainable water resource management.

CONCLUSION

The majority of water quality parameters fall within the permitted boundaries established by national and international quality assessment authorities, according to the findings of the physicochemical analysis of water samples collected from eight different locations in Ambikapur, Chhattisgarh. Instances of slight deviations from desirable limits are primarily attributed to factors such as poor water usage practices, contamination from sewage and wastewater, and overexploitation due to the accessibility of water resources. Even if the water isn't very contaminated, it still needs to be treated before drinking because of a few undesired characteristics. The water quality varies significantly by source. Tap water is the safest and most versatile, while pond water is the least suitable for most uses. This highlights the importance of source selection and treatment for safe water use.

RECOMMENDATION

Based on the water quality data, here are specific recommendations for each source:

• For Pond Water (Poorest Quality, WQI 78.54): Water quality and source management can be enhanced by installing aeration systems to raise oxygen levels, removing sediments and algae on a regular basis, and using natural filtration from aquatic plants.

• For Borewell Water (Fair Quality, WQI 58.61): Installation of iron removal units, Regular maintenance and Implementation of water softening systems can play significant role in enhancing the water quality.

• For Well Water (Good Quality, WQI 47.37): Regular cleaning and maintenance, Protection from surface runoff, Installation of covers to prevent contamination, Periodic water testing are some common methods to safeguarding/improving the quality of water.

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