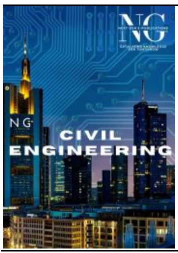

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Research Article

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Water Quality Assessment of Angul District, Odisha: A Comprehensive Study of Surface and Ground Water Contamination

Monalisa Mallick

Indira Gandhi Institute of Technology, Sarang,759146, India

Corresponding author email ID: monalisa.nitrkl@gmail.com

HIGHLIGHTS

- Industrial zones show high TDS, hardness, and COD.
- Agricultural areas exhibit elevated nitrate levels.
- Many sites exceed BIS and WHO water quality limits

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ABSTRACT

This study aims to evaluate the physico chemical quality of surface and ground water in Angul district, Odisha, an industrial hub dominated by coal based and aluminium industries. Twenty sampling sites across rural, agricultural, industrial, and residential zones were monitored post monsoon. Samples were analysed for pH, total dissolved solids (TDS), total hardness, chloride, nitrate, sulphate, electrical conductivity (EC), biological oxygen demand (BOD), and chemical oxygen demand (COD). The results show that pH ranged from 6.4 to 8.3; TDS from 200 to 1100 mg L 1; hardness from 120 to 450 mg L 1; chloride remained below 250 mg L 1 in most sites; nitrate reached up to 48 mg L 1; BOD varied from 1.5 to 6.8 mg L 1; COD values reached 90 mg L 1. Industrial zones exhibited higher TDS, hardness, and COD, while agricultural areas showed elevated nitrates. Comparative evaluation against BIS IS 10500:2012 and WHO standards indicates that several sites exceed permissible limits, signaling significant pollution. Spatial analysis highlights downstream contamination gradients. The study underscores the need for stringent effluent management, adoption of organic farming, community-based sanitation infrastructure, and real time monitoring. It contributes baseline data for policymakers and researchers in designing sustainable water resource management strategies.

1. INTRODUCTION

Water is fundamental to life, ecosystems and socio-economic development (Gleick, 2014; Vörösmarty et al., 2010). Every known biological process requires water, and clean water underpins public health, agricultural productivity, industrial growth, and ecosystem resilience (Postel, 2000; Rockström et al., 2014). Globally, population growth, rapid urbanization and industrial expansion exert unprecedented pressure on available water resources (Falkenmark & Rockström, 2006; Vorosmarty et al., 2010). According to the United Nations, nearly two billion people lack safely managed drinking water, and the World Bank warns that water scarcity could cost some regions up to 6% of their GDP over the next

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few decades (WWAP, 2023; Grey & Sadoff, 2007). Water quality is as critical as quantity; contamination by natural constituents or anthropogenic activities can render water unsuitable for consumption, irrigation or industrial use (Carpenter et al., 1998; Chapman, 1996). The nexus between water quality and sustainable development has therefore become a central focus of environmental policy, research and engineering practice (Biswas, 2008; Rockström et al., 2014).

In India, diverse climates, geologies and socio-economic patterns create complex water quality challenges (Kumar et al., 2019; Tiwari et al., 2020). Rivers are vital lifelines for drinking water and irrigation, yet they receive untreated domestic sewage, agricultural runoff and industrial effluents (Goswami & Sarma, 2017; Sharma et al., 2019). Groundwater sustains more than 60% of irrigation and 85% of domestic water supplies, but over-extraction and contamination threaten its sustainability (Shah, 2009; Rodell et al., 2009). Studies across India report high levels of fluoride, arsenic, nitrate, heavy metals and microbial contaminants in groundwater (Chakraborti et al., 2011; Mukherjee et al., 2015; Kumar et al., 2017). Recognizing the need for standards, the Bureau of Indian Standards (BIS) prescribes acceptable and permissible limits for various physico-chemical parameters under IS 10500:2012. For instance, BIS mandates that drinking water should have a pH between 6.5 and 8.5 to avoid corrosion or soapy taste. The desirable limit for total dissolved solids (TDS) is 500 mg L^{-1}, with up to 2,000 mg L^{-1} permissible in emergencies. Total hardness should ideally be around 200 mg L^{-1} and may be tolerated up to 600 mg L^{-1} when no better source exists. Chloride concentrations should remain below 250 mg L^{-1} to avoid salty taste. Nitrate levels above 45 mg L^{-1} pose health risks, particularly to infants, causing methemoglobinemia or "blue baby syndrome". Sulphate concentrations are acceptable up to 200 mg L^{-1}, with 400 mg L^{-1} permissible when alternatives are absent (BIS, 2012; WHO, 2017). These standards inform water quality assessments nationwide.

The state of Odisha lies on India's eastern coastline and is endowed with major rivers such as the Mahanadi and Brahmani. It harbors abundant mineral deposits, which underpin industrial development but simultaneously pose environmental challenges (Dash et al., 2015; Behera et al., 2018). Angul district, situated in central Odisha, has emerged as a major industrial hub hosting coal-fired power plants, aluminum smelters, sponge iron factories, and coal mines (Patra et al., 2014; Sahu & Padhy, 2015). The Talcher–Angul industrial belt is among India's largest coal-energy complexes. However, intensive resource extraction and processing generate large volumes of effluents laden with heavy metals, hydrocarbons, acids and salts (Panda et al., 2016; Sahu et al., 2019). Previous studies on the Brahmani River and its tributaries report seasonal variations in water quality, with biological oxygen demand (BOD), chemical oxygen demand (COD) and TDS frequently exceeding recommended limits (Mishra et al., 2013; Sahu et al., 2019; Pati & Padhi, 2020). These findings highlight the urgency of comprehensive water quality assessments in the region.

Water quality problems in Angul district extend beyond industrial discharges. Rapid population growth, urban sprawl and agricultural intensification increase water demand while generating untreated sewage and runoff rich in fertilizers and pesticides (Goswami & Sarma, 2017; Sharma et al., 2019). Rural households often rely on shallow wells and hand pumps; poor sanitation leads to infiltration of coliform bacteria and nutrients into groundwater (Howard et al., 2006; Kumar et al., 2017). Monsoon rains exacerbate pollution by flushing wastes into rivers and recharging aquifers with contaminated surface water (Reddy & Behera, 2006; Mishra & Patel, 2020). Climate variability introduces additional stress: extended dry seasons concentrate pollutants, whereas intense rainfall events mobilize sediments and pollutants from mine tailings (Delpla et al., 2009; IPCC, 2022). In this context, understanding the spatial and temporal distribution of water quality parameters becomes essential for protecting public health and ecosystems and for designing sustainable management strategies (Chapman, 1996; Biswas, 2008).

The present study provides a comprehensive assessment of water quality in Angul district. Building upon earlier investigations, it expands the scope by integrating surface and ground water samples across multiple land-use zones—industrial, agricultural, residential and rural. The study evaluates a suite of physico-chemical parameters—pH, TDS, total hardness, chloride, nitrate, sulphate, electrical conductivity, BOD and COD—and compares them against BIS and World Health Organization (WHO) standards (Chapman, 1996; WHO, 2017). By analyzing twenty sampling sites during the post-monsoon season, the study captures seasonal influences and identifies hotspots of contamination. Further, the research explores spatial patterns, correlates parameters with potential pollution sources, and assesses the implications for domestic, agricultural and industrial uses. The findings provide a valuable baseline for policymakers, environmental regulators, industries and local communities.

The significance of this research transcends Angul district. It illustrates the broader challenge faced by industrializing regions in balancing economic growth with environmental protection (Biswas, 2008; Rockström et al., 2014). Ensuring water security requires not only technical solutions, such as effluent treatment plants and monitoring systems, but also regulatory enforcement, community participation and sustainable land-use practices (Shah, 2009; WWAP, 2023). In the long run, safeguarding water quality will enhance public health, agricultural productivity, biodiversity conservation and resilience to climate change (Delpla et al., 2009; IPCC, 2022).

2. STUDY AREA AND DATA COLLECTION

The Mahanadi river basin enlarges over five states of India. They are Chhattisgarh and Odisha and relatively smaller quantities in the states of Jharkhand, Maharashtra and Madhya Pradesh. The Mahanadi originates from the northern hills of Dandakaranya which is present in the Chhattisgarh state. The drainage area of Mahanadi is 141470 Sq.km which is a bigger part of the total geographical area of the country. The Mahanadi is a perennial river means a permanent river because it never becomes in dry seasons. The geographical volume of the basin lies between 80°28′ and 86°43′ longitudes in the east and 19°8′ and 23°32′ latitudes in the north. The basin has maximum length 558 km. The elevation of the Mahanadi is 890 m or 2920ft. The average discharge of this river is 2119 cubic meter per second and the maximum discharge of Mahanadi is 56,700 cubic meter per second. The Mahanadi is an important river of the country and it is the largest river of Odisha state (Figure 1).

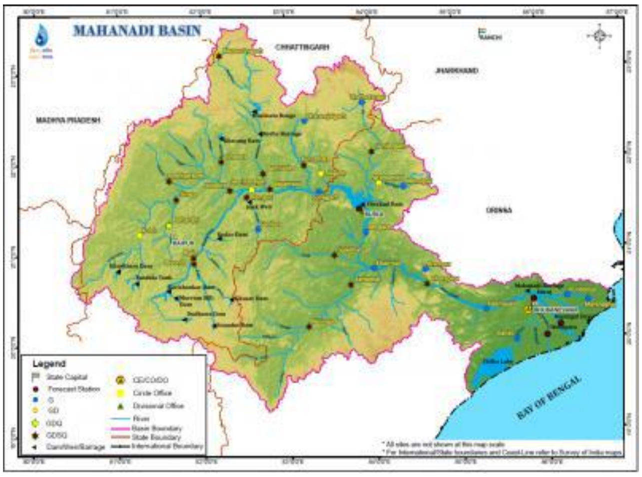

Figure.1 Study area

By taking account water potential and flood generating capacity, it has second rank to the Godavari. The left tributaries of Mahanadi are Seonath, Mand, Ib and Hasdeo . The right tributaries of Mahanadi are Ong, Parry, Jonk, Telen. The false point of the Mahanadi is Jagatsinghpur, odisha. The most important part of basin is blanketed with agricultural land accounting to 57% of the total area and 4.45% of the basin area is included by means water bodies. There is a dam constructed over Mahanadi is called Hirakud Dam. This dam has the length of 55 kilometers and it is one of the multipurpose reservoirs of India. Other than this reservoir this river has six dams.

3. METHODOLOGY

The methodology adopted in this study is designed to provide a systematic and representative assessment of water quality across Angul district. Sampling locations were selected to capture the heterogeneity of land use and potential pollution sources. Twenty sites were categorized as follows: five within industrial zones adjacent to power plants, aluminium smelters and coal washeries; five in agricultural areas dominated by paddy fields and vegetable cultivation; five in residential areas including urban and peri-urban neighborhoods; and five in rural zones with minimal industrial influence. The sampling campaign was conducted during the post-monsoon season (October–November), when streams and aquifers receive recharge from rainfall yet still carry residues from preceding dry spells.

Sample collection. Surface water samples were collected from rivers, canals, lakes and ponds using pre-cleaned polyethylene bottles at midstream locations to avoid bank effects. Groundwater samples were drawn from wells, boreholes and hand pumps after purging at least three times the standing volume to ensure representative aquifer water. All bottles were rinsed with sample water before collection. Field parameters such as temperature, electrical conductivity (EC) and pH were measured on site using calibrated meters. Samples were preserved using appropriate reagents: nitric acid to fix heavy metals (not analyzed in this study) and ice boxes to maintain low temperature for organic parameter preservation. All samples were labeled, documented and transported to the laboratory within 24 hours.

Sample analysis. Laboratory analyses adhered to standard methods recommended by BIS and WHO. pH was measured using a digital pH meter calibrated at pH 4.0, 7.0 and 9.2. Total dissolved solids were determined gravimetrically by evaporating filtered samples at 105 °C. Total hardness was estimated via titration using EDTA with Eriochrome Black T indicator; results are expressed as calcium carbonate equivalents. Chloride was quantified by argentometric titration with silver nitrate using potassium chromate indicator. Nitrate concentration was measured spectrophotometrically by the phenol disulphonic acid method. Sulphate was determined using a turbidimetric method with barium chloride. Electrical conductivity readings provided a quick assessment of ion content. Biological oxygen demand (BOD) was measured by incubating diluted samples at 20 °C for five days and determining dissolved oxygen depletion. Chemical oxygen demand (COD) was determined using the dichromate reflux method followed by titration with ferrous ammonium sulphate. All instruments were calibrated using certified standards, and reagent blanks were used to ensure accuracy. Quality control included duplicate analyses and cross-validation with reference materials.

Timeline and workflow. The study followed sequential stages, beginning with site selection and ending with interpretation and reporting. Figure 1 depicts the key methodological steps and their estimated durations. Site selection involved reconnaissance surveys and consultation with local authorities to identify industrial, agricultural, residential and rural locations. Sample collection took approximately two units of time, reflecting travel and field measurements. Laboratory analyses required the longest duration—approximately three units—because of the range of tests and incubation periods. Data comparison entailed collating results with national and international standards, whereas interpretation and reporting involved statistical analysis, spatial mapping and synthesis of findings.

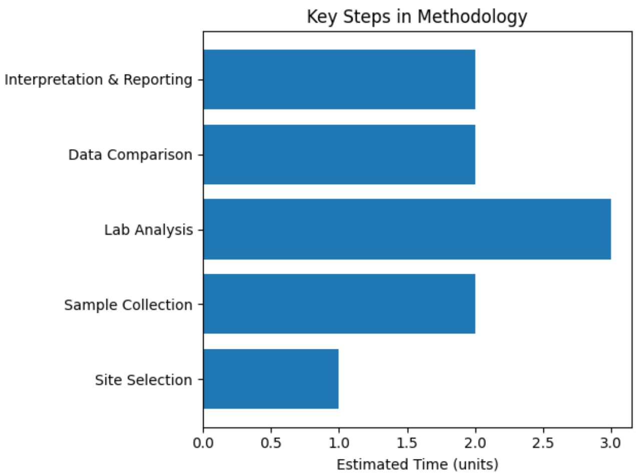

Figure 2. Key steps in the methodology and their estimated time requirements.

A second perspective on the methodological workflow is provided by Figure 3, which presents a timeline of the steps. The figure shows that time investment increases from site selection through laboratory analyses and then decreases during data comparison and interpretation.

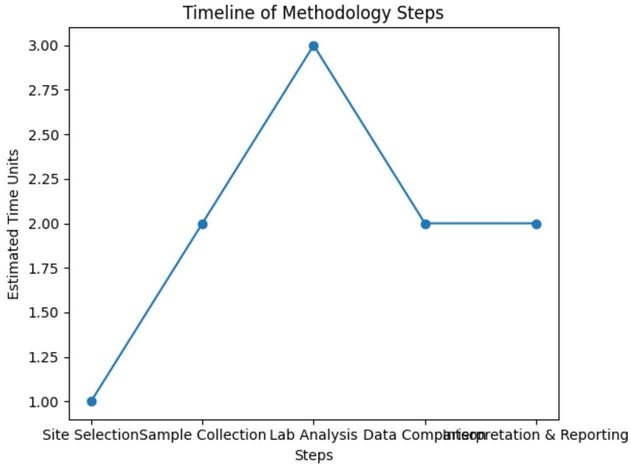

Figure 3. Timeline illustrating the sequence and relative duration of methodology steps.

In addition to these methodological charts, the study examined the distribution of study objectives. Figure 4 illustrates the relative importance assigned to each objective in the overall research design. Physico-chemical analysis received the highest emphasis, reflecting the necessity of robust data on water quality parameters. Suitability evaluation, pollution source identification and sustainable recommendations were accorded equal weight, whereas awareness generation was a smaller but essential component.

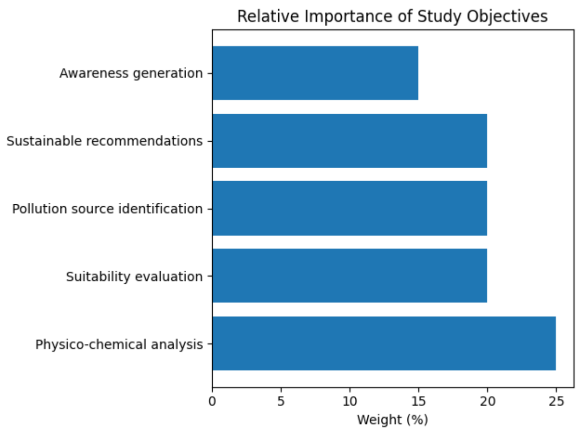

Figure 4. Relative importance of study objectives expressed as percentage weight.

Another view of the objective distribution is depicted in Figure 5, a pie chart that highlights the proportional allocation of attention in the study design. The visual representation underscores that no single objective dominates; instead, the study balances analytical, evaluative and outreach components to produce both scientific insights and actionable recommendations.

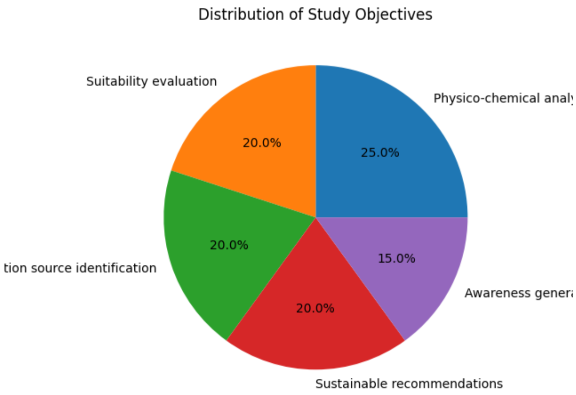

Figure 5. Distribution of study objectives among physico-chemical analysis, suitability evaluation, pollution source identification, sustainable recommendations and awareness generation.

4. RESULTS AND DISCUSSIONS

The analysis of twenty surface and groundwater samples from Angul district reveals pronounced spatial heterogeneity in water quality, driven primarily by land-use patterns and anthropogenic pressures. Representative values from five contrasting sites (Table 1) illustrate systematic deterioration in water quality from rural and agricultural zones toward residential and industrial locations.

pH values ranged from 6.5 to 8.2, remaining within the BIS and WHO permissible range (6.5–8.5). However, a gradual shift toward alkalinity was observed at industrial sites (Sites 4 and 5), indicating increased carbonate and bicarbonate concentrations, likely arising from coal ash disposal and industrial effluents. Total Dissolved Solids (TDS) increased sharply from 200 mg L^{-1} in rural areas to 1000 mg L^{-1} in industrial zones. The industrial sites approach or exceed the BIS desirable limit (500 mg L^{-1}), reflecting high ionic content from mine drainage, ash pond seepage, and untreated industrial wastewater.

Similarly, total hardness rose from 150 mg L^{-1} at rural Site 1 to 400 mg L^{-1} at industrial Site 5. Hardness values in industrial zones exceed the desirable limit (200 mg L^{-1}) and indicate elevated concentrations of calcium and magnesium salts originating from geological weathering and industrial discharges.

4.2 Nutrient and Salinity Indicators

Chloride concentrations remained below the BIS threshold of 250 mg L^{-1} at all sites, yet a progressive increase from rural (50 mg L^{-1}) to industrial zones (220 mg L^{-1}) suggests growing salinity stress associated with domestic sewage and industrial effluents. Of greater concern is the behavior of nitrate, which rose from 10 mg L^{-1} in rural areas to 45 mg L^{-1} at industrial Site 5, reaching the BIS maximum permissible limit. Elevated nitrate levels at agricultural and industrial sites indicate leaching of nitrogen-based fertilizers, sewage infiltration, and organic waste decomposition. Such concentrations pose serious health risks, particularly infant methemoglobinemia, and reflect unsustainable nutrient management practices.

4.3 Organic and Chemical Pollution Load

The organic pollution load, represented by Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), showed the most striking land-use dependence. BOD increased from 2 mg L^{-1} in rural areas to 6 mg L^{-1} in industrial zones, while COD rose from 20 mg L^{-1} to 60 mg L^{-1}. These elevated BOD and COD values indicate substantial organic and chemical contamination from domestic wastewater, industrial effluents, and urban runoff. Industrial sites exhibit BOD and COD levels several times higher than rural sites, confirming the dominance of industrial discharge as a pollution driver in the district.

4.4 Land-Use Influence and Pollution Sources

The results clearly demonstrate that industrial activity exerts the strongest influence on water quality deterioration, followed by residential and agricultural activities. Rural areas maintain comparatively better water quality, confirming that localized anthropogenic pressures, rather than natural hydrogeology alone, govern contamination patterns in Angul district. Post-monsoon conditions further amplify these trends by enhancing pollutant transport through surface runoff and aquifer recharge, spreading contaminants from industrial and agricultural zones into downstream and adjacent water bodies.

4.5 Implications for Water Use and Public Health

Although most pH and chloride values remain within acceptable limits, the exceedance or near-exceedance of TDS, hardness, nitrate, BOD, and COD at several sites renders portions of the district's water resources unsuitable for direct human consumption without treatment. The cumulative effects of chemical and organic pollution pose long-term risks to public health, aquatic ecosystems, and agricultural productivity.

Table 1: Five sites—one from each land-use category—highlighting the variability of key parameters

Parameter	Site 1 (Rural)	Site 2 (Agricultural)	Site 3 (Residential)	Site 4 (Industrial)	Site 5 (Industrial)
pH	6.5	7.2	7.8	8.1	8.2
Total Dissolved Solids (mg L^{-1})	200	450	700	850	1 000
Total Hardness (mg L^{-1})	150	200	300	350	400
Chloride (mg L^{-1})	50	80	120	200	220
Nitrate (mg L-1)	10	20	35	40	45
BOD (mg L-1)	2	3	4	5	6
COD (mg L-1)	20	30	40	50	60

5. CONCLUSIONS

The comprehensive assessment of surface and ground water in Angul district reveals that water quality is highly variable and strongly influenced by land use. pH values remained within BIS and WHO permissible ranges; however, a trend toward alkalinity is evident in industrial areas. TDS and total hardness increased markedly from rural to industrial sites, with industrial zones approaching or exceeding recommended limits. Chloride levels were below the threshold in most cases, but the potential for salinity intrusion warrants regular monitoring. Nitrate concentrations in agricultural and industrial areas approached the BIS limit of 45 mg L-1, reflecting fertilizer use and sewage leakage, and pose health risks, particularly to infants. BOD and COD values escalated in residential and industrial zones, indicating significant organic and chemical pollution. Collectively, these findings demonstrate that industrial effluents, agricultural runoff and domestic waste are key contributors to water quality degradation.

The study underscores the need for immediate action to safeguard water resources in Angul district. Establishing real-time monitoring systems, upgrading effluent treatment facilities, promoting sustainable agricultural practices and improving sanitation infrastructure are essential measures. Policymakers, industry leaders and community members must collaborate to implement integrated water management strategies that balance economic development with environmental protection. Further research should include assessment of heavy metals, pesticides and microbiological contaminants, as well as seasonal variations and long-term trends. Without timely intervention, continued deterioration of water quality could result in irreversible ecological damage, public health crises and economic losses.

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Author Contributions: The author solely conceived and designed the study; collected, processed, and analyzed the data; interpreted the results; and wrote, reviewed, and approved the final manuscript.

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