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Abundance, Characterization, Understanding Water Quality Degradation and Strategies for Pollutant Reduction in Mahanadi River Basin, Odisha

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Abstract. The open dumpsite is frequently chosen as the trash disposal option in most emerging economies, yet it poses serious environmental risks. Mahanadi River Basin (MRB) is one of Odisha's most heavily populated by agriculture and drinking, particularly for human consumption and farming. It faces severe surface water quality and quantity constraints. Water assessment indices such as Criteria Importance through Inter-criteria Correlation (CRITIC) and MCDM techniques like Complex Proportional Assessment (COPRAS) have been employed in the evaluation of water quality for human use, using integrated techniques. The study focuses on 20 water quality parameters taken from 19 stations over a period of 2021-2023 and compared them with the World Health Organizations (WHO). To investigate the spatial distribution maps of all approaches, the geo-spatial tools (IDW method) were considered. Coliform and TKN concentration mostly responsible for the high index scores in all locations. From the findings of CWQI, it has been determined that higher water quality is found to be 84.21% and a value of 15.79% belonging to poor/extremely poor category. MCDMs like COPRAS has been utilized for ranking evaluation, which shows that the highest rating provided for each period, that would cite the sampling location with the highest pollution. For instance, S-9 was found to as most polluted site because of elevated degree of certain parameters containing SO_4^{2-}, SAR, EC, Cl^-, TKN, TDS, TH and TC. Based on the results, it is evident that deterioration in water quality is mostly correlated with population growth, urbanization, industry, agricultural output, and the growth of ecotourism and hospitality in high areas close to the source areas. This study's uniqueness showed how to use water quality index methods to gauge or comprehend the quality of river water, and it seemed to hold promise for the future of water quality management.

Keywords. Mahanadi, CRITIC, COPRAS, integrated, urbanization, management

1. Introduction

Rivers are one of the principal sources of freshwater for supplying water for irrigation, industry, and daily requirements for people [1]. Water quality can be evaluated based on its chemical, physical, and biological characteristics, hence assessing these features

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is thought to be a good way to gauge the quality of the water. There are a number of ways that pollutants can enter river systems, including storm water runoff, stream and ditch discharge, leaching, seepage, and atmospheric deposition [2]. While natural elements like rainfall, surface runoff, and groundwater level are seasonal occurrences that are mostly influenced by climate, manmade causes like residential and industrial wastewater are a constant polluting source in metropolitan areas. Hence the need for regular monitoring and control of water quality in these areas is a serious agenda in today's scenario. As a detailed overview, Water Quality Index (WQI) gives straightforward, scientific summaries of water quality and prospective changes [3]. Therefore, the status of the water quality can be represented by integrating the data set with a geographic information system (GIS). GIS is frequently used to describe spatially variable phenomena through overlay analysis in the spatial register domain and the collection of diverse spatial data. Inverse Distance Weighted (IDW) is a type of spatial modelling approach, which uses an algorithm to interpolate data geographically or estimate values between observations, employed interpolation [4]. It can also be anticipated that decision-making techniques, such as parameter selection procedures, can be helpful for minimizing uncertainty in phases because the steps of constructing a WQI are prone to subjectivity and ambiguity [5]. Therefore, Criteria Importance Through Inter-criteria Correlation (CRITIC) method is being used in the present work, which demonstrates, a group of correlation-based techniques that rely on analysing the decision matrix to extract the data from the standards used to evaluate the weights of the criteria [6]. Thus, this approach eliminates human bias and is highly objective when determining weights. Multi-Criteria Decision-Making (MCDM) methods can provide precise values with minimal effort in the creation of the WQI [7]. Complex Proportional Assessment (COPRAS) is one of the most popular MCDM approach that discusses the direct and proportional dependence on the significance and utility of the available options in the presence of criteria that are in conflict with one another [8]. It is a fairly well-known MCDM tool that is widely used for its adaptability to be employed in resource allocation, estimation of water quality, and various criteria measurements [9]. However, no study is conducted to utilize CRITIC water quality index (CWQI), GIS and MCDM analysis such as COPRAS to assess the status of the river's water quality. In order to complete this study, and the physicochemical variables were examined, using the different proposed indexing methods in Mahanadi Basin, Odisha, by using the MCDM approach, to maintain the quality of water resources while taking into account the significance of various factors based on the four major uses, including drinking, industrial, household, and agriculture/irrigation. A substantial data matrix has been created for 2-year (2021-2023) sampling period at 19 various locations for twenty indicators of water quality. Also, the pollution potential zones have been attempted to be delineated using GIS.

2. Study Area

The Mahanadi River system is the greatest river in the state of Odisha and the third largest river on the Indian peninsula. River drainage over a region of 141600 Km^2 which pertains to 4% of the total geographical boundary. The river basin emerges between latitude (19°21'N-23°35'N) and longitudes (80°30' E-86°50'E). The average rainfall is approximately 142 cm, with 90% of that falling during the SW monsoon, which primarily occurs from June to September and occasionally produces severe cyclonic storms [10, 11, 12]. In later stage, it experiences a tropical monsoon climate with an average annual temperature recorded from 15.8°C to 28°C, that exists within the river framework. The most common soil types are red, mixed red, yellow, and finally. laterite soils. Following this, the significant land use activities in the valley namely, urban territories, coal mines, natural forests, and pastureland. Figure 1 demonstrates the investigated research region and the chosen sampling points on the river Mahanadi.

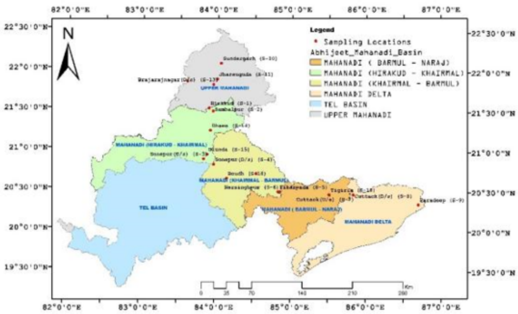

Figure 1. Study map of Mahanadi River showing sampling points

3. Water Sampling

Sites were chosen in the present study, owing to their contamination vulnerability, gathered in high density polyethylene bottles, dispatched for lab testing, and inspected within 48 hours. Standard methods [13] were used to evaluate the river's water quality at all places. The quality assurance and quality control (QA/QC) procedure of the data has been taken into account during the research [14]. The reliability of the laboratory testing has been confirmed by charge balance errors and specimens, approximately less than 5% error were reported.

4. Methodology

In this study, we considered the standards recommended by [15] for the calculation of WQI. CRITIC Water Quality Index (CWQI) technique is based on the measurement of ambiguous information present in the decision matrix and produces a set of weights for each criterion directly based on the mutual comparison of the individual criteria values of variations for each criterion, then for all the criteria simultaneously. For a certain standard, when compared to the other criteria, a large standard deviation with weak correlation statistics denotes that the provided criterion weight is quite high [16]. A rating scale for each indicator was allocated by: $Q_j = (C_j/S_i) *100$, where C_j reflects observed value for each indicator. Further, it was computed by CWQI = Σ $W_j * Q_j$. Classification of CWQI into five ranks, such as excellent (<50), good (50-100), average (100-150), poor (150-200) and extremely poor (>200). On the other hand, COPRAS, a multi-criteria decision-making method, concerns with the immediate and proportional reliance on the significance and utility of the available options when there are mutually competing criteria [9]. It is represented as $r_{ij} = x_{ij} / \Sigma x_{ij}$, where, r_{ij} depicts the normalized value of the j^{th} criteria for the i^{th} alternative. To find the normalized matrix, it is evaluated as the product of weights with the weighted normalized matrix, which is explained as $R_{ij} = W_j * r_{ij}$. The row sum of the adjusted weighted matrix is for beneficial criteria (S_i^+) and non-beneficial criteria (S_i^-) are represented as $S_i^+ = \Sigma R_{ij}$ for all j=1 to p and $S_i^- = \Sigma R_{ij}$ for all j=1 to q, where, p and q are respectively, the number of favorable and unfavorable criteria. The utility coefficient index is determined using $U_i = Q_i/Q_{max}$, where, $Q_i = S_i^+ + (S_{min}^- * \Sigma S_i)/ S_i^- * \Sigma (S_{min}^-/ S_i^-)$, where $S_{min}^- = \min (S_i^-)$. Finally, rankings of evaluation options are determined by the relative level of approximation.

5. Results and Discussion

Below are shown and discussed the features of the water samples that were taken at various times during a 5-year period. The surface water's pH value indicates if the water is alkaline or acidic. The observed pH varied from 7.74-7.92 mg/l and the calculated values would be within the specified potable level by the [15]. DO (Dissolved Oxygen) level is essential to all aerobic marine life in a river or lake. The level of DO vary from 7.26 to 7.83 mg/l. In almost all stations, DO is above the permissible limit (6.0 mg/l) for drinking water. On account of higher levels, it will maintain the biological diversity. BOD (Biochemical Oxygen Demand) shows the amount of garbage that can be organically destroyed. It varies from 1.05 to 2.40 mg/l, which is less than 5 mg/l as per WHO standards for all sites. Dilution of the effluents and no organic compounds have been mixed together to lessen the BOD content in this river water. TC (Total Coliform) generally, could survive and expand typically in water delivery systems, often in the midst of biofilms. The water samples' TC counts during the course of the study varied from 1212.4 to 42529.3, which should be less than 5000 according to WHO recommendations. As per reported results, each station operates within the agreed limits with an exception of S-8, 9, and 19. It demonstrated that elevated coliform concentrations in the water are caused by sewage discharges in the area. TSS (Total Suspended Solids) comprises of inorganic salts (principally Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, SO_4^{2-}, HCO_3^-) and a few trace quantities of suspended biological materials in water. Turbidity and water conductivity may be impacted by a rise in their concentrations. The values had a usual amount of 28.63 to 74.90 and an average of 39.33 mg/l. All readings that have been reported are under 100 mg/l. Alkalinity is a measurement of the water's bicarbonate, acidosis, and hydroxyl ions. Water's taste gets unpleasant over 200 mg/l, which is the ideal level for drinkable water. Its value span between 70.40 and 100.90, with a mean of 85.71 score, representing that these levels were lower than what WHO had advised, i.e., 200 mg/l. COD (Chemical Oxygen Demand) uses a powerful chemical oxidant to calculate the amount of oxygen necessary for the chemical oxidation of most organic materials and oxidizable inorganic compounds. However, the estimation of all samples ranged from 6.76-21.88, which substantially within the advised value of 25 mg/l. NH_3-N (Ammoniacal Nitrogen) and Free Ammonia (Free NH_3) are the plausible sources, resulting from the oxidation of nitrogen-based fertilizers, human waste, and animal excrement by microorganisms engaged in nitrification and phytoplankton processes. In the investigating region, ammoniacal nitrogen (NH_3-N) concentrations ranged from 0.5-1.93 mg/l, while at later stage, free ammonia (Free NH_3) levels span between 0.02 and 0.06 mg/l. As per (WHO 2011), for both cases, the value is within 2 mg/l threshold.

After wards, an important indicator namely, TKN (Total Kjeldahl Nitrogen) indicates a higher concentration of ammonia in the water, which can be dangerous, or a risk of eutrophication. Its values span between 3.28 to 11.80 mg/l, and found that the readings are higher than the WHO acceptable limit of 5 mg/l. The frequent cause of TKN in water can be attributed to runoff from polluted agricultural farmlands. In case of EC (Electrical Conductivity), a sudden increase or decrease in the water body may be a sign of water pollution. Measurements for drinking water will be done as per WHO limit i.e., 2250 μS/cm. In the present investigation, its level varied from 138.10 to 7779.35 micros/cm. Because of this, all of the examined samples' EC values, with the exception of S-9, were within the allowable limit for drinking. Therefore, high EC measurements recorded at S-9 suggest likelihood of domestic and agricultural wastes. SAR (Sodium Adsorption Ratio) shows how much irrigation water enters the soil's cation-exchange reaction. In the present investigation, SAR values observed between 0.41 to 16.59 mg/l. All sites rated under excellent category, having values less than 10 except S-9. Na^+ ions in polluted water may inhibit plant growth by altering the soil's oxygenation, conductivity, acidification, and structure. Although boron (B^+) is essential for plant growth, but when the concentration in irrigation water rises beyond 2 mg/l, it becomes dangerous for most field crops and interferes with their metabolic processes. It is noticed that the range of its levels is estimated as 0.03 to 0.55 mg/l. Based on this, the results are found to be under the 0.6 mg/l limit. Various anthropogenic and natural sources, such as the discharge of untreated sewage, industrial wastewater, and urban runoff, as well as soil, rock, and water interaction, are the main contributors of TDS (Total Dissolved Solids) in potable water. The variation of readings was varied from 82.30 to 13230.60 mg/l. If the TDS value is more than 500 mg/l, drinking water quality is substantially impacted. High value observed in site S-9 is due to industrial discharge and agricultural runoff. While evaluating surface water's appropriateness for household and industrial uses, Total hardness (TH) is a significant benchmark, because it contributes to the hardening of the water; however, it increases the amount of detergents used for cleaning, and some research suggests it may contribute to heart disease. The upper limit for TH in water for human consumption, according to Indian guidelines, is 300 mg/l. In this most recent study, the noticeable value span from 51.20-2195.20 mg/l. Every research location except S-9, showed results below the standard limit. The existence of surplus Cl^- (Chloride) in water creates salty water and has significant health consequences, including kidney and heart problems. In this studied region, the optimum chloride value, i.e., 4904.91 mg/l is seen at S-9, whereas lesser score of 9.65 mg/l has been reflected at S-1. Concentrations were below the WHO threshold limit of 250 mg/l, except S-9. Higher Cl^- values observed, due to both anthropogenic and natural processes, such as the discharge of untreated sewage and the passage of water through naturally occurring salt deposits in the earth. Surface runoff from agricultural fields and excessive fertilizer use, can both be a supplementary source of growing sulphate (SO_4^{2-}) accumulation in water surface. Concentration in the present investigation varied from 4.97 to 376.07 mg/l. It is exhibited from the data that observed values were much below the allowable limit of 250 mg/l except S-9. The area (S-9) is under-saturated in terms of limestone and siliceous breakdown, which raises the level of sulphate along the path of surface water flow. Fluoride (F^-) has a significant impact on teeth by limiting and eliminating risks that could affect teeth at low concentrations, while its readings greater than 1.5 mg/l, can cause fluorosis in water supplies. Fluoride was found in almost all samples taken from the research region, and its content ranged from 0.26 mg/l to 1 mg/l, which is within the acceptable range for drinking. Significant nitrogenous waste product decomposition in human waste, including septic tanks add nitrates (NO_3^-) to the water. In the current study, its level spanned from 1.29 to 2.7 mg/l. As per [16], the permissible value is taken as 45 mg/l. The examination indicated that the nitrate levels in the study area's water sources were substantially below the levels that are acceptable for consumption. High Iron (Fe^{2+}) content leads to an overabundance that can result in porphyria, hyperglycemia, vomiting, and gastrointestinal issues. However, the value showed a variation of 0.60 to 2.61, which is well within the desirable limit set by WHO (3 mg/l). Therefore, this study used CWQI to evaluate the river water quality, and MCDM methods to identify the sources of contamination and pollution. These findings suggested the necessary treatment steps to make the water safe to imbibe [17]. CWQI was utilized to establish the overall quality for drinking purposes as well as to calculate the contribution to pollution of each parameter in each sample in relation to the allowable limit. The findings were extrapolated through IDW geo-statistics using ArcGIS to improve the results' interpretability. In this ongoing study, the value ranged from 36.07 to 290.88, suggesting excellent to extremely poor category (table 1). However, at S-8, 9 and 19 shows severely erratic, due to locational context and also, the sources of pollution's effects. According to the results, 16 samples fall into excellent category, 2 belongs to poor class and 1 fall under extremely poor zone. Figure 2 shows the variation of CWQI map. The map amply demonstrates that S-8 and 9 lies in the poor group, which is because of elevated values of TDS, EC, SAR, Cl^-, Sulphate, TH, TKN, DO and TC, that suggests relatively high in terms of WHO criteria, which led to a decline in CWQI levels. The fecal material overflow from the latrines in the densely populated area in the watershed, sewage from marketplaces and other factories, and wastewater from municipal discharges are the most likely causes [18]. Furthermore, However, the substantial organic matter composition of these discharges suggests that significantly higher concentration results may be anticipated. The methodology of COPRAS, which is a solid technique that rely on CRITIC weights and using rough set theory yields a trustworthy analysis from various parameter weights. The priority ranks and its utility coefficient scores are shown in table 1. The highest quantitative utility coefficient (U_i) value seen at priority rank 1 (S-9), 2 (S-8) and 3 (S-19), could be due to runoff from urban areas, agricultural areas and landfill sites mixes with river water [19]. The station 9 is placed in the category of most polluted site with the rank of 1 on account of greater value containing Cl^-, SAR, TH, EC, SO_4^{2-}, TKN, TDS and TC, which were also highest among all the locales and higher than their optimal concentration. Figure 2 illustrates the spatial variation that was created using the IDW approach in the ArcGIS tool. The results show that this approach can be used as a good and complementary technique to eliminating ranking inconsistencies by WQIs.

Table 1. Scores of CWQI and COPRAS of 19 water monitoring points in Mahanadi River, Odisha.

Site No.	CWQI	Grade of CWQI	COPRAS (Ui)	Ranking
S-1	36.52	Excellent	2.18	16
S-2	44.38	Excellent	2.52	9
S-3	36.29	Excellent	2.20	15
S-4	43.90	Excellent	2.66	5
S-5	41.72	Excellent	2.48	11
S-6	42.93	Excellent	2.49	10
S-7	41.25	Excellent	2.43	12
S-8	174.00	Poor	6.23	2

S-9	290.88	Extremely Poor	99.98	1
S-10	41.50	Excellent	2.08	19
S-11	36.43	Excellent	2.09	18
S-12	38.40	Excellent	2.09	17
S-13	42.25	Excellent	2.28	14
S-14	43.76	Excellent	2.62	7
S-15	36.07	Excellent	2.34	13
S-16	40.87	Excellent	2.69	4
S-17	42.84	Excellent	2.60	8
S-18	41.24	Excellent	2.65	6
S-19	162.00	Poor	3.87	3

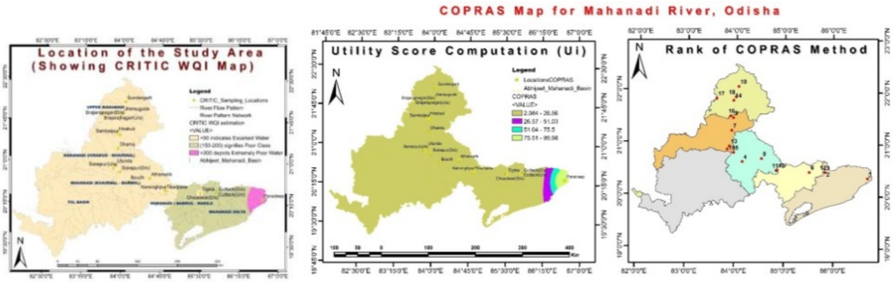

Figure 2. Spatial distribution of CWQI and COPRAS map in surface water.

6. Conclusion

This research thoroughly examined the water quality of the Mahanadi River Basin, Odisha. Using the spatial analyst features of the ArcGIS software, 20 water quality parameters were tested for 19 water locations and the spatial map for drinking was displayed. Based on monitoring environmental factors, the current work has proposed a potential combination of quality and pollution indices for determining the quality of rivers. TC and TKN concentrations are higher than the regulation for domestic water supply at all locations. The CWQI approach, indicated that 84.21% of sites were located in excellent-good water quality class that could be used for drinking, irrigation and industrial uses. According to the spatial map, it is clear that the quality of the water somewhat improves upstream compared to downstream. More rainfall and groundwater infiltration are to blame for this outcome, which diluted the groundwater system. The percentage of sampling points located at poor/extremely poor class in both approaches is found to be 15.79%. These indicators showed that the rivers' water quality had dramatically declined from upstream to downstream, which was evidenced by their high nutrient levels, agricultural runoff, leaching, anthropogenic input, and longer migration distances of surface water. Besides, the COPRAS technique was used to implement the weights generated from CRITIC approach, to evaluate the surface water's suitability for consumption. It is important to note that the water stress at S-8, 9 and 19 is caused by the accelerated use of surface water for irrigation and drinking, and that surface water pollution from anthropogenic inputs such fertilizer threatens the availability of sufficient supplies of safe drinking water. The open dump site lacks both a leachate collection system and a permeable barrier system. Contamination of surface water could result from this. Pollution potential and organic load at poor sites are at their highest points during the sampling period. As a corollary, it is recommended that urban local government entities regularly assess the levels of surface water contamination and put in place the necessary long-term corrective actions.

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