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Characterization of Surface Water Quality Using Water Evaluation Indices, EDAS and Geo-Statistics in Brahmani River Basin (BRB), Odisha, India

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Abstract. In this work, an effort has been made to comprehend the applicability of surface water in Brahmani Basin, Odisha for human consumption. Seven samples totalling 14 physicochemical parameters for the 2020–2023 period were examined and compared to the standard criteria advised by WHO methodologies to measure water quality using two indexing methods: Weighted Arithmetic (Wa) Water Quality Index (WQI) and Criteria Importance Through Intercriteria Correlation (Cr) WQI. As a result, Multiple-criteria decision making (MCDM) models, such as Evaluation Based on Distance from Average Solution (EDAS) were implemented to eliminate WQI index discrepancies, and they have been used to pinpoint the best spots along a river stretch where the water quality meets acceptable drinking criteria. The result of the WQI indicates that 57.14% (Wa-WQI & Cr-WQI) of surface water samples had poor drinking water quality. The area under study's overall WQI, demonstrates that the water is fit for drinking (around 42.86% good water) except few localized pockets in location S-I, II and VII. Farmland, landfills, industrial effluent, residential sewage discharge, pesticides, garbage, habitations, and other potential sources of pollution can all contribute to poor water quality. Putting the above MCDM models into practice, it was clarified that S-I, II and VII was the most polluting area compared to most places. This was evident from the highest Wa-WQI and Cr-WQI values at these locations. The results revealed that this approach brings about noticeable results, which can support water resource planning and sustainable use in the research area.

Keywords. Brahmani Basin, WA-WQI, Cr-WQI, EDAS, semi variogram

1. Introduction

Rivers are a vital freshwater resource that provided a home for many human communities and allowed ancient civilization to flourish in their basins. Surface water is one of the most important sources of water on the globe, and it is used for essential purposes like drinking, farming, and manufacturing. However, Rapid, unanticipated, and uncontrolled alterations to the local environment can cause water resources to degrade and become scarce [1]. Negative effects such as soil contamination, water pollution, and contamination of agricultural goods will result from the discharge of

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untreated or only partially treated waste water and its reuse as irrigation methods on agricultural farms. Therefore, For the sustainable use and protection of essential surface water resources, it is vital to create effective management techniques. However, there are few studies that describe the effects of surface water irrigation and drinking on the entire water circulatory system, including consumption, water use, soil, and crop growth [2]. The creation of Geographic Information System (GIS) based maps is one management option that might be used to offer a map that is simple to comprehend and help combine spatial data with other types of information [3]. IDW (Inverted Distance Weighting) is a methodology for predicting weights across observations or spatially interpolating information. When compared to IDW, the spline and kriging procedures are less advantageous since, alternately, kriging requires more user input and spline demands a great deal more processing and modelling time [4]. Therefore, Water Quality Indices (WQIs) may be evaluated using a straightforward mathematical process that reduces a vast array of water properties to a single number that represents the sum of all water quality ratings [5]. To fill this gap, previous researchers have created and developed the paradigm of WQI [6]. A number of scholars created distinct WQI models by comparing and evaluating various water quality parameters that are generated by the weighted arithmetic (W_a) method. It is an easy and reliable method for assessing the quality of the water [7]. Since then, numerous indices have been put out, but there is not a WQI, that is universally recognized. Furthermore, excessively weighted characteristics have the potential to negatively impact the index's sensitivity, making it crucial to weight the parameters according to how much water is used for drinking, residential usage, or irrigation [8]. The proper weighting of variables can solve issues like eclipse and ambiguity. To overcome the erroneous parameter weighting and to get rid of the subjective weighting assigned by prior approaches, namely Criteria Importance through Intercriteria Correlation (C_r) was used to reflect the parameters' built-in unpredictability. The precision and objectivity of weights are higher and stronger in comparison to those subjective valuation methods, which can better explain the results produced [9]. Multi-criteria decision-making (MCDM) processes are typically regarded as particularly effective in solving water management issues. Over the past few decades, analytical techniques have considerably improved to handle issues relating to water resources. In the ongoing analysis, the effectiveness of the WQI index was discussed, using MCDM with Evaluation Based on Distance from Average Solution (EDAS). The theoretical model of assessment procedures and the common language used to recognize the potential complex water concerns, that are both critical to the method's performance. Additionally, EDAS makes it simple to engage in decision-making, which increases the impact of uncertainties that frequently characterize issues with water management. However, this system would be useful for ranking water quality and might be used to lessen conflicts between the home and agricultural sectors [10]. Hence, it might lead to a trustworthy analysis for the sensitivity of several physicochemical factors. C_r is used to determine the weight of the criteria, while EDAS is employed to rank the options and select the best one. Therefore, the major goal of this review was to establish a straightforward WQI calculation process that requires less work and has better accuracy based on MCDM techniques for determining the quality of subterranean water and surface water. In order to identify the major sources of pollution and their effects on surface water, less thorough research studies have up until now been conducted throughout the river basin. There has not even been a single integrated study of W_a-WQI, C_r and EDAS, to evaluate the WQ of this area. Thus, to understand the scope and reasons for WQ degradation, there is a research gap that requires further discussion. In this current region, we suggested combining the two pieces of information, i.e., C_r-based weight determining method and the EDAS method to estimate the quality of surface water in Brahmani Basin during a period of 2020-2023. Thus, understanding the overall quality by specific factors and places, as well as integrating the geographical and temporal fluctuations, will be facilitated by this technique, thus, acknowledging the river's conditions and especially if the data set is large, it will be valuable in understanding the pollution assessment.

2. Study Area

The proposed research is a part of Brahmani River Basin (BRB), that covered an area of approximately 39268 Km^2, out of which 15405 Km^2, in Jharkhand state, 22516 Km^2 is in Odisha state, and 1347 Km^2 in Chhattisgarh state, and has a rich history of drainage for agriculture and fisheries to the State of Chhattisgarh and Odisha, India. Many cities get their household water supply from it. The area lies within geographic coordinates 84°47' E and 22°14'N. The basin is distinguished by its tropical climate, with a difference in average annual rainfall, which is depicted between 969 and 1574 mm. Nearly 45% of the basin is under agricultural land. Approximately, the estimated annual renewable water resources in the river basin are 21920 million cubic meters and the livestock is around 9.547 million in the basin area [11]. However, the range of mean maximum temperature is 38° to 43° C, and the minimum temperature contains around 10 and 15° C. Since BRB helps in protecting the river's physical, ecological, and chemical composition, because it provides drinking water for a sizable population. A location of the research area (Figure 1) was generated using ArcGIS version 10.8.

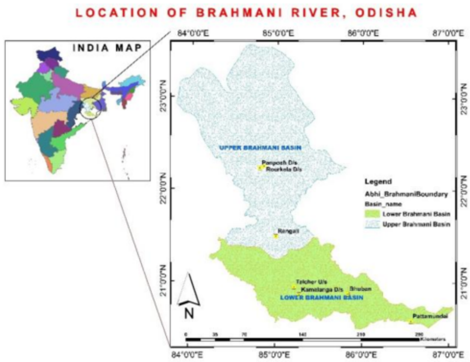

Figure 1. Sample and study area location map.

3. Sample Collection, Preservation and Analysis

Sampling was conducted on yearly average basis, during the period of 2020-2023, to account maximum potential pollution scenario. The Global Positioning System (GPS) captured the addresses of the 7 observation locations. The bottles were sealed, labelled, and delivered to the State Pollution Control Board's laboratory in Odisha, where they were kept at 4°C until additional examination. A total of 14 Parameters considered into the research area namely, pH, DO (Dissolved oxygen), EC (Electrical conductivity), TDS (Total dissolved solids), Alkalinity, Sodium (Na^+), Potassium (K^+), Nitrate (NO_3^-), Sulphate (SO_4^{2-}), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Fluoride (F^-), Chloride (Cl^-) and Phosphate (PO_4^{3-}). Analytical procedures for all the parameters were conducted as suggested by [12]. As a component of the quality assurance and control procedure, the investigation was highlighted using international standards ION 915. In case of relative standard deviation (RSD), its element values get examined and thus, were found to be <=2%. Further, the ionic balance errors for every quantitative result, were within the allowable threshold of ± 5%, thereby ensuring the accuracy of analytical outcomes.

4. Methodology

WQI is a single arithmetic value that expresses a function based on a weighted average of chosen parameters to find out the overall WQ. W_a-WQI is used to assess the drinking water quality using the chosen physicochemical characteristics. Further, the relative weight (X_i) of each parameter is computed according to [13] and it is calculated from the equation: $X_i = H_i / \Sigma H_i$, where X_i represents relative weight and H_i is the weight of each parameter. The quality rating scale (L_i) for each parameter was obtained from equation: $L_i = [V_i/U_i] * 100$, where L_i referred as quality rating scale, U_i stands for permissible standard and finally, V_i illustrates about the monitored value of each variable, which is expressed in mg/l. Finally, the computed WQI index ascertained the Sub-index (S.I) for each variable, that is calculated using the formula, which is represented as $S.I = X_i * L_i$. Then, in order to get the overall score, all sub-index values for each parameter were added and it is given as: W_a- WQI = Σ SI. Considering its results, the five classes that the water quality is divided into are, excellent (0-25), good (26-50), poor (51-75), very poor (76-100) and unsuitable (>100). The weights assigned to the various parameters are arbitrary and hence subjective. So, CRITIC-based weight is assigned to each parameter, to compute C_r-WQI. This group of correlation-based techniques is based on analyzing the decision matrix to ascertain the data present in the criteria used to assess the weights of the criteria. The main benefit is that it produces accurate results because human intervention in the parameter weighting process is completely eliminated. The stages involved in computing, defining, and ranking the decision criteria, determining the relative weights of each criterion, estimating each criterion's coefficient, and determining the revised weight and finally, calculation of the relative weight (W_y) are suggested by [14]. Lastly, the ultimate weight accumulation and a quality rating scale (P_i) result in $C_r\text{-WQI} = \sum W_y * P_i$, where P_i is calculated as the ratio of the monitored value (K_x) to its permissible value (R_x), which is expressed as $P_i = (K_x/R_x) *100$. Afterwards, EDAS is a MCDM technique, which is used for ordering the alternatives. The appeal of alternatives to this approach, is calculated using distances of them with the help of average solution (AV). Here, we have two methods for addressing how desirable the choices are. The positive distance from average (PDA) is the first metric, followed by the negative distance from average (NDA). Further, the evaluation of the alternatives is made according to higher values of PDA and or lower values of NDA represent that the solution (alternative) is better than average solution. Ultimately, its procedural steps are enumerated for this method with ‘n’ criteria and ‘m’ alternatives can be analyzed as suggested by [10]. Additionally, this method was utilized to calculate and combine numerous factors, weights, and constraint maps. Therefore, after normalizing the obtained data, these models might produce accurate results for grading survey sites. So, the challenge is based on, in which the C_r/W_a analysis is used to assess the significance of the criterion and the EDAS technique will be used to determine the best option and to rank the options in order of preference.

5. Results and Discussions

In this article, World Health Organization [15] standards are recommended as the benchmark for all parameters. The pH, which denotes whether water is acidic or basic, provides information on the concentration of hydrogen ions in a solution. Hence, the pH value for our investigation ranges from 7.51-8.07, emphasizing the slightly alkaline characteristics. In majority of the sites, the pH was within the permissible limit for drinking as specified by WHO (6.6-8.5). DO helps to evaluate the quality and natural contamination in the surface water. For this study, the DO was noticed as 6.78-7.67 mg/l. For drinking water, the minimum DO allow is 5 mg/l. However, it has been noticed that recorded values were significantly high from all the stations throughout the study period. TDS readings at each of the sampling stations were seen to be within the allowable limit i.e., 500 mg/l. It lies in the range of 86.39-182.72 mg/l. However, extremely low TDS water has a bland smell. Comparatively higher values seen at S-I, II, which is because of the river's discharge of untreated sewage, stormwater activities, and sewage sludge [16]. Alkalinity at sampling locations was discovered somewhere in the range of 51.67-72.89 mg/l. It is mentioned that Water at S-I was, compared to other stations, comparatively more alkaline, which may have been caused by the presence of extra salts. However, all sites contained within the desirable limit (200 mg/l). EC is crucial for estimating total ionic concentration, because a high EC value indicates a high TDS. 250 µS/cm is the optimum limit in case of drinking water. Observed value of EC was found to be 151.44-311 µS/cm. Excess salt in water felt at S-I, II and VII, which arises because plants are unable to maintain the osmotic equilibrium as a result of increased soil salinity. A certain quantity of Na^+ is crucial for maintaining good health, but if consumed in excess of the maximum allowable amounts, it can lead to negative health effects like headache and nausea. Therefore, in the ongoing study, its value lies in between 5.39-15.38 mg/l, which satisfies well with the WHO criteria of 200 mg/l. Residents' garbage disposal in open spaces, sewage disposal, and chemical fertilizers were the main contributors to K^+ contamination in surface water. It can be originated from natural and anthropogenic processes occurring in the surface water environment. The reported value recorded as 1.76-7.24 mg/l, which is well satisfying within the WHO guidelines of 12 mg/l. Ca^{2+} can be originated from natural and anthropogenic processes occurring in the surface water environment. In drinking water, the natural background levels may not exceed 75 mg/l. The observed values in the present research, vary in the range of 29.6-66.44 mg/l. All surveyed locations are within the acceptable range. Mg^{2+} is a crucial element for plant growth in low concentrations, but at higher amounts, it becomes highly toxic. Threshold limit is taken as 30 mg/l. It is associated with natural rock weathering and runoff. If water hardness is too high, it can lead to human renal failure, scaling in pots and boilers, and other problems [17]. Its concentration ranged between 18.78 and 29.22 mg/l, indicating its compatibility for public water supply. F^- primarily found in water as a result of geological process. Comparatively higher values are due to the amount of sewage that is dumped into a river from a household, an agricultural operation, or an industrial facility. The range of the reported measurements in the research area was varied from

0.3-1.16 mg/l. Except for two places, it was observed that every sample was within the permitted limit (1 mg/l) for drinking. Thus, water quality at S-I and II (higher F^- values), revealed that improved agricultural practices are seen in the study location, with agriculture serving as the primary source of income for the community. Usually, Cl^- in drinking water is a byproduct of natural sources, sewage, industrial effluents, fertilizers, leachate, and saltwater intrusion. The value of Cl^- was found to have in between 8.21-23.59 mg/l. The WHO's established acceptable limit is 250 mg/l. It is noticed that Cl^- arises in excessive amounts at sites (I, II & VII), which gives water a salty flavor, enhances its corrosivity, and can have a laxative impact on people when exposed in large doses. Further, the recommended NO_3^- level in potable water is 45 mg/l. The results revealed that nitrate falls in a value of 0.65-3.53 mg/l. It is emphasized that industrial production and agricultural cultivation are two significant regional activities that also attracted migration, making them two possible sources of pollution in the area. High SO_4^{2-} concentration causes abdominal discomfort in adults and has an antidiarrheal effect. The value of SO_4^{2-} was considered to be in a range of 7.89-40.12 mg/l, in the present study, which is well within the acceptable limits of 200 mg/l. Substantial amounts at three locations, can also derive from anthropogenic activities such as industrial pollution. At all sites, the concentration of PO_4^{3-} were allowable (0.1 mg/l) according to the WHO desirable limit and the water could be utilized for drinking after a disinfection step. High value is observed in S-I, II, III, IV, and VII, which is more than 1 mg/l. The main cause could be, fertilizer-containing runoff from agricultural areas and industrial effluent. In the present study, two indexing methods namely W_a-WQI and C_r -WQI and one MCDM method namely, EDAS has been incorporated to evaluate the WQI findings. This process undertook only 14 physicochemical variables. The obtained W_a-WQI range is 49-72.02 i.e., from good to poor categories (Figure 2). For the study (Figure 2), C_r-WQI was additionally used for the assessment of water quality. It values varied in the range 67-175. These values (Table 1) signified that the water quality was found to be 'good to poor'. Furthermore, the highest WQI value generated from both stated approaches was reviewed at S-I, which had elevated amounts of TDS, EC, Na^+, K^+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, NO_3^-, SO_4^{2-}, and PO_4^{3-}. Based on these two techniques, 57.14% of the sampling places represents water quality corresponds to good water while 42.86% represents poor water quality. Collectively, out of 7 samples, 3 sites (S-I, II and VII) recorded poor or very poor quality WQI values and this observation could result from the area's careless handling of home, industrial, and manufacturing effluents. Although, the river crosses the city's periphery considering significantly high values of EC, Na^+, K^+ and Cl^-, that were captured in all sites, suggesting that surrounding residential and agricultural activities may have contaminated the area. To understand pollution levels in the river, MCDM methods namely, EDAS is used to resolve the conflicts that currently exist inside the general WQI technique. This mechanism is applied on all the water quality parameters to establish overall rankings so that the location with the most pollution throughout each period would be indicated with the highest rank. It serves as an effective tool for making decisions. Table 1 displays the sampling locations' performance score and rankings. During the study period (Figure 3), the sampling location S-I was perhaps the most polluted relative to other places, followed by S-II and VII. It is evident that from the analysis at S-I that Ca^{2+}, Mg^{2+}, F^-, Cl^-, NO_3^-, SO_4^{2-} and Fe^{2+}, had high values relative to their permissible drinking water standards. Poor water quality demonstrates the presence of a significant amount of contaminants from the textile industry and related industrial effluents, sewage disposal, and agricultural runoff, yet it is safe to drink without treatment. Semi-variogram models must be generated for each of the factors in order to assess the water quality and to do so, the results of each model (circular, exponential, spherical, and Gaussian) in the Kriging method were analyzed to create a map that has the least amount of error for each measure of water quality. Based on outcomes, the Gaussian model was regarded as the most appropriate semi-variogram model for both indexing protocols (Table 2). The values of RMSE and ASE is 6.25 and 6.21 for W_a-WQI and 36.001 and 35.693 for C_r-WQI, that is presented by the Gaussian model, and the results found that the reported values were the minimum in comparison to other models. Based on the acquired maps (Figure 4), the majority of the factors are evident in S-I and II location, which contains larger values, indicating higher pollution. The spatial dependence, in our study, is usually understood with the help of 'nugget/sill' ratio. The 'nugget/sill' values of 0.063 and 0.025 have been retrieved from both these techniques. Moreover, the reason might be from both indices, that represent a strong spatial dependence which indicates factories close to rivers and rivers receiving urban waste stream flow.

Table 1. Evaluation of the monitoring point's quality.

Sample No	Locations	W_a-WQI	Water type	Cr-WQI	Water type	EDAS	Rank
S-I	Panposh D/s	72.02	Poor	175	Poor	0.97	1
S-II	Rourkela D/s	68.79	Poor	169	Poor	0.76	2
S-III	Rengali	63.05	Poor	162	Poor	0.13	5
S-IV	Talcher U/s	50.00	Good	67	Good	0.01	6
S-V	Kamalanga D/s	49.00	Good	76	Good	0.20	4
S-VI	Bhuban	49.14	Good	72	Good	0.01	7
S-VII	Pattamundai	64.67	Poor	171	Poor	0.38	3

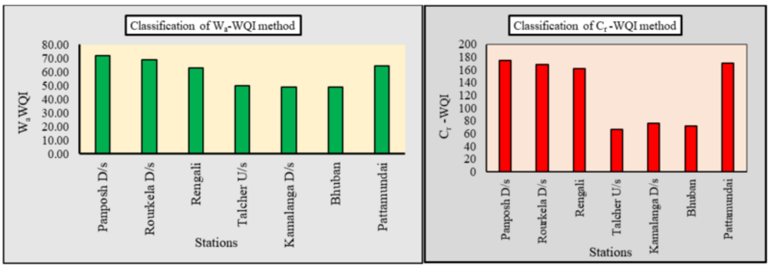

Figure 2. Variation of all quality monitoring points based on W_a-WQI and C_r-WQI.

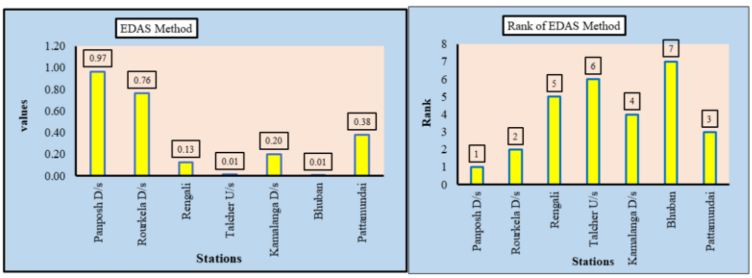

Figure 3. Variation and rating of all quality monitoring points based on EDAS.

Table 2. Description of semi-variogram model for all chosen 7 sites.

WQI methods	Best-fit model	Nugget	Sill	Nugget/sill	ASE	RMSE	MSE	RMSSE
W_a-WQI	Circular	15.00	195.31	0.08	6.76	6.29	-0.08	0.80
	Spherical	15.00	172.44	0.09	6.86	5.89	-0.07	0.76
	Exponential	14.00	185.24	0.08	7.28	5.78	-0.05	0.71
	Gaussian	13.27	207.60	0.06	6.21	6.25	-0.10	0.78
C_r -WQI	Circular	0.05	2.11	0.09	36.94	37.75	0.05	0.99
	Spherical	0.06	1.87	0.03	37.40	36.36	0.05	0.95
	Exponential	0.14	1.92	0.07	40.39	36.84	0.01	0.86
	Gaussian	0.20	2.22	0.03	35.69	36.00	-0.03	0.80

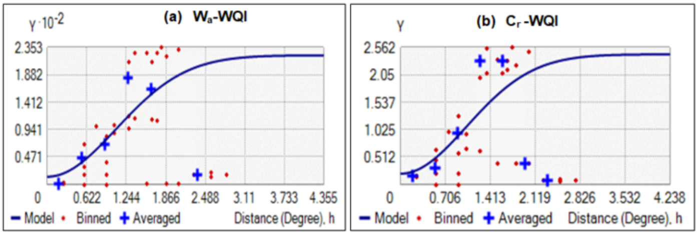

Figure 4. The best-fit semi variogram models for (a) W_a-WQI and (b) C_r–WQI.

6. Conclusion

In this ongoing work, the effectiveness of combined use of W_a- WQI, C_r -WQI and EDAS approach has been demonstrated with a case study. The outcomes of various indexing schemes namely, W_a- WQI and C_r -WQI, jointly reveal 42.86% of samples to be in the good category. Hence, both indexing techniques graded three Sampling locations (S-I, II and VII) as poor and all other locations as good. According to the findings of the drinking WQI assessment, the Brahmani River in Odisha is fresh at its source and could be used for consumption and household applications without being treated before it enters the city. Moreover, EDAS technique was performed including all the measured parameters for characterization of sampling locations and provided an overall ranking of the survey points, because of their relative pollution levels. The results denoted that S-I was most polluted in comparison with other sites. It also accompanied with high values of Ca^{2+}, TDS, EC, F^-, Na^+, K^+, NO_3^-, Cl^-, Mg^{2+}, SO_4^{2-}, and PO_4^{3-}, which were highest among all the areas and also higher than their desired concentration. Afterwards, semi variogram modelling shows that Gaussian model finds the optimal match for both approaches i.e., (W_a- WQI and C_r -WQI). Overall findings suggests that the level of pollution would be high in the basin at Stations (S-I, II, & VII), subjected to extensive human activity, industrial waste water, landfill, living quarter, pesticides, garbage, and other polluting components. Therefore, it was concluded that this hybrid framework suggested in this study can be readily used in various parts of the world to assess whether surface water quality is suitable for household and agricultural uses.

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