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Study On Spatial Variations of Surface Water Quality Vulnerable Zones in Baitarani River Basin, Odisha, India

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ABSTRACT

The stated goal of the research is to investigate the surface water quality of the Baitarani River in Odisha to ascertain its compatibility for various uses. Large, complex datasets generated during the one-year (2021-2022) monitoring program were collected from 13 locations and encompassed 22 parameters. To examine temporal and spatial fluctuations in and to interpret these datasets, MCDMs like TOPSIS and the Entropy-based Water Quality Index (EWQI) were utilized. The physical and chemical outcomes of the current experiment were compared to WHO standards. According to the analysis's results, turbidity and total coliform (TC) are indicators that have a greater impact on water quality in all locations during both seasons and are directly linked to home and agricultural non-point source pollution. As per EWQI interpretation, 30.77 % of the observations in PRM and POM fall under the poor category. The findings showed how anthropogenic activities have harmed St. 8, 11, 12, and 13 and require effective management. A quantifiable approach was also carried out to decide the efficacy of TOPSIS. Farming attributes, including SAR, % Na, RSC, MR, KI, and PI, were estimated to delineate the agriculturally practicable zones. This work can offer a reference database for the betterment of water quality.

INTRODUCTION

Water pollution is the accumulation of naturally occurring organic matter, which is a complex mixture of different organic molecules resulting primarily from aquatic life, soil, and terrestrial vegetation, as well as toxic chemicals that are available in higher concentrations than what is usually found in water and may be dangerous to the environment (Thakur et al. 2020, Das 2022a). These days, water quality has become a severe problem that has drawn attention from all around the world to preserve and safeguard them (Banda & Kumarasamy 2020). River water quality is being negatively impacted by a number of anthropogenic and natural processes, which is preventing rivers from being used for a variety of purposes (Das 2022b, 2023). It is also a significant issue in the governance and design of water resources (Akhtar et al. 2020). In addition, a rise in urbanization, building, agricultural, and industrial activities, as well as natural processes like bedrock weathering, volcanic and earth crust erosion as well as human-induced actions like wastes generated from coal combustion, metallurgy, mining, and metal smelting are all contributing factors (Meng et al. 2017, Jha et al. 2020, Jinisha et al. 2020). Additionally, it has a negative influence on surface and groundwater, as well as on human well-being (Meshram et al. 2022). Surface water quality has grown extremely important in recent decades, especially in emerging nations like India. It has also become a touchy subject (Bora et al. 2017, Singh et al. 2020a). Therefore, monitoring the level of components, their concentration, sources, and distribution is crucial to managing water resources and preventing water pollution (Usman et al. 2018, Hong et al. 2020). Surface water quality (WQ) monitoring experts confront a difficult problem when elucidating monitored data (Hong et al. 2016). Water Quality Indices (WQIs) were developed as a result, and they are quite user-friendly and simple to use in computing hardware (Shrestha & Basnet 2018). Horton (1965) made the first modern WQI suggestion. Since then, a number of studies have put out and used several indexes to categorize the water quality in the concerned area (Tiyasha et al. 2020), but there isn't a WQI that is universally recognized. WQI development involves a lot of subjectivity and unpredictability (Landwehr 1979). Subjective disturbances would be reduced by assigning fixed weights based on the indices and using intrinsic information (Li et al. 2010). Shannon (1948) or information entropy may be used to explain this data. Researchers applied information entropy effectively in their work (Singh 2013, 2014, Talukder et al. 2017). The term "entropy-weighted water quality index (EWQI)" refers to the summation of respective parameter weights and rating scales based on quality, taking all the criteria and transforming them into a cumulatively calculated numerical score. These are an enhancement over traditional WQIs which generally focused on the Delphi technique. Another major feature is the Analytical Hierarchy Process (AHP) approach, along with the expert survey method (ESM), which is jointly dependent on the assigning of weights to the concerned or relevant parameters that depend upon individual judgments and expert advice (Gorgij et al. 2019, Singh et al. 2020b). Geographical Information System (GIS) is a crucial concept to understand geospatial details in today's world for surface WQ (Balamurugan et al. 2020). Scientists from several domains have developed the GIS in recent decades for geospatial investigation, case studies, and its blending technique (Burrough & McDonnell 1998). Inverse Distance Weighting was used to accomplish this (IDW). Large datasets can be quickly and affordably transformed into a variety of spatially distributed diagrams and projections, which show trends, correlations of indicators, and vital pollution sources (Reddy et al. 2019). In the Adyar River basin, Chennai, Tamil Nadu, India, for instance, Ramachandran et al. (2020) illustrated seasonal quality water based on drinking WQI in conjunction with GIS. They discovered that the quality was contaminated for human use in many parts of the area investigated. Researchers have assessed the possibilities of multi-objective decision-making strategies in stream restoration initiatives in addition to WQIs, including demand response, redressing management, renewable energy sources, and WQI ranking modifications (Yousefi et al. 2018). TOPSIS determined the overall rating of each sampling site's pollution level (Technique for Order of Preference by Similarity to Ideal Solution). It uses information entropy and aims to find the scenario that is the farthest away from the negative ideal solution (NIS) and closest to the positive ideal solution (PIS) (Hwang et al. 1993). For exhibiting the quality of surface water in terms of irrigation, agricultural indicators namely Sodium adsorption ratio (SAR), Permeability index (PI), Residual sodium carbonate (RSC), Kelley's (1963) index (KI), Percent sodium (% Na), Magnesium hazard (MH) ratio, Residual sodium bicarbonate (RSBC), and Potential salinity (PS) have been widely used (Brhane 2018). To demonstrate the caliber of the water evaluation of the Baitarani River in Odisha, India, which aims to determine the many causes responsible for the fluctuations in the water quality, the present study was undertaken in 2021–2022. 22 physiochemical water quality parameters were inspected during the detection period, i.e., Pre-monsoon (PRM) and Post-monsoon (POM). The time frame considered for analysis is 1-year. The novelty of this recent study is a result of the integration of EWQI, GIS, and MCDMs in the management and monitoring of water quality. To evaluate if surface water is suitable for irrigation, calculations of agricultural indices such as SAR, % Na, RSC, PI, KR, MR, RSBC, and PS are also taken into account.

MATERIALS AND METHODS

Description of Study Area

The planned study would focus on the Baitarani River basin, which is located between 21°0'0" and 22° latitude and 85°0'0" to 86°30'0" east longitude. Because agriculture predominates in this region, crops like rice, maize, wheat, groundnuts, vegetables, and green gram are grown all year round. Vegetables and rice (paddy) are the prominent food crops grown in the area. Additionally, it is a popular tourist site and has built 7200 small-scale manufacturing enterprises. Due to the abundance of alluvial soil in the area, several crops thrive there. The mean annual rainfall is 1628 mm, and summertime temperatures range from 30 to 36°C to 16 to 17°C in winter. The topography of the basin is undulating, with an average slope of between 0 and 2 percent. It has a surface area of approximately 8645 km^2 and an elevation range of 32 to 1181 m above mean sea level (MSL). Most of the human population in this basin depends upon agriculture for their livelihood, and it is majorly used for cultivation, production, and horticulture techniques. However, the river has experienced quick and unchecked development activities, including the installation of industries, building projects, and the use of agricultural and forest areas for further development purposes. The soils also experience mild to severe erosion as a result of the absence of integrated soil conservation and irrigation methods. Since they are of enormous ecological and environmental value, proper monitoring is required to implement plans for their preservation and restoration. Fig. 1 shows the map showing locations and river path of the Baitarani River in the State of Odisha.

Sample Collection, Preservation, and Analysis

The watershed was first surveyed to determine the sampling site's location and to explain the specific point and non-point sources of contamination. 13 locations were selected owing to

Fig. 1: Location of the study area with sampling points.

the research area's high population density, agricultural activity, and waste disposal facilities. A weighted bottle sampler was used to collect water samples in triplicate throughout the years 2021–2022. After collection, the bottles were firmly shut and maintained in a refrigerator at 4°C. The dilutions were performed using deionized water. By dilution, the stock solutions were made into standard solutions. When sampling and testing, quality assurance and quality control are effective ways to get more precise data. The analysis has adhered to quality control in accordance with the 20th edition under the norms of Standard Methods which is used for the Examination of Water and Wastewaters, issued by APHA (2017). For their correctness in interpreting chemical data, these variables were cross-checked depending upon the principle of ionic balance error (IBE), which is otherwise defined as IBE = [(cations - anions)/ (cations + anions)] × 100. The cations and anions are displayed in milligrams per liter ($mg.L^{-1}$). The IBE value should not go over the permissible threshold of 5%.

Data Processing

Inverse distance weighted approaches are the most widely used techniques for creating spatial distribution maps (IDW). Using ArcGIS, this method was utilized to produce spatial variation maps (Anand et al. 2020, Ram et al. 2021). Microsoft Excel 2016 with XLSTAT 2015 was used to undergo statistical and computational analysis.

Entropy-Weighted Water Quality Index (EWQI)

The evaluation of water quality frequently uses the EWQI (Marghade et al. 2019). The following are the steps taken in the EWQI calculation as per (Gorgij et al. 2017). The following formula, developed by Claude Shannon in 1948, calculates the information entropy (E) of each assessed parameter, and it is expressed as $E_n = -(1/\ln n) \sum_{i=1}^{m} Vij \times \ln Vij$, whereas the variable "n" stands for a number of locations, and V_{ij} is taken as the probability of occurrence on the basis of the normalized value of examined parameter 'j' within the i^{th} specimen. It is expressed as $V_{ij} = v_{ij} / \sum v_{ij}$. Entropy weights (W) are calculated using $W_j = (1-E_j)/\sum(1-E_j)$. Lastly, the conjunction of entropy weights with the quality rating scale results in the given equation, and it is stated as $EWQI = \sum W_j \times U_j$, where U_j talks about individual variable which denotes the ratio which explains as monitored value gets divided by its standard value (S_j) for that indicator and it expresses in the form of $U_j = (I_j/S_j) \times 100$. Waters with an EWQI of 50 or less are considered to have excellent quality, those between 50 and 100 are considered to be good, those between 100 and 150 are considered to be average, those between 150 and 200 are considered to be poor, and those greater than 200 are considered to have extremely poor quality.

Determination of Rank using the TOPSIS Method

While calculating the Euclidean distances between the positive ideal solution (PIS) and the nearest ideal solution (NIS), TOPSIS, which is based on information entropy, seeks to find the alternative or scenario that is closest to each. It is a useful tool for decision-making processes and can be used in the ways listed below (Hwang et al. 1993): Employing matrix P, grades for the sampling areas and their parameters were assigned. The matrix is clearly expressed below:

$$P_{m*c} = \begin{matrix} P11 & P12 \ldots & P1c \\ : & \ldots Pij & : \\ Pm1 & \ldots & Pmc \end{matrix}$$

Where P_{ij} displayed the value of the i^{th} alternative for the j^{th} criterion, the following criteria weights were generated using information entropy approaches. It is expressed in the following equation: $q_{ij} = P_{ij}/ (P_{ij} + \ldots\ldots\ldots + P_{mj})$; for all j € {1…., c} And, $E_j = [-1/\ln (m)] \sum q_{ij} \times \ln q_{ij}$; for all j € {1…., c}, where $0 \leq E_j \leq 1$. It talks about an index with a greater entropy value having a higher variation. Therefore, the weight is calculated as $W_j = d/ (d_1 + \ldots\ldots + d_j)$ and $d_j = 1-E_j$. The equation $V = [N]_{m*c} \times w_{c*c}$ represents the normalized weighted decision matrix. Two ideal solutions namely PIS and NIS were computed from PIS = {max v_{ij}I v_{ij} € V} = (v_1^+, …., v_c^+) & NIS = {min v_{ij}I v_{ij} € V} = (v_1^-, …., v_c^-). Finally, the Euclidean distance of individual alternative from the PIS (d_i^+) and NIS (d_i^-) was computed as: $d_i^+ = [\sum (v_{ij} - v_j^+)^2]^{0.5}$ & $d_i^- = [\sum (v_{ij} - v_j^-)^2]^{0.5}$. Proximity or closeness coefficients (C.C) of each and every alternative was calculated as $PS = d_i^- / (d_i^- + d_i^+)$. Finally, the possibilities were ordered by their closeness coefficients.

Irrigation Water Quality Parameters

The quality of irrigation water indicates the appropriateness for agricultural use. In light of this, Equations based on Subramani et al. (2019) were used and taken to calculate the agricultural parameters such as SAR, % Na, RSC, PI, KR, MH, RSBC, and PS, in which all the ions are addressed in meq.L^{-1}. An important salinity tool, namely the sodium adsorption ratio (SAR) index, measures the ratio of the ions Na^+, Ca^{2+}, and Mg^{2+} in a water sample. In this index, Sodium hazard can be easily understood by estimating SAR, and it is computed with the help of this equation suggested by Richard (1954) and Adimalla (2018). Hence, it is expressed as $SAR = Na^+ / 2\{(Ca^{2+} + Mg^{2+})/2\}^{0.5}$. According to the index, irrigation water falls into one of four categories: excellent (<10), good (10-18), doubtful (18-26), and unsuitable (>26). Another indication of the quality of irrigation water is the sodium percentage (%Na), or soluble sodium concentration. Na^+ reacts with the soil and causes particle blockage, which lowers permeability (Suresh & Kottureshwara 2009, Keesari et al. 2016). It can be estimated using the relationship shown below: $Na\% = [Na^+ / (Ca^{2+} + Mg^{2+} + Na^+)] \times 100$. Fipps (2003) claims that irrigation with water that has a sodium concentration of more than 60% may result in Na+ build-ups in the soil, which will damage the soil's physical properties. The compound residual sodium carbonate (RSC) is a mixture of the ions Ca^{2+}, Mg^{2+}, and CO_3^{2-} and HCO_3^- (Zaki et al. 2018). It is a crucial parameter and is expressed as $RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$ to determine the appropriateness. It is dangerous to use water for irrigation that has an RSC index > 2.5 meq.L^{-1}. It is safe for cultivable crops when the RSC index is less than 1.25 meq.L^{-1} and somewhat suitable when the RSC index is between 1.25 and 2.5 meq.L^{-1} (Narsimha 2020). In order to improve agriculture, the permeability index (PI), a key measure, is used to examine the effectiveness of irrigation water in relation to the soil. The following formula is used to calculate this value, and it is expressed as $PI = [Na^+ + (HCO_3^-)^{0.5}/(Ca^{2+} + Mg^{2+} + Na^+)] \times 100$. Using the permeability index (PI), Doneen (1965) divided the irrigation water into three classes. Class I talks about 100% maximum permeability, hence, safe for irrigation). On the other hand, Class II represents 75% maximum permeability, and it comes under the slightly appropriate class. Ultimately, Class III belongs to 25% maximum permeability, which depicts that it is not safe for farming. Kelly (1963) suggested that the values of the Kelly Index (KI) ratio might be used to conveniently handle the Na^+ problem in irrigation water. Na^+ is in opposition to Ca^{2+} and Mg^{2+} ions in this combination. This is computed by a formula, i.e., $KI = Na^+ / (Ca^{2+} + Mg^{2+})$. When KR is less than 1, water is suitable for irrigation, and when KR is greater than 1, it is not suitable for irrigation. The soil structure is typically harmed by greater Mg^{2+} concentrations, which causes the water to absorb more Na^+ and salts and reduce crop yields (Keesari et al. 2018). The magnesium hazard (MH) is the harmful result of the excessive concentration of Mg^{2+} in the irrigation water. The index for calculating the index, developed by Paliwal (1972), is $MH = [Mg^{2+} / (Ca^{2+} + Mg^{2+})] \times 100$. Water with an MH of less than 50 is regarded as appropriate for irrigation. However, surface water with an MH of more than 50 is not useful for irrigation. Because extended watering reduces soil permeability owing to HCO_3^- precipitation, an index termed residual sodium bicarbonate (RSBC) will be used to assess the alkalinity risk. It is determined using the Kadam et al. (2021) -proposed equation, i.e., $RSBC = HCO_3^- - Ca^{2+}$. The index values of 5 meq.L^{-1} were deemed satisfactory by Ravikumar and Somashekar (2017). Plant growth may be impacted by concentrations higher than 10 meq.L^{-1}. The river's potential salinity (PS) is steadily rising each year and is now acknowledged as a significant issue for downstream water users (Kumarasamy et al. 2014). It is thought to be equal to the Cl^- concentration plus 50 percent of the sulfate concentration (Ravikumar & Somashekar 2017). This is represented or calculated using an equation, i.e., PS = Cl^- + (½ * SO_4^{2-}).

RESULTS AND DISCUSSION

Using pH, one may determine if surface water is acidic or alkaline (Balamurugan et al. 2020). In PRM and POM, the pH values ranged from 7.3 to 9.7 $mg.L^{-1}$, indicating alkaline conditions that favor phytoplankton development. In accordance with the WHO's (2017) recommendation for the pH range (6.5-8.5) for standard drinking water quality. Because of the increased warmth and photosynthetic activity, some stations have detected higher pH levels in drinking water. Due to the presence of these suspended particles, also known as turbidity, which get deposited in the water, the purity of the water reduces. The WHO has set a turbidity permissibility limit of 5 NTU (Nephelometric Turbidity Unit) (Kumar & Puri 2012). During the PRM and POM seasons, the values in the current study range between 8.2-25.2 and 11.8-38.7. Due to the presence of organic and inorganic debris from sewage discharge and agricultural runoff, the value was found to be high in all-weather circumstances. TDS (total dissolved solids) is a measure of the total salt content dissolved in water. The recorded values during PRM and POM in the experiment varied from 74 to 178 and 97 to 247, respectively, showing that they were well within the limitations (500 $mg.L^{-1}$). Due to excessive TSS (total suspended solids), less light enters the water, and photosynthesis proceeds more slowly. These effects lower the DO (dissolved oxygen) level and lessen the clarity of the water. On the other hand, during the seasons, i.e., PRM and POM, the value ranged between 30-121 and 97-247. According to WHO (2017), the amount was significantly below the 500 $mg.L^{-1}$ minimum threshold for drinking and agricultural purposes. The dissolved and suspended component or saltiness of the water is measured by the EC (electrical conductivity). It was in the range of 96-318 and 121-393 during PRM and POM, which is well satisfying the WHO criteria of 2250 $\mu S.cm^{-1}$. Because it has an impact on the organisms that live in the water body, DO is a crucial indicator for evaluating the quality of surface water (Bu et al. 2019). For this study, the DO values were noticed as 4.78-8.01 in PRM and 5.03-7.69 in POM respectively. As a result, DO levels are optimal over the whole research region. Higher alkalinity in water, and vice versa, increases its ability to neutralize acids. According to WHO (2017), it shouldn't be more than 120 $mg.L^{-1}$. The values fall between 43-99 in PRM and 69-99 in POM. The reading was discovered to be within the acceptable limit (120 $mg.L^{-1}$) for the entire sampling season. BOD (biochemical oxygen demand) measures how much oxygen microorganisms utilize to break down organic materials (Siraj et al. 2010). The recorded BOD values varied in a span of 0.86-4.23 in PRM and 0.88-4.54 in POM, respectively. The value was found to be under the WHO guideline limit (5 $mg.L^{-1}$). According to Marko et al. (2014), TH (total hardness) results from the presence of Ca^{2+} (calcium) and Mg^{2+} (magnesium) ions in the river and ranges from 64 to 121 in PRM and 71 to 135 in POM. The findings in this investigation were below the 300 $mg.L^{-1}$ acceptable limit (WHO 2017). In addition, rock weathering and rock-water interactions were blamed for the bicarbonate (HCO_3^-) concentration. In the current work, the values for PRM and POM, respectively, varied from 41.92 to 87.55 and 55.64 to 91.46. Readings from all of the chosen locations indicated that concentrations were higher during the wet season than they were during the dry season. Gypsum leaching results in the naturally occurring presence of SO_4^{2-} (sulfate) in water. The observed values for PRM and POM are respectively 2.4-6.87 and 2.31-7.16. The concentration in the river was at a level that did not provide a health risk, and the current readings in the study region were below the norm of WHO criteria and taken as 250 $mg.L^{-1}$. The primary causes of NO_3^- (nitrate) contamination of surface water were residential trash disposal in open areas, sewage disposal, and chemical fertilizers (Panneerselvam et al. 2020). The NO_3^- readings ranged in the ongoing work, with a value of 0.65 to 4.15 $mg.L^{-1}$ during the PRM and POM periods, respectively. It is suggested that 45 $mg.L^{-1}$ is the desirable upper limit for human consumption (WHO 2017). All observations, though, fell within the permitted ranges for each sample site. An exceptionally high dosage of PO_4^{3-} (phosphate) could cause digestive issues (Pandit & Yousuf 2002). Its value during the study period varied between 0.25 and 1.04 in PRM and 0.31 and 1.17 in POM. The findings showed that all of the water samples were within the WHO (2017) recommended limits of 1.2 $mg.L^{-1}$ and could be consumed directly without further treatment. The main sources of Cl^- (chloride) in surface water include arid climate, household waste, septic tanks, leaks, and irrigation return flows (Sadat-Noori et al. 2014, Wu et al. 2011). Cl^- levels in PRM and POM ranged from 7.87 to 28.18 and 8.72 to 28.86, respectively; these values fall within the allowable range of 250 $mg.L^{-1}$. Ca^{2+} is crucial for the normal development of bones, bodily fluid balance, muscle contraction, and testicular descent (Heaney et al. 1982). The usual threshold for Ca^{2+} in drinking water is taken as 75 $mg.L^{-1}$ (WHO 2017). It varied between 14.83 and 28.72 for PRM and 14.03 and 29.74 for POM in the research area. All places have water with Ca^{2+} levels that are within WHO guidelines. Additionally, the increased Mg^{2+} in the irrigation water aids in the plant's uptake of Ca^{2+} or K^+,

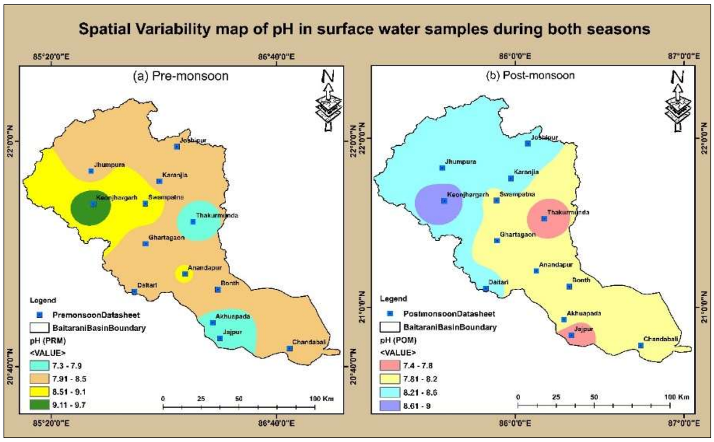

Fig. 2a: pH map.

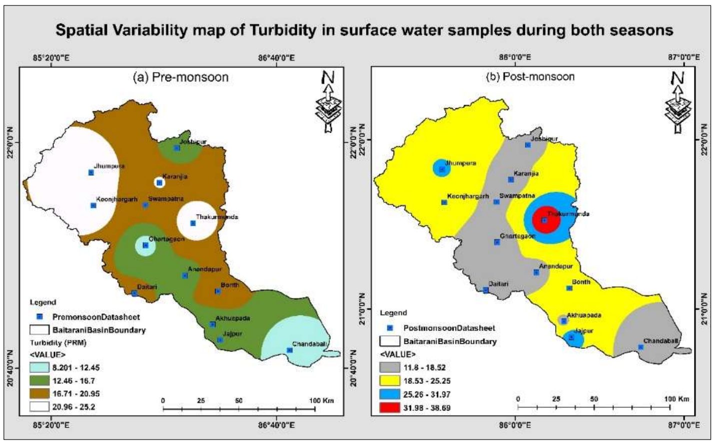

Fig. 2b: Turbidity map.

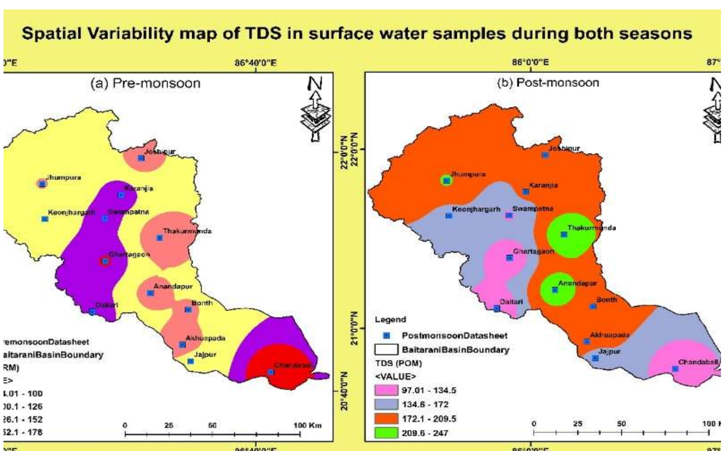

Fig. 2c: TDS map.

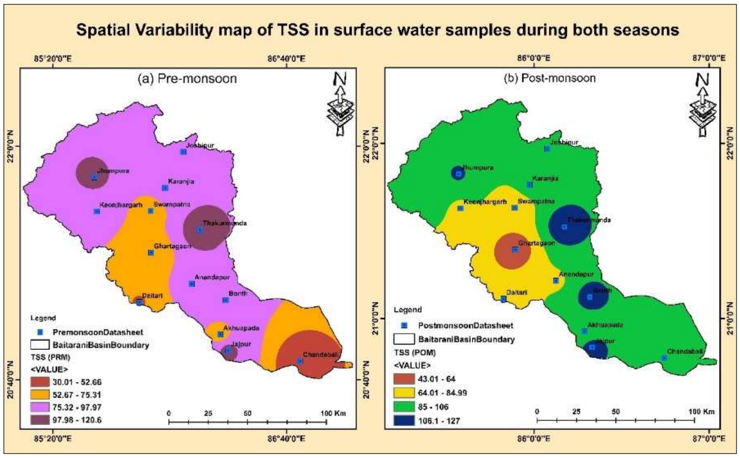

Fig. 2d: TSS map.

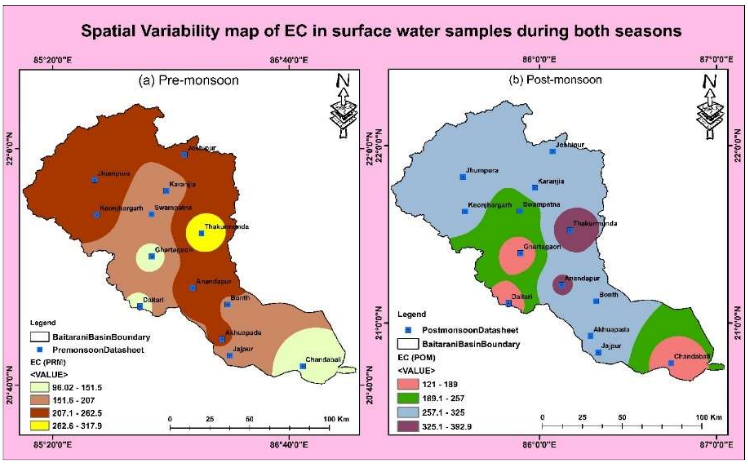

Fig. 2e: EC map.

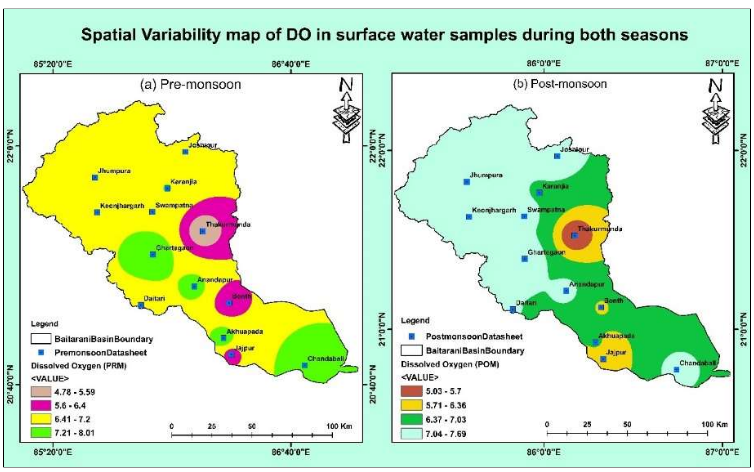

Fig. 2f: DO map.

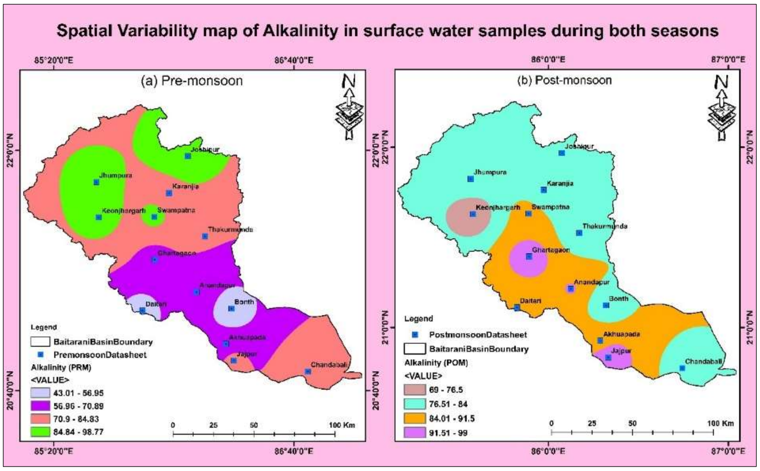

Fig. 2g: Alkalinity map.

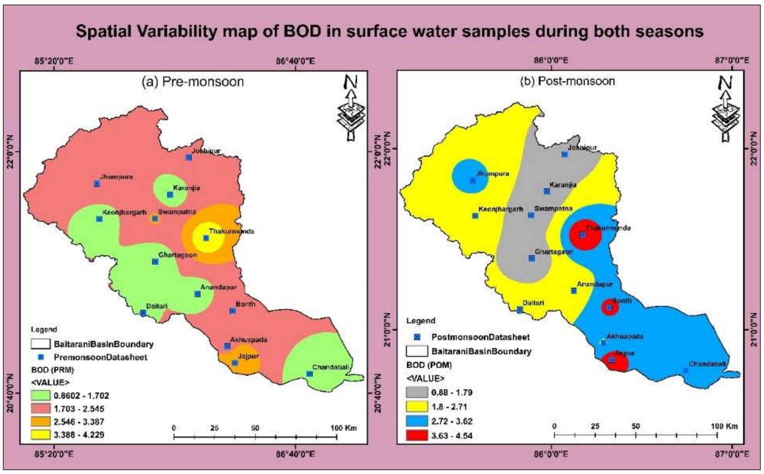

Fig. 2h: BOD map.

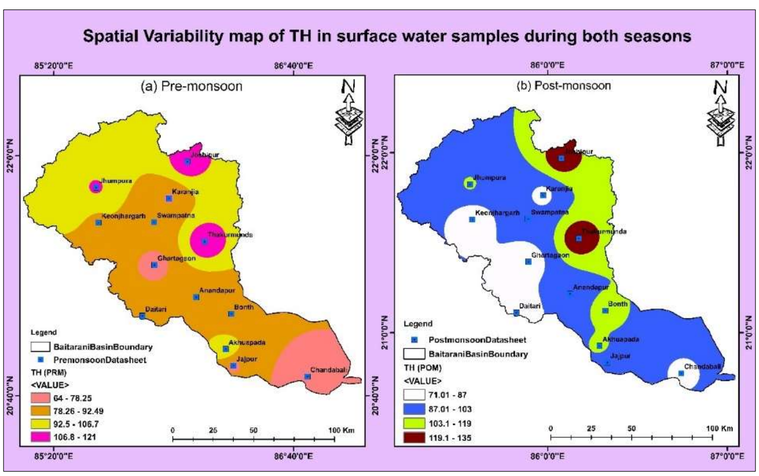

Fig. 2i: Total hardness (TH) map.

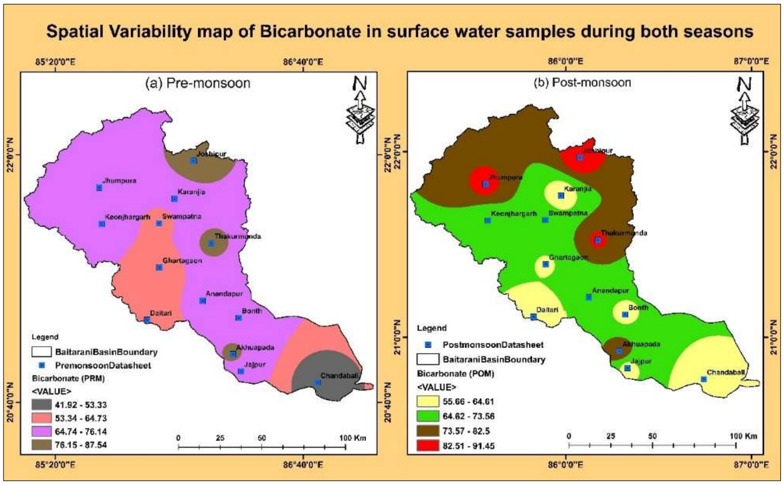

Fig. 2j: HCO_3^- map.

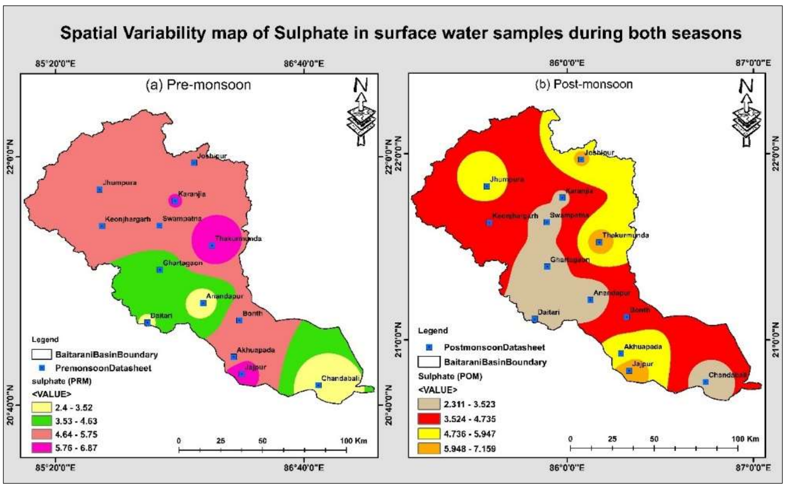

Fig. 2k: SO_4^{2-} map.

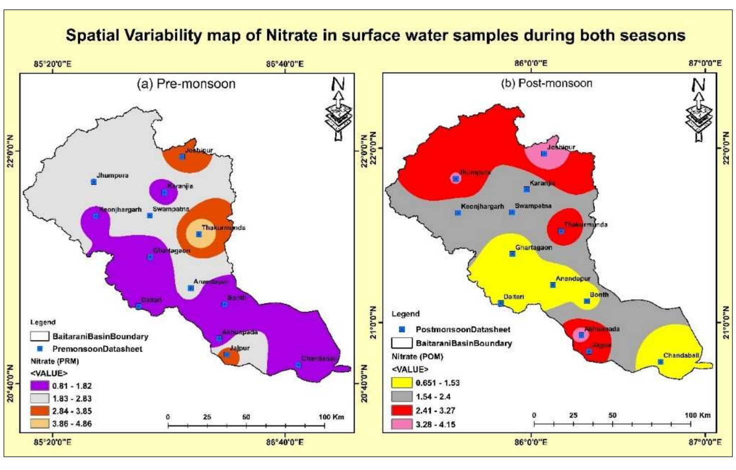

Fig. 2l: NO_3^- map.

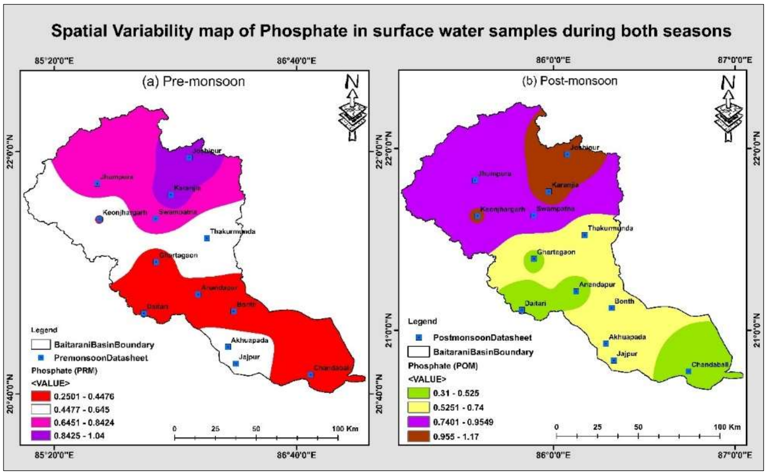

Fig. 2m: PO_4^{3-} map.

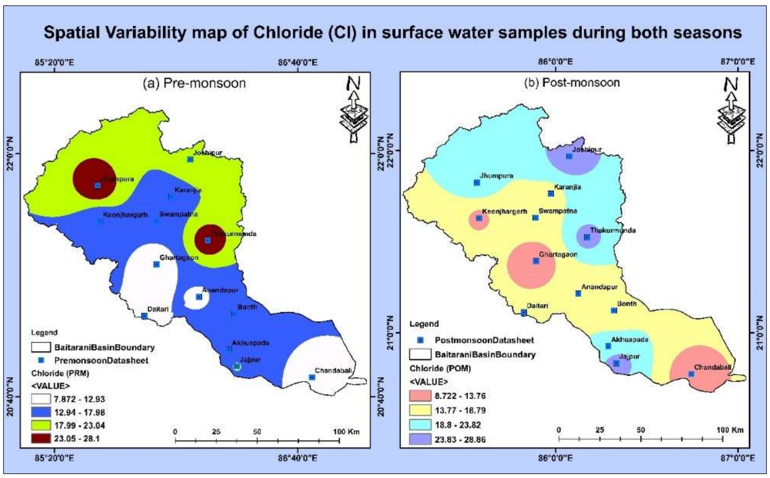

Fig. 2n: Cl^- map.

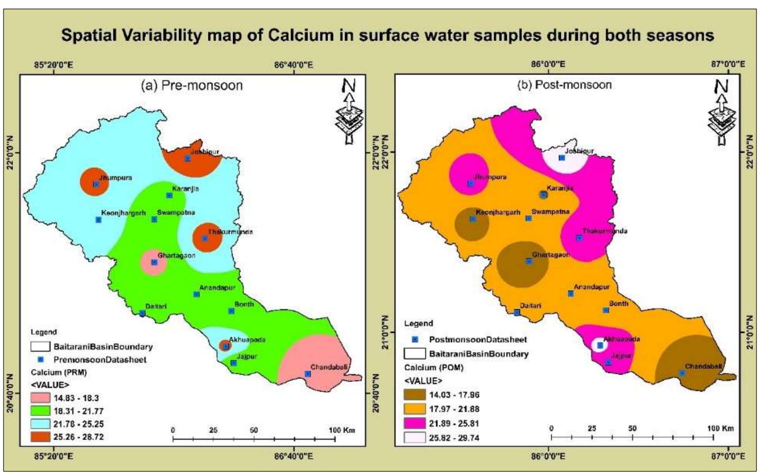

Fig. 2o: Ca^{2+} map.

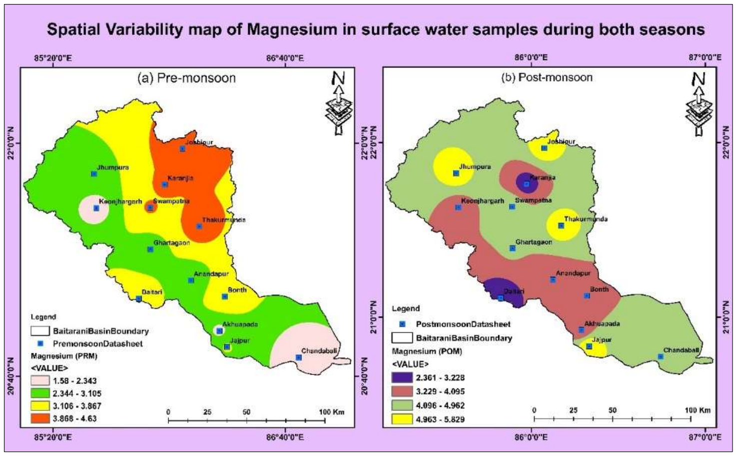

Fig. 2p: Mg^{2+} map.

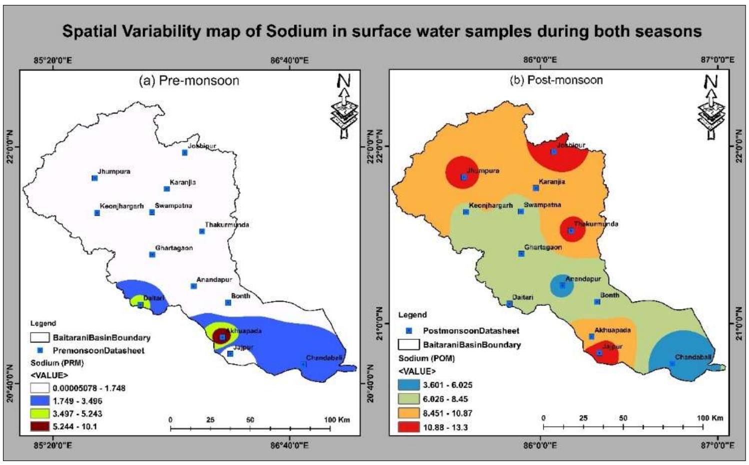

Fig. 2q: Na^+ map.

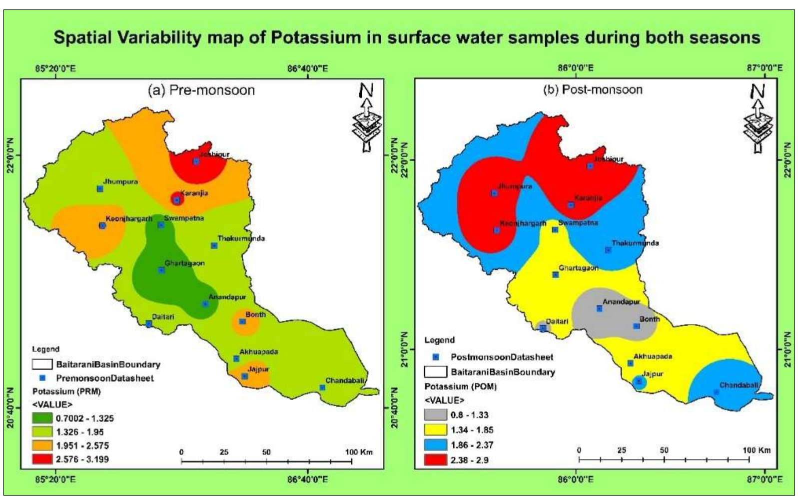

Fig. 2r: K^+ map.

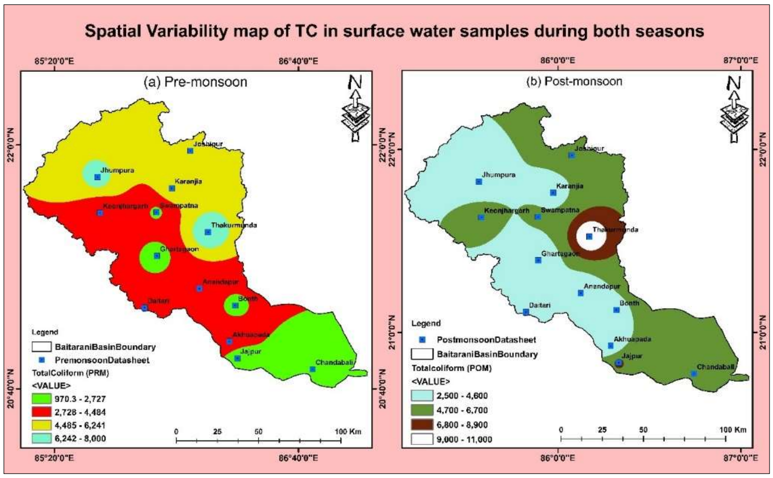

Fig. 2s: TC map.

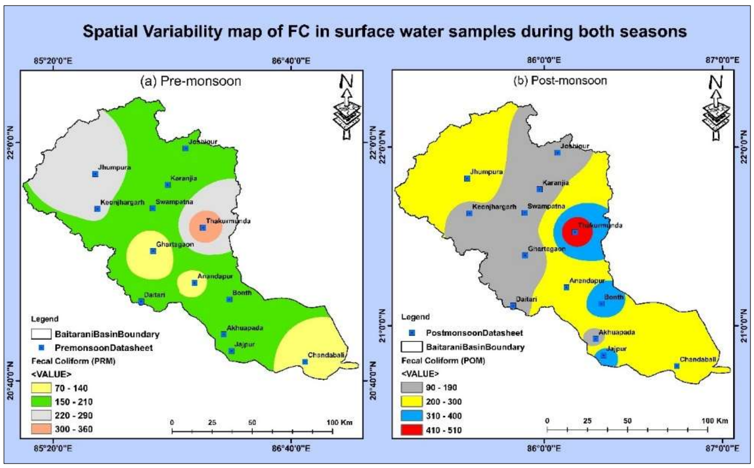

Fig. 2t: FC map.

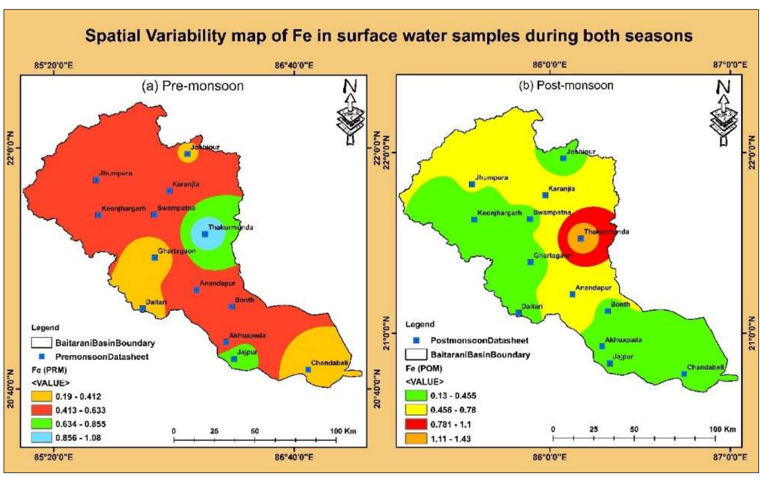

Fig. 2u: Fe^{2+} map.

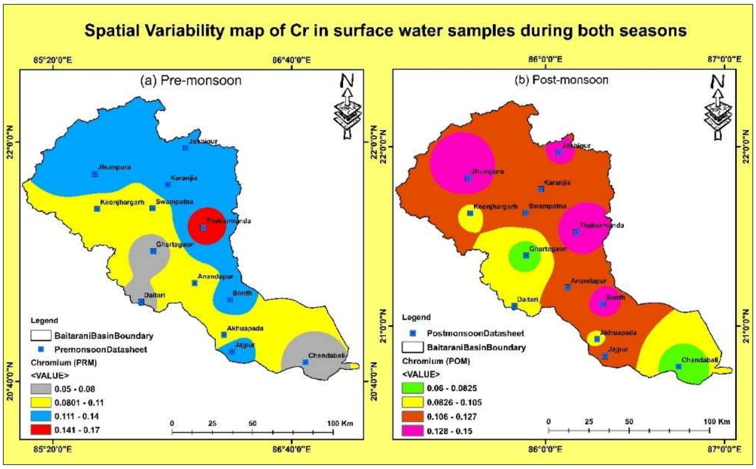

Fig. 2v: Cr^{2+} map.

which results in deficiencies in plant tissues (Bauder et al. 2011). Based on WHO norms, the allowable higher value for Mg^{2+} is 30 mg.L^{-1}. The Mg^{2+} concentration was below the maximum permitted level at all sampling locations, ranging from 1.58 to 4.63 in PRM and 2.36 to 5.83 in POM. The most significant element, Na^{+} (sodium), can be found in natural water (Haritash et al. 2016). According to WHO (2017), the limit for drinking water is 200 mg.L^{-1}. The values that were reported ranged from 3.6 to 13.30 in POM and 2 to 10.10 in PRM. The fertility of soils will decline with K^{+} (potassium) treatment under long-term farming. Consequently, this is a crucial component for improving irrigation (Li et al. 2019). The results found in the current analysis fell under the WHO threshold, and it is taken to be 12 mg.L^{-1} in the present study, the readings ranged from 0.7 to 2.20 for PRM and 0.8 to 2.9 for POM. In the study region, the value for PRM varied from 970 to 8000, and for TC (total coliform), it varied from 2500 to 11000 in POM. Most places that are close to industrial, municipal sewage systems, or hospitals have reported higher levels in the water. FC (fecal coliform) scores range from 70 to 360 in PRM and from 90 to 510 in the POM season, suggesting that all places are secure. In the current study, the concentration of Fe^{2+} (iron) in the river ranged from 0.19 to 1.08 in PRM and from 0.13 to 1.43 in POM season. Fe^{2+} is necessary for the transport of oxygen in the blood, but at high concentrations, it may result in hemochromatosis and DNA damage (Saleh & Al-Ruwih 1999). Except for St. 8 in PRM and St. 7 and 8 in the POM period, all water samples have concentrations below the permissible limit of 1.0 mg.L^{-1}. Water containing Cr^{2+} (chromium) lowers fatty acid and cholesterol levels and controls blood sugar and insulin levels. Cr^{2+} values (0.05-0.17 in PRM and 0.06-0.15 in POM) are below the 0.2 mg.L^{-1} criterion for drinking water in every sampling site in the research area. All units are in mg.L^{-1} for all indicators except pH (unitless) and EC in µS.cm^{-1}. As shown in Fig. 2a-v, spatial distribution maps were created for various parameters, which were performed in the Arc GIS 10.3 program, utilizing the inverse distance weighting (IDW) over the entire catchment to illustrate a link for enhancing water quality evaluations.

Some significant indices are used to assess the quality of river water used for irrigation, including SAR, % Na, RSC, MH, KI, PI, RSBC, and PS. A method called SAR is used to measure the proportion of Na^{+} to Ca^{2+} and Mg^{2+} ions in irrigation water, and it exhibits a maximum tendency to trigger a cation exchange reaction in soil (Singh et al. 2017). Implementing this index to the water samples reveals that during PRM and POM, recorded SAR values ranged from 0.09 to 0.39 and 0.15 to 0.46, suggesting excellent class with zero salinity. Fig. 3 depicts the interpolated map that was created. Na^{+} concentration has an impact on soil permeability. Hence, irrigation in the basin area could benefit from water grading depending on Na^{+} concentration. Fig. 4 illustrates the computed % Na findings for PRM and POM, which ranged from 12.56% to 28.43% and 15.73% to 29.76%, respectively. It has been found that most of the locations belong to excellent and good-quality zones. Higher Na percent (>10) is seen in some places, indicating that ion exchange and rock weathering from lithological units are dominant processes (Vasanthavigar et al. 2010). RSC is considered an efficient parameter for reviewing the suitability of water for irrigation/agriculture. Fig. 5 depicts the recorded range of RSC, which varies from -0.33-0.09 in PRM and -0.38-0.13 in POM. However, it is seen from the results that all locations belong to the zone of good water, which has an RSC value < 1.25 meq.L^{-1}. It is noted that water with a high MH ratio can impede the overall strong Ca^{2+} and Mg^{2+} ratio (Khanoranga & Khalid 2019, Das et al.

2023a). According to Fig. 6, the MH values vary from 11.92 to 25.81 for PRM and from 16.20 to 35.12 for POM. The findings show that all samples (100%) were appropriate for irrigation (MH<50). The surface water samples were used to compute the KI, which fluctuated between 0.10-0.35 and 0.14-0.36 during the PRM and POM seasons, respectively. Fig. 7 shows that 100% of the samples in the study region, which is less than unity, and infers that these samples are suitable for irrigation. Relying on the PI values seen in Fig. 8, the values for PRM and POM, respectively, varied from (41.8-65.7) % and (38-60.7) %. It implies that every place is classified as Class II or doubtful (25-75) percent. Based on RSBC, PRM and POM scores spanned from -0.16 to 0.29 and -0.09 to 0.34, respectively. The numbers are safe because they are far below the satisfactory value. In Fig. 9, the spatial variety of RSBC is clearly visible. According to the study region, the PS values varied from 6.05 to 2.83% in PRM and 7.38 to 25.81% in POM and are regarded as fair low. Fig. 10 demonstrates it clearly.

Additionally, EWQI assessed the water quality of Baitarani River, Odisha, in relation to the drinking water quality standard, and their results are displayed in Table 1. It is observed from the findings that TC holds the maximum entropy weight and is considered to have the highest influence on the water quality. The second-most important factor was NO_3^-. It was discovered that the calculated EWQI ranged from 46 to 199 in PRM and 42 to 199 in POM, respectively, and was rated as excellent to poor in both periods. In both seasons, St. 8 received the highest EWQI ratings and had high levels of turbidity, TC, FC, EC, TSS, BOD, TH, SO_4^{2-}, NO_3^-, Fe^{2+}, and Cr^{2+}.

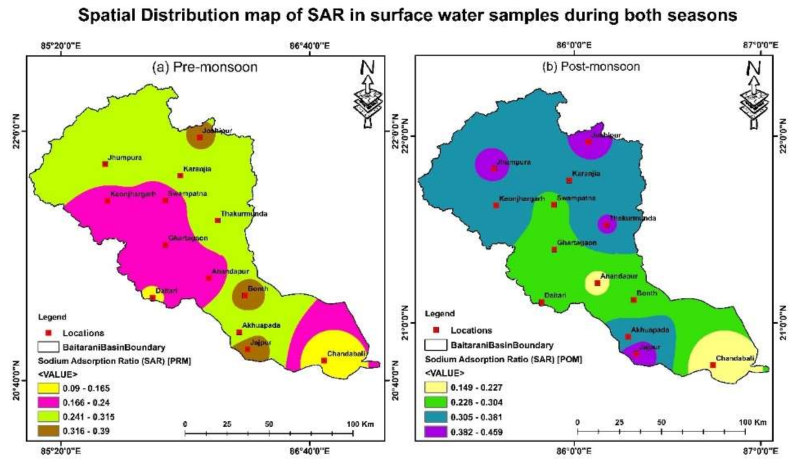

Fig. 3: Sodium adsorption ratio (SAR) map.

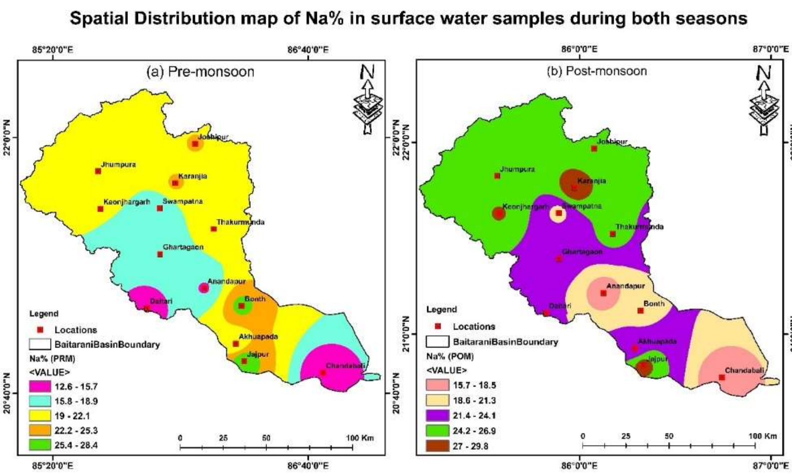

Fig. 4: Percent sodium (% Na) map.

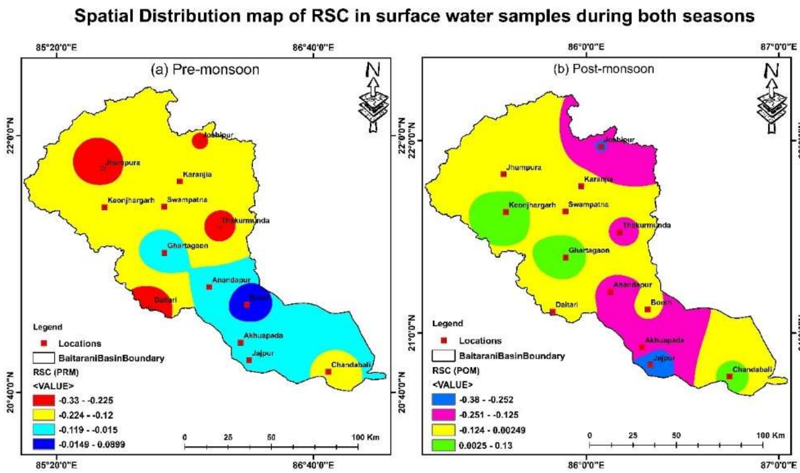

Fig. 5: Residual sodium carbonate (RSC) map.

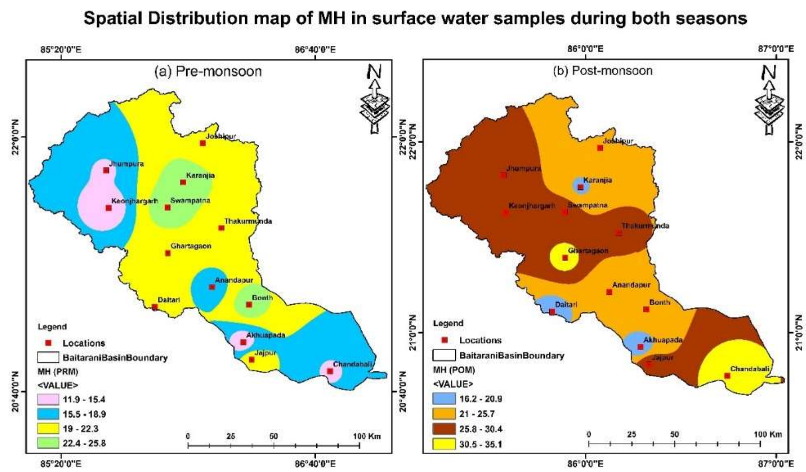

Fig. 6: Magnesium hazard (MH) map.

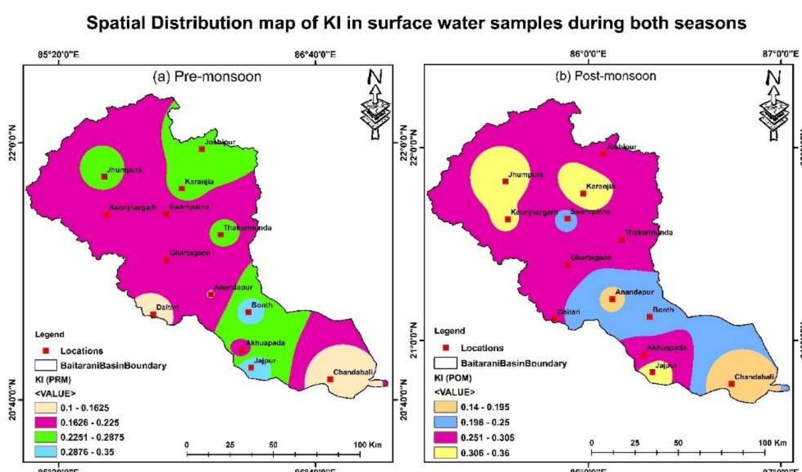

Fig. 7: Kelly's Index (KI) map.

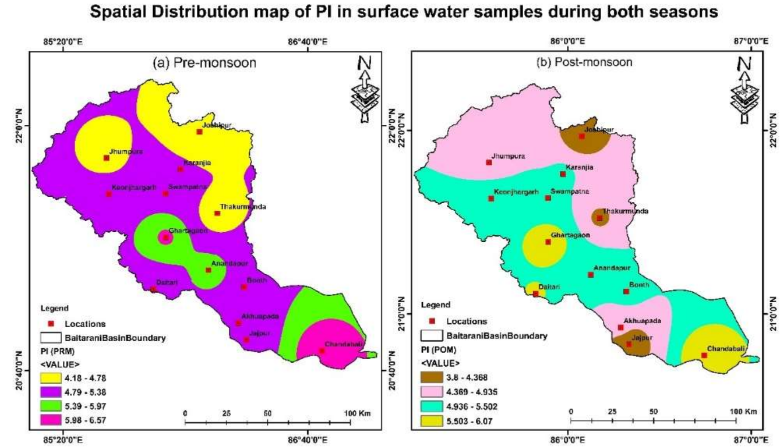

Fig. 8: Permeability Index (PI) map.

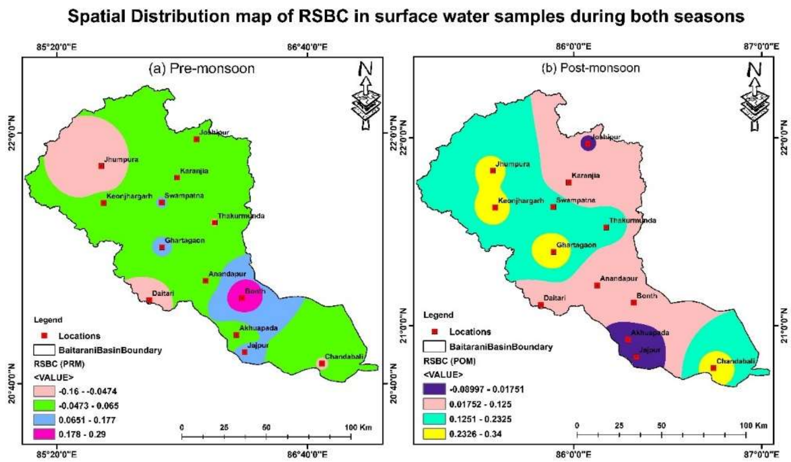

Fig. 9: Residual sodium bicarbonate (RSBC) map.

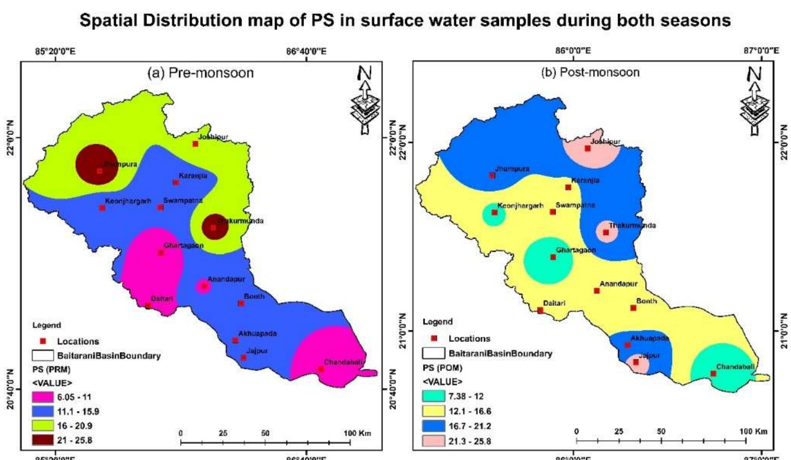

Fig. 10: Potential Salinity (PS) map.

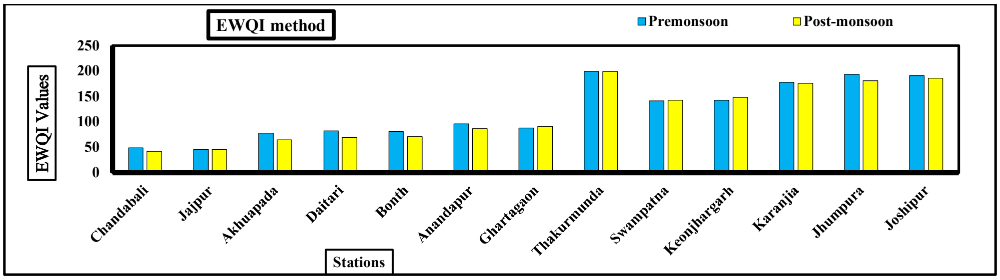

Fig. 11: EWQI classification.

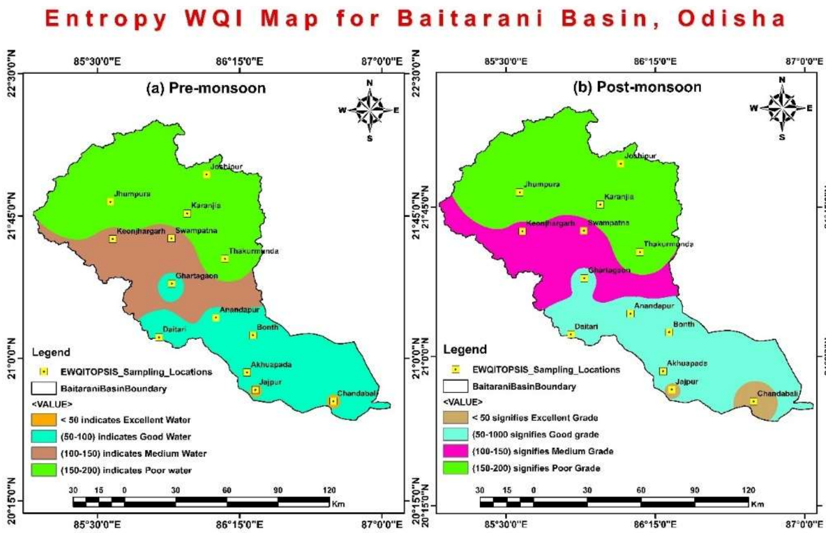

Fig. 12: Entropy WQI map.

Additionally, it is clear from the analysis at St. 8 that turbidity and TC had high values in comparison to their acceptable drinking water requirements (WHO 2017). Fig. 11 illustrates how the EWQI varies across the research area. The dispersal of the samples in percentage terms reveals that throughout the entire study area, Excellent water was found in 15.38% of samples, good water was found in 38.46%, Medium water was found in 15.38% of samples, and Poor water was found in 30.77% of samples in both periods. Fig. 12 depicts the interpolated map that was created. Results show that St. 8, 11, 12, and 13 in PRM and POM, which are described as having inadequate water, are extremely susceptible to activity caused by humans (Das et al. 2023b).

However, by assigning them their overall scores based on CC to PIS, the TOPSIS technique clearly indicates the relative pollution level. The rankings for CC and TOPSIS are shown in Table 2. The sampling location, St. 8, was the most contaminated compared to other locations during PRM and POM. Figs. 13 and 14 show the results of performance score and rank for both seasons. As the St. 8 had significant anthropogenic impacts, it was utterly unfit for drinking and irrigation purposes. Fig. 15 depicts the regional variation in output over the area. In order to draw drinking and irrigation water, TOPSIS ranks were therefore strongly identified as being substantially superior.

Table 1: EWQI in sampling locations of Baitarani River, Odisha.

Locations	Pre-monsoon (PRM)	Post-monsoon (POM)
St. 1	49	42
St. 2	46	46
St. 3	78	65
St. 4	82	69
St. 5	81	71
St. 6	96	87
St. 7	88	91
St. 8	199	199
St. 9	141	143
St. 10	143	148
St. 11	178	176
St. 12	194	181
St. 13	191	186

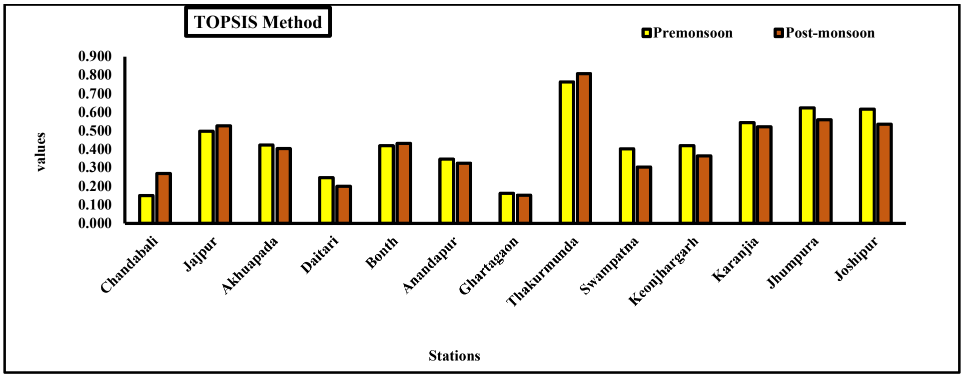

Fig. 13: Variability of TOPSIS ranks of concerned locations.

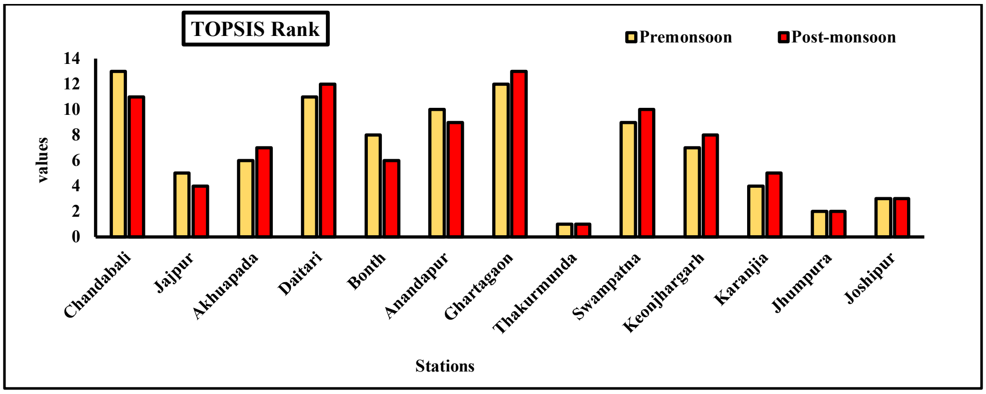

Fig. 14: Rank of all sampling sites during both seasons.

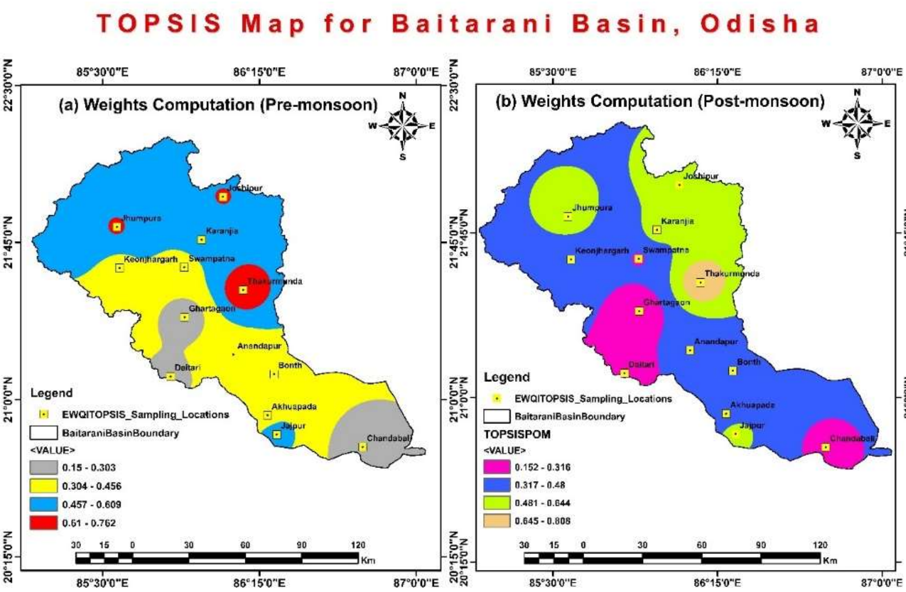

Fig. 15: TOPSIS spatial map.

Table 2: Closeness coefficients (C.C) and TOPSIS ranks of all the locations of the Baitarani River.

St. No.	Pre-monsoon (PRM)		Post-monsoon (POM)	
	C.C	Rank	C.C	Rank
St. 1	0.150	13	0.270	11
St. 2	0.497	5	0.525	4
St. 3	0.424	6	0.404	7
St. 4	0.247	11	0.199	12
St. 5	0.419	8	0.431	6
St. 6	0.347	10	0.325	9
St. 7	0.162	12	0.152	13
St. 8	0.762	1	0.808	1
St. 9	0.403	9	0.303	10
St. 10	0.419	7	0.364	8
St. 11	0.544	4	0.520	5
St. 12	0.623	2	0.559	2
St. 13	0.616	3	0.536	3

CONCLUSION

All living creatures rely on rivers as a natural resource. Thus, protecting the quality of the water is crucial for both the present and the future. In this study, a more effective method to measure water quality was developed using the TOPSIS method in conjunction with the entropy-based weight-determining method (EWQI), which explains and provides sufficient information on both geographical and seasonal variations for examining the compatibility of surface water for human intake and irrigation. By converting the dataset into corresponding unit data and numerical index values, the EWQI and TOPSIS models were shown to be effective methods for categorizing the differences in river water quality.

In order to evaluate the water quality, water samples were taken on a yearly basis over a period of one year (2021-2022) at 13 discharge locations that represent the stream's overall pollution load. The river's pH was found to remain comparatively higher, indicating an alkaline character in both seasons. In both seasons, adequate DO is present, which promotes good health of the aquatic ecosystem. The threshold limits are determined to be met for all the tested parameters. However, in both seasons and locations, the turbidity and TC concentrations were greater than the desirable limit for water for drinking. Throughout the period, i.e., both pre-monsoon and post-monsoon seasons, heavy rainfall-runoff discharge is the prominent cause of high turbidity. The removal of sediments from the river's bottom surface also caused a rise in turbidity, as well as related measures, including TC, TDS, and EC, in the majority of the stations. In PRM and POM, the recorded EWQI scores ranged from 46 to 199 and 42 to 199, respectively.

Based on the EWQI ratings, it is concluded that the water quality at all test sites ranges from excellent to poor. High EWQI levels indicate the water's toxicity at St. 8, 11, 12, and 13, which is the primary contributor to a number of health issues. Monitoring the treatment and disposal of sewage, industrial, and home waste is crucial during both seasons at these places in order to reduce water body pollution and prevent it from changing the chemical and physical makeup of drinkable water.

To characterize sampling locations, TOPSIS was further run with all measurable data included. This resulted in an overall rating of the sites based on their relative levels of pollution. According to the findings, St. 8 was the most contaminated location in both the periods compared to other places. The main causes are the effects of climate change, population growth that is occurring at a rapid rate, urbanization, and agricultural practices, all of which have a significant impact on human activities, including the quantity and quality of surface water resources.

All locations in the research region were determined to be suitable for irrigation water based on evaluations of SAR, % Na, RSC, MH, and KI values as indicators of irrigation water quality in both seasons. However, the PI of a river's water quality indicates doubt and should be controlled during both seasons because it could have dangerous consequences when used for irrigation. This was done in order to ascertain the water's suitability for agricultural usage. The TOPSIS ranking findings are consistent with the entropy method's results for calculating water quality, demonstrating its validity and application.

Based on the study's findings, it can be seen that combining these two models with irrigational indices can be used to find and separate the sources of surface water contamination, opening new possibilities for surface water protection and purification. In this context, it is predicted that decision-makers employed by agencies that safeguard water quality will discover the research findings to be of great value.

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