A Coherent Approach of Indexing Methods to Assess the Water Quality of River Bodies in Arrah, Bihar, India

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Abstract: Different river bodies are diverse sustaining systems that provide freshwater to rapidly growing needs at the domestic, agricultural and industrial levels of the people of India. The river bodies need periodical examination for conservation and rejuvenation because they are currently under stress due to pollution and climate change. Arrah is a district of Bihar, India and occupies an area of 2395 km^2 for agriculture as the predominant activity. It is an attempt to assess the water quality of River Ganga, Sone and Gangi in this area by combining the overall pollution index (OPI), comprehensive pollution index (CPI) and water quality index (WQI) from November 2021 to October 2023 from 648 water samples and nine sampling sites to establish a relationship between any change in water quality and their sources. We assessed eleven water quality parameters following standard methods for winter, summer and monsoon seasons. Observations showed that dissolved oxygen, total alkalinity, fluoride and rarely biochemical oxygen demand exceeded Bureau of Indian Standards (BIS 2012) prescribed limits and indicated deterioration in the water quality of these river bodies. Two-way ANOVA suggested that the water quality parameters of these river bodies showed significant differences ($p<0.05$). We used Numerical equations to transform the concentration values into pollution indices. Values of OPI (1.70 to 2.40) and CPI (0.65 to 0.90) indicate acceptable/ slightly polluted/moderately polluted water in these rivers. Values of WQI of these river bodies ranged from 182.0-192.1, 220.1-242.2 and 190.7-238.9 during winter, summer and monsoon seasons, indicating poor/very-poor water quality. The observation shows that the causes of the declining water quality in these water bodies are anthropogenic activity, agricultural waste runoff and entry of untreated sewage. To reduce the time-consuming and expensive water quality monitoring and assessment programmes for these river bodies, the water quality of these water bodies felt the need to adopt proper management policies and conservation efforts.

Keywords: River Bodies, Physicochemical Parameters, Seasonal Values, Water Quality Indices, ANOVA, India.

INTRODUCTION

Different river bodies provide freshwater to rapidly growing needs at the domestic, agricultural, and industrial levels of the people of India. River bodies give life support to the population, but human health is affected by water pollution. In India, Around 37.7 million people are affected by waterborne diseases and 1.5 million children are estimated to die of diarrhoea each year (UNICEF 2019).

A variety of pollutants enter into the river body through anthropogenic perturbation like mining, discharge of municipal, domestic and agricultural runoff containing chemical fertilizers and industrial effluents (Amman et al. 2002; UCOST 2012; Paul, 2017; Kumar et al. 2021; Matta et al.2022). Along with climate change, various natural processes and soil erosion also affect the quality of water resources (Kansal et al. 2013; Santy et al. 2020; Mama et al.2021).

Because of the exponentially growing river pollution, various studies have evaluated the seasonal effect on river water quality in recent years (Seth et al. 2013; Matta et al. 2018; 2020; 2021; 2022). However, there is no harmony data for the water quality of the River Ganga in India (Trombadore et al. 2020).

Water quality is intrinsically connected to human health, food production, gender equality and economic development (Jha et al. 2020). Monitoring river water quality seems fundamental for assessing information on water pollution prediction, control and evidence for planning the sustainable use of water resources (Firoz 2007; Mama et al. 2021). However, in recent years, developing countries have faced challenges in upgrading water supply and sanitation in maintaining water quality (Debels et al. 2005; Carvalho et al. 2011; Mammari et al. 2023). It is considered harmful and ill-suited for different human usage and other agricultural activities once they occur more than the well-defined limits (BIS, 2012).

The water quality index (WQI) is one of the most effective tools for describing water status and determining its suitability for researchers and decision-makers on the possible uses of a given water body (Kannel et al. 2007). It assists with understanding the water quality status of resources at a time and their suitability for various beneficial uses (Yogendra & Puttaiah 2008). WQI is non-generic and usually developed on site-specific guidelines for a particular region of indices that apply to all water types are dependent on time, location and frequency for sampling as number, variety and weight allocation of physicochemical parameters. Changing large amounts of water quality data into a single index is uncertain (Uddin et al. 2021; Chidiac et al. 2023).

Horton (1965) initiated the concept of WQI and many applicable water quality indices such as the Comprehensive Pollution Index (CPI), Overall Pollution Index (OPI), National Sanitation Foundation Water Quality Index (NSFWQI), (Brown et al.1970; Pesce & Wunderlin 2000; Sargaonkar & Deshpande 2003; Yogendra & Puttaiah 2008; Shi et al. 2009; You et al. 2009; Sebastian & Yamakanamardi 2013; Matta et al. 2017) assess the quality of water within a particular area. Many workers (Debels et al. 2005; Bouslah et al. 2017; Matta et al. 2020) have worked out the study of the WQI of different rivers. Reports are available to assess water quality using 10-OPI models (Kumar et al. 2019).Pesce & Wunderlin (2020) used water quality indices to verify the impact of Cordoba City (Argentina) on the Suquı`a River. 23-WQI models (Uddin et al. 2021) and statistical methods are reported for periodic assessments and time-series analysis (Schreiber et al. 2022).

A novel industrial water quality index (IndWQI) model determines the overall industrial water quality based on scaling and some physicochemical parameters (Nsabimana & Li 2021) and the Canadian Council of Ministers for Environment Water Quality Index (CCMEWQI) (Kumar et al. 2021). Machine Learning (ML) algorithms such as the M5P Model tree, Multivariate Adaptive Regression Splines (MARS) and Gene Expression Programming (GEP) are employed to predict WQI in Iran as the calculation of WQI is time-consuming (Goodarzi et al. 2023).

The overall pollution index (OPI) helps understand the pollution levels of the surface water sources and is applicable for expressing the state of water fitness in Indian conditions. Development of an OPI based on a general classification scheme (Sargaonkar & Deshpande 2003).

The comprehensive pollution index (CPI) has been developed and introduced worldwide with various applications of surface water quality (Matta et al. 2017). It uses monitoring statistics to determine the pollution in a water body.

OPI and CPI are key indices for assessing the consistency of surface water in India (Matta et al. 2020).

18% of the world's population of India and 4% of the world's water resources is a water-stressed nation with a 1588 m^3 per capita per annum water supply. In India, Yogendra & Puttaiah (2008) in Karnataka; Kumar et al. (2011) in Gujarat; Sharma & Kansal (2011) in Delhi, Bora & Goswami (2017) in Assam and Lkr et al. (2020) at Nagaland have worked on various parameters of the WQI of rivers in India. Such informative investigations are rare in Bihar.

Arrah is an agricultural area dominated by the paddy culture, especially aromatic rice and also is one of the best wheat-growing areas in Bihar. The climatic condition is subtropical to temperate with winter, summer and monsoon seasons (Chauhan 2010). The City has three river bodies: River Ganga, River Sone and River Gangi.

Therefore, the aims and objectives of this study are (i) to provide an appropriate picture of the present water quality, (ii) to evaluate the physicochemical properties of the water and their seasonal/annual variations, (iii) to calculate WQI and (iv) to establish suitable management policies and conservation strategies for people in the future of the River bodies at Arrah, through various indices.

MATERIALS AND METHODS

(A) Study area

Arrah occupies an area of 2395 km^2 and is situated in the Eastern-Central part of India at a longitude of 83°39' to 84°45' east and a latitude of 25°10' to 25°40' north at a height of 193 meters above sea level. It is situated close to the confluence of the perennial River Ganga (R1) (85.4769^{0}E, 25.1285^{0}N) and River Sone (R2) (84.6665^{0}E, 25.5541^{0}N). The River Ganga shapes the northern boundary of the city from a rural area; Keshavpur is 10 km from Arrah. The River Sone enters the state of Bihar at the tri-intersection of Palamu (Jharkhand), Mirzapur (UP) and Rohtas (Bihar). It runs along the southern and eastern boundaries of the districts of Bhojpur to cover Koilwar, Sahar and Sandes. It merges with the river Ganga near Maner in Patna. River Gangi (R3) (85.6738^{0}E, 25.5767^{0}N) is a perennial body terminating in River Ganga near Barhara/Samaria and crossing the city at Gangi Bridge near Gausganj (Figure 1). The distance between River Ganga and Gangi is about 14km, but between Gangi and Sone is 19km.

(B) Sample collection and analysis

A total of 648 Water samples were collected in triplicate from 9 selected sites of three water bodies monthly from a 15 cm depth of superficial layer from November 2021 to October 2023. The data were later categorized into winter (November-February), summer (March-June) and monsoon (July-October) seasons for interpretation. Each water sample was preserved and analyzed for eleven parameters: water temperature, pH, dissolved oxygen, total alkalinity, hardness, total dissolved solids, chloride, nitrate, sulphate, biochemical oxygen demand and fluoride using the standard methodology recommended by APHA (2012) and organized in Table 1. The observed values (mean$\pm$SD) in seasonal and temporal variations in water quality in R1, R2 and R3 are represented in Tables 2 to 4.

Observed data were analysed using Graph Pad Prism 5 software for two-way t-test and ANOVA. We selected $p<0.05$ as the significance level.

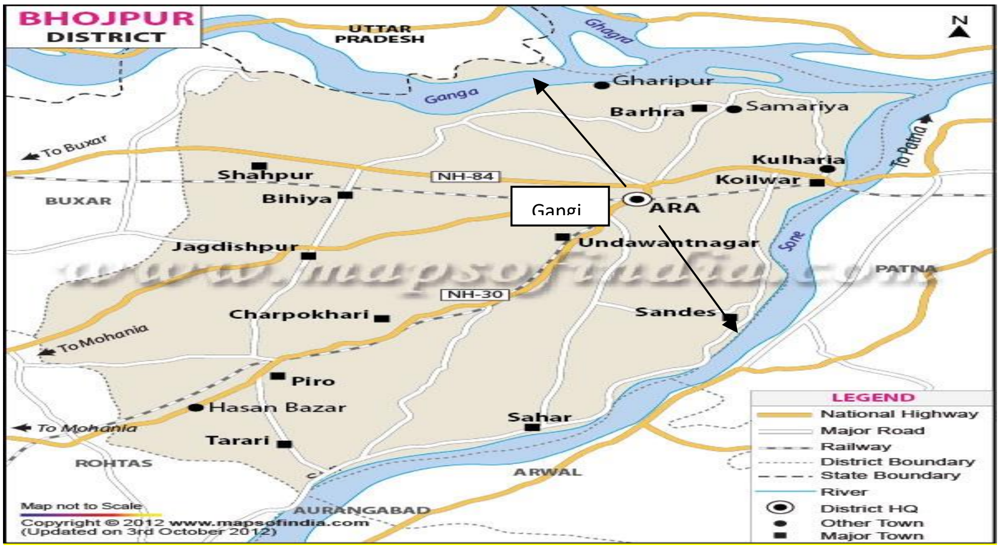

Fig. 1: Study area as River Ganga, Sone and Gangi at Arrah (Eastern part of India)

(C**) Methods of water quality assessment**

(I) The water quality index (WQI): It is inevitable and applied to understand the water quality of rivers, lakes, reservoirs and estuaries. Its value is determined using the weighted arithmetic water quality index method proposed by Horton (1965), in which we multiplied water parameters a weighting factor and aggregated using simple arithmetic mean by these three equations:

$$\text{(i) WQI} = \frac{\sum_{i=1}^{n} q_i W_i}{\sum_{i=1}^{n} W_i}$$

Where q_i = sub-index or water quality rating scale of the i[th] parameter. w_i = the Unit weight of the i[th] parameter was an inverse proportional value to the recommended standard value of BIS (2012) of *Si*.

$$\text{(ii)} \quad q_i = \left(\frac{C_i - I_i}{S_i - I_i}\right) \times 100$$

C_i = the water suitability calculated coefficient value or the observed value of the i[th] parameter, I_i = the ideal value of the i[th] parameter. S_i = guideline value of the i[th] water quality parameter or the standard permissible values of the i[th] parameter.

$$\text{(iii)} \; w_i = \frac{K}{Si}$$

i = number of parameters taken during observation. *K* = constant for proportionality.
*T*he following equation is applied to calculate K:

$$\text{(iv)} \; K = \frac{1}{\Sigma}\left(\frac{1}{Si}\right)$$

In this experiment, the value of K = 1.234589.

The total water quality index (WQI) by adding the quality rating to the unit weight. q_i of zero means the complete absence of pollutants and $0 < q_i < 100$ implies that the toxicants are above the standards (Ahmad 2014). The I_i for pH = 7, dissolved oxygen = 14.6 mg/L, and for other parameters, it is zero (Chowdhury *et al.*2012; Prasad *et al.* 2019). A comparison of analysed data to the BIS (2012) recommended standards to evaluate the relationship between different parameters and arranged in Tables 5-7.

(II) Overall Pollution Index (OPI) (Sargaonkar & Deshpandey 2003): Based on the individual index values, we calculated OPI. OPI assesses the surface water quality status in the Indian context. Application of OPI for assessment of surface water quality and the health condition of freshwater at the level of contamination in a specific water body under Indian conditions. It is calculated as a middling of pollution index (*Pi*) for individual variables and expressed as:

$$\text{OPI} = \frac{\sum_{i=1} P_i}{n}$$

Where *n* = number of observing parameters; *Pi* according to the following equation is

$$Pi = \frac{Ci}{Si}$$

P_i = the measured concentration of numerical value through various mathematical expressions for individual variables and C_i = measured value of parameter number in water (Table 9).

(III) Comprehensive pollution index (CPI) (Liu & Zhu 1999): Application of CPI to classify the water quality status by many of the research findings (Zhao et al. 2012; Mishra et al. 2016; Matta et al. 2020). Considering the most significant water quality parameters for which a standard permissible limit is proposed by different government agencies use CPI.

$$CPI = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{S_i}$$

Table 10 depicts the ranges of the CPI, the corresponding status of water quality and their possible use (Liu et al.2010; Tiwary et al.2017).

RESULTS AND DISCUSSION

Information on the water quality of a river is vital to maintaining aquatic life. The physicochemical parameters characterise water quality and these parameters may change due to sources, places, pollution, seasons, etc. Human interventions are responsible for the enrichment of contaminants in the environment. The present work of 2021-2023 provides considerable insight into the water quality of River Ganga (R1), River Sone (R2) and River Gangi (R3) (Tables 2-4). Table 8 presents a statistical relationship between the seasonal and annual differences in the physicochemical parameters of these river bodies.

(A) Assessment of seasonal variation

Water temperature is one of the most dominant factors in the aquatic environment since it influences the physicochemical, environmental and biological activities (Ali et al. 2016). We observed a range of water temperature of 10.86-24.85^{0}C with a lowest of 13.39±2.26^{0}C during winter and the highest of 22.70±0.99^{0}C during monsoon in R1 (Table 2). We also calculated a significant difference ($p<0.05$) in the water temperatures. Chaturvedi et al. (2003) observed similar trends in the Ganga River. Matta et al. (2020) observed a comparable range (9.9 to 23.0^{0}C) of water temperature in the Ganga River, Uttarakhand. The lowest temperature is due to a strong breeze and its highest value is attributed to high solar radiation (Santhanam & Perumal 2003). The temperature of any river does not remain the same due to various environmental conditions (Kumari et al.2013). An increase in water temperature is inversely proportional to the pH and dissolved oxygen in water but directly proportional to total alkalinity, hardness, chloride, total dissolved solids (TDS), nitrate, sulfate, BOD and fluoride (Perlman 2013) and accelerates metabolism (Sardana et al. 2022).

The pH of water remained alkaline due to the presence of carbonate and bicarbonate originating from the alkaline earth metals. The pH was lowest (6.91±0.29) at R2 during monsoon and highest (7.50±0.05) at R3 in winter (Table 4). We calculated a significant difference ($p<0.05$) in the pH. The observed values were within the permissible pH as per BIS (2012) standards of 6.5 to 8.5.

Earlier, Kamboj et al. (2016) observed the pH from 7.8 to 8.07 of the water in the Ganga River. The acidic nature of water in the monsoon season may be due to increased free carbon dioxide (Gupta et al. 2017). The pH from 6.68-7.58 of these water bodies is better for fish life. A change in pH affects the TDS. Aquatic organisms are sensitive to pH below 5.0 and may die at these low pH values. A higher pH may cause the skin to become dry, itchy and irritated.

Dissolved oxygen (DO) plays a vital role in the biological system and in assessing the freshness level of surface water. A DO range of 6.51-8.00 mg/L is desirable for good for the growth of fauna and flora. A low DO of 6.51 mg/L of R3 during summer months was possibly due to the lower oxygen-holding capacity of water at high temperatures and the increase in its assimilation for biodegradable organic matter by a microorganism (Table 4). We calculated a significant difference ($p < 0.05$) in DO for these water bodies. The value was more than 5.0 mg/L higher than the standard of the BIS. The maximum DO of 8.77 was observed in the winter and a minimum of 8.535 mg/L in the post-monsoon season by Matta et al. (2020) of the water of Ganga at Haridwar. The trends of observations are similar, while the differences in sources. Sharma et al. (2008) observed DO between 6.5 to 15 mg/L of the Narmada River at Hoshangabad. A low level of DO of water and decomposition of organic matter started (Mahobe & Mishra 2013). It also helps to evaluate the quality and natural contamination in the surface water (Wetzel & Likens 2006). High DO levels are beneficial for drinking water as it improves the taste.

Total alkalinity is the ability to deactivate a solid corrosive and is a characteristic salt in water (Sharmila & Rajeswari 2015). Maximum total alkalinity of 268.2±12.52 mg/L of R1 (Table 2) exceeding BIS (2012) standard (200 mg/L) in summer might be due to increased photosynthesis leading to greater use of carbon dioxide (Patil et al. 2018), disposal of dead bodies of animals and urban discharge through open drains in the river. Statistical analysis inferred a significant seasonal and annual difference ($p<0.05$) in total alkalinity. However, the River Ganga at Haridwar has a lower average for total alkalinity of 88.30 in summer, 84.45 in winter and 89.41 mg/L for monsoon season (Kamboj & Kamboj, 2019). The highest total alkalinity of water during summer and the lowest during winter (Ghosh 2018) was reported earlier. An alkalinity of more than 100 mg/L is productive and ideal for fish culture (Pandit et al. 2020). Fish farmers maintain at least 20 mg/L of total alkalinity for catfish production and 80-100 mg/L or hybrid bass production. Alkaline water can help with cancer and heart disease.

Hardness is the capacity of water to react with detergent (Deepa et al. 2016). Hard water can cause indigestion problems and the possibility of forming calcium oxalate crystals in urinary tracts. The average annual hardness of 116.4-141.0 mg/L varied from 120.2 (R1)-125.3 mg/L (R3) during winter, 133.4 (R2)-137 mg/L (R3) during summer and 128.8 (R1)-134.6 mg/L (R3) during monsoon (Tables 2-4). Statistical analysis indicated an annual significant difference ($p < 0.05$) in the total hardness. Total hardness below 500 mg/L comes under the permissible levels of the BIS for drinking water. Kamboj & Kamboj (2019) recorded hardness 127, 134.4 and

129.07 mg/L in winter, summer and monsoon seasons at River Ganga at Haridwar. The high value of hardness is probably due to the regular addition of large quantities of detergents used by nearby residential localities drain into water bodies. Total hardness of 40-400mg/L is optimum for water bodies and less than 5mg/L leads to the eventual death of fish. The increase in the hardness of water may change the pH of the skin and weaken it as a barrier against harmful bacteria and infections.

We determined TDS by measuring the number of solid materials dissolved in water. Any change in the balance of ionic concentrations by natural or anthropogenic activities causes detrimental effects (Tiwari 2015). The mean TDS ranged from 332.9 to 383.3 during winter, 421 to 478.3 during summer and 386.6 to 433.2 mg/L during monsoon (Table 4). We calculated a highly significant difference ($p < 0.001$) in the TDS of water. The TDS will be zero at pH = 7 and DO = 14.6 mg/L (Chowdhury et al. 2012). Jindal & Sharma (2010) observed the TDS value 156 mg/l–582 mg/L for the Sutlej River around Ludhiana. Water containing more than 500 mg/L of TDS is un-palatable as drinking water (BIS, 2012). The increase in TDS increases the apparent colour of the water and the water temperature and decreases the rate of photosynthesis (Chauhan & Sagar 2013). Farmers maintain a TDS of 450-525mg/L for fish production. It can dehydrate the skin of fish and may be fatal. Agricultural runoff, storm water, road de-icing, soil leaching and soil contamination are the primary sources of TDS. TDS increase may lead to kidney stones and other health problems like heart disease and diabetes.

Chloride values ranged between 18.2-18.7, 24.3-25.8 and 19.2-20.7 mg/L during winter, summer and monsoon below the BIS 200 mg/L. The highest chloride concentration was observed at R3 (summer) and the lowest was at R1 (winter) (Tables 2 and 4). We determined a significant seasonal difference ($p < 0.001$) in the chloride. An increasing occurrence of low river flows from summer to autumn reduces the dilution of the chloride. An earlier record of such a decline from summer to winter is available (Arya et al.2011). It is mainly present in sewage and effluent farm drainage and remains unaltered during the purification of sewage (Patil et al. 2018). Excess chloride would reduce the DO of water, which turns harmful to aquatic organisms (Deepa et al. 2016).

Nitrate is a nutrient that plays a deciding role in the productivity of the aquatic ecosystem and accelerates the growth of algae and macrophytes. The annual range of nitrate was 12.05-12.24 during winter, 12.42-12.63 during summer and 12.77-13.20 mg/L during monsoon. The highest of 13.20 at R2 and the lowest value of 12.50 mg/L at R1 indicate excellent water (BIS, 2012 standard 45 mg/L) in these water bodies (Table 2). Statistical analysis indicated a moderately significant difference ($p < 0.01$) in nitrate of water. Nitrate of less than 100 mg/L is optimum for water bodies and is below 50 mg/l, the threshold value of the BIS. A high nitrate during monsoon is due to the excessive entry of water from agricultural fields, decayed vegetables, animal matter etc. (Lodh et al. 2014). The high nitrate is attributed application of fertilizers, which leached and eroded in river bodies. Such findings on nitrate of water were also reported (Kadam 2005). An increase of nitrate in drinking water causes methemoglobinemia.

The average seasonal value of sulphate varied from 132.1(R1)-136.6(R3) during winter; 147.2(R1)-154.6(R3) during summer and 145.1(R1)-147.4(R2) mg/L during monsoon (Tables 2-4). We calculated a significant difference ($p < 0.001$) in the sulfate level of water. In another study, Pandit et al. (2020) reported an average of 137.08±8.93 mg/L of sulphate in the River Ganga at Arrah. On the other hand, we recorded the average sulfate of 20.74 ± 1.40 mg/L of the Ganga River System at Uttarakhand, India (Matta et al.2020). A high sulphate during monsoon is due to the excessive entry of water from agricultural fields, decayed vegetables, animal matter etc. (Pandit et al. 2020).

The fluoride application from vegetation and fertilizers occurs in crop fields and lotic water bodies. The mean value of fluoride ranged from 1.12-1.15 mg/L during winter, 1.36-1.37 and 1.10-1.1 5mg/L during monsoon in this study (Tables 2-4) exceeded the BIS (2012) standard. In this study, R2 had the highest fluoride in summer and R1 the least in the rainy season. We calculated a highly significant seasonal difference ($p < 0.001$) in the fluoride of water (Table 8). Sharma et al. (2017) reported fluoride ranging from 0.06 mg/L to 0.6 mg/L along the Kolong River Nagaon of Assam.

The amount of biochemical oxygen demand (BOD) in the water is from domestic waste and local areas of human settlement in and around the river bodies. The BOD ranges from 1.46 during winter to 5.52 mg/L during monsoon months (Tables 2-4). We found the annual, spatial and temporal significant ($p<0.05$) differences in BOD for these water samples. The observations exceed the standard BOD limit of BIS of 3 mg/L. Matta et al. (2020) recorded an average BOD of 1.88 ± 0.55 mg/L of the Ganga River System at Uttarakhand, India. The variation in BOD content was also reported within the range of 2.25–3.51 mg/L during the assessment of anthropogenic activities on Ganga River water quality (Kumar et al. 2012). Aenab (2013) observed that the BOD (6.5 mg/L) value did not follow WHO standards. Higher BOD indicates the requirement for more oxygen, which is less for oxygen-demanding species to feed on lower water quality.

(B) Calculation of Overall Pollution Index (OPI)

OPI is the simple way to summarize many water characteristics in a uniform non-dimensional value. The calculation of OPI with the help of 10 physicochemical parameters of these water bodies follows the standards given by Sargaonkar & Deshpande (2003) to calculate the OPI (Table 9). The average annual value of the OPI of River Ganga, River Sone and River Gangi was 1.97, 2.00 and 2.27 with a range of 1.80–2.01, 1.70-2.30 and 1.80–2.40 (Tables 9). The average annual value indicates that the water quality of River Ganga and Sone comes under the C2 ($2 < OPI < 3.9$) acceptable category but of the River Gangi to the C3 ($4< OPI < 7.9$) or slightly polluted. However, on a seasonal basis, the water quality of these river bodies is acceptable/slightly polluted. An earlier observation also showed that the water quality of Ganga River was excellent (1 < OPI < 1.9) in winter, acceptable (2 < OPI < 3.9) in summer, and slightly polluted (4 < OPI < 7.9) in monsoon season at Haridwar, India (Kamboj & Kamboj 2019). The ANOVA inferred that the difference in the OPI was statistically ($p<0.05$) significant on a seasonal basis (Table 8). The results, therefore, define temporal and spatial changes in water quality and reveal a specific trend of vacillations among different seasons.

The water quality of River Sone and River Gangi was slightly polluted (4 < OPI < 7.9) in the summer and monsoon seasons. In these seasons, water quality got contaminated because of the addition of dust particles, water runoff, agricultural and untreated sewage. Shukla et al. (2017) also examined the water quality of the Upper Ganga River basin using OPI and analysed water quality at Uttarkashi was acceptable (class C2) from 2001 to 2012, while slightly contaminated (class C3) in the monsoon period during 2006. Some researchers also showed similar results of pollution levels in the monsoon season, like Bora & Goswami (2017) in the Kolong River and Jindal & Sharma (2010) in the Sutlej River.

(C) Calculation of Comprehensive Pollution Index (CPI)

CPI is an essential tool to evaluate the water quality of water bodies (Kumar & Sharma 2015; Yadav et al. 2018; Das et al. 2022). CPI determines the pollution degrees by the appropriate method. The CPI of River Ganga, River Sone and River Gangi ranged from 0.65 to 0.85, 0.66 to 0.90 and 0.66 to 0.87 with an annual average value of 0.78, 0.78 and 0.77 (Table 10). The water of these rivers is qualified (Table 10) following CPI classification. The ANOVA inferred that the difference in CPI in these rivers was statistically ($p<0.01$) significant on a seasonal basis (Table 8). In a recent study, the CPI of the Cau River of China ranged from 0.50 to 1.57, an average of 1.08 determined by Son et al. (2020) considered water to be seriously polluted. CPI showed sub-clean to slightly polluted Ganga water from Harshhil to Haridwar (Das et al. 2022).

(D) Calculation of water quality index (WQI)

Tables 5-7 present observed values to ascertain the WQI for the river bodies applying the weighted arithmetic index equations specified previously. The results showed that water samples of these river bodies fall under the poor water (C) (WQI: 100-200) to very poor water (WQI: 200-300) category. We observed the highest value of the WQI of 263.7 at River Gangi during monsoon and the lowest of 182.0 at River Ganga during winter. On average, the water of these river bodies falls under grade C with a 211.6 values and poor category (Table 11). The ANOVA showed that the difference in WQI in these rivers was statistically ($p<0.05$) significant on a seasonal basis (Table 8).

The water quality applying WQI of the river was evaluated by Ewaid (2016) using 13 parameters; the range obtained 64–70 indicates a good water quality and grade B. Ewaid & Abed (2017) observed a range of WQI of Al-Gharraf River in Iraq of 43.0 to 88.7 indicating excellent (A) to good (B) water quality. Sudarshan et al. (2019) calculated the WQI from 59.8-136.09 of the Herbal Lake, Bangalore, India good (B) to poor (C) category. Prasad et al. (2019) also calculated a range WQI index of 33.65-125.73 at Obulavaripalli Mandal of YSR District, Andhra Pradesh, India. Lkr et al. (2020) calculated the WQI range of 33.00-55.45 indicating excellent (A) to good (B) quality of water for the Doyang River, Nagaland, India. The values of the WQI of this study exceeded the range of the observations of Sudarshan et al. (2019) and Lkr et al. (2020).

CONCLUSION

We examined 11 physicochemical parameters of the River Ganga, River Sone and River Gangi to calculate the seasonal variation in OPI, CPI and WQI from 2021 to 2023 and conclude that (i) The main nutrient concentrations in these water samples are $SO4^{-2}$> Cl^{-}> NO^{-3}> F^{-} and TDS (mg/L) > TH (mg/L) > pH. (ii) Throughout the study period, the water quality showed notable seasonal variation. (iii) A comparison between the measured concentrations of various variables and the BIS-permissible limit. (iv) DO, BOD and total alkalinity concentration exceed the BIS-permissible limit. (v) The water quality was classified as poor to very poor, acceptable to slightly polluted and slightly polluted to moderately polluted based on the calculations of the WQI, OPI and CPI (vi) The water quality indices over the study years showed a gradual decline in water quality as the seasons changed from winter to summer.

Therefore (i) protect river water from direct human influences like sewage input, bathing, washing of animals and clothes, etc.; (ii) maintain rivers for trap soil and surface run-off; (iii) regular and proper monitoring of the catchment areas prevent willful waste and effluent dumping through drains. The results of this work may help manage the river water in the future.

Regarding health concerns, this study suggests strict following of policies and legislation to monitor and regulate the disposal of household and agricultural waste before consumption of river water for drinking and other aquatic uses.

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Table 1 Measurement methods for the water quality parameters

Sl. No.	Parameters	Unit	Method	Site of measurement	Sl. No.	Parameters	Unit	Method	Site of measurement
1.	Water temperature	^{0}C	Thermometric method	*in situ*	2.	pH	-	Portable pH meter	*in situ*
3.	Total dissolved solid	mg/L	Temperature controlled oven	In the Laboratory	4.	Dissolve oxygen	mg/L	Winkler's volumetric method	,,
5.	Nitrate	,,	Cadmium reduction	,,	6.	Total alkalinity	,,	Titration method	In the Lab.
7.	Fluoride	,,	Distillation method	,,	8.	Hardness	,,	EDTA method	,,
9.	Sulfate	,,	Titration method	,,	10.	Chloride	,,	Silver nitrate method	,,
11.	BOD	,,	Electrode method	,,					

Table 2. Seasonal variations in certain Physico-Chemical parameters of water of Ganga River (R1) at Barhara, Arrah during 2021-2023

	WT (^{0}C)	pH	DO (mg/L)	TA (mg/L)	HA (mg/L)	TDS (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	SO_4^{-2} (mg/L)	F^- (mg/L)	BOD (mg/L)
Winter	13.39±2.26	7.30±0.50	8.00±0.07	239.2±8.10	120.2±4.48	332.9±44.84	18.2±0.8	12.05±0.11	132.1±5.70	1.12±0.08	1.78±0.67
Summer	21.61±2.89	7.22±0.07	6.84±0.51	268.2±12.52	135.8±2.69	421.0±9.86	24.3±1.79	12.42±0.34	147.2±3.90	1.36±0.04	1.82±0.56
Monsoon	22.70±0.99	6.96±0.12	6.69±0.23	267.4±5.78	128.8±1.95	386.6±53.48	19.2±0.95	12.77±0.39	145.1±8.46	1.10±0.08	1.72±0.58
Range	10.86-24.85	6.78-7.38	6.30-8.10	230.4-279.3	116.4-137.1	292.6-429.7	17.1-25.9	11.90-13.08	125.1-152.9	1.01-1.41	0.70-2.83
Annual mean	18.68±5.51	7.13±0.22	7.19±0.73	256.9±18.74	127.7±8.24	372.6±52.45	20.9±3.50	12.44±0.44	140.5±10.27	1.20±0.16	1.77±0.67

Table 3. Seasonal variations in certain Physico-Chemical parameters of water of Sone River (R2) at Sahar, Arrah during 2021-2023

	WT (^{0}C)	pH	DO (mg/L)	TA (mg/L)	HA (mg/L)	TDS (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	SO_4^{-2} (mg/L)	F^- (mg/L)	BOD (mg/L)
Winter	14.72±2.00	7.38±0.05	7.91±0.07	237.7±6.36	122.9±4.23	360.8±43.92	18.32±1.14	12.24±0.09	135.0±4.95	1.13±0.11	1.46±0.48
Summer	21.95±2.57	7.34±0.06	6.68±0.48	263.6±11.88	133.4±2.03	456.2±12.56	25.21±1.83	12.73±0.35	152.2±2.92	1.37±0.04	3.54±1.06
Monsoon	21.82±0.80	6.91±0.29	6.89±0.63	262.1±7.56	130.8±3.89	412.7±53.36	19.93±1.09	13.20±0.22	147.4±8.10	1.14±0.08	3.49±0.38
Range	12.70-24.72	6.88-7.42	6.18-8.02	234.3-274.8	117.8-135.9	321.8-468.4	17.54-26.68	12.14-13.31	129.5-157.8	1.01-1.43	1.01-4.91
Annual mean	19.18±4.63	7.19±0.24	7.14±0.72	254.5±15.77	128.2±6.77	404.0±55.80	21.54±3.71	12.72±0.48	144.4±10.70	1.22±0.16	2.88±1.44

Table 4. Seasonal variations in certain Physico-Chemical parameters of water of Gangi River (R3) at Arrah during 2021-2023

	WT (^{0}C)	pH	DO (mg/L)	TA (mg/L)	HA (mg/L)	TDS (mg/L)	Cl^- (mg/L)	NO_3^- (mg/L)	SO_4^{-2} (mg/L)	F^- (mg/L)	BOD (mg/L)
Winter	15.59±2.26	7.50±0.05	7.70±0.07	236.6±4.41	125.3±3.94	383.3±44.56	18.70±1.20	12.24±0.09	136.6±4.99	1.15±0.13	2.48±0.47
Summer	22.36±2.04	7.42±0.07	6.51±0.50	263.0±13.51	137.0±3.59	478.3±9.01	25.80±1.78	12.63±0.34	154.6±3.04	1.36±0.04	4.57±1.07
Monsoon	21.15±0.71	6.94±0.23	6.52±0.16	263.2±7.18	134.6±3.83	433.2±50.88	20.70±0.91	13.00±0.48	147.3±5.72	1.15±0.08	5.52±0.36

Range	12.06-24.05	6.68-7.58	6.00-7.80	231.4-279.3	120.5-141.0	343.5-486.2	17.30-27.40	12.16-13.29	130.9-157.9	1.00-1.42	2.02-5.95
Annual mean	19.04±4.50	7.22±0.35	6.91±0.72	254.7±17.98	131.7±7.61	424.9±54.84	21.98±3.96	12.66±0.43	145.5±10.32	1.22±0.15	4.11±1.58

Table 5: Calculation of Overall Pollution Index (OPI), Comprehensive Pollution Index (CPI) and Water Quality Index (WQI) of Ganga River at Barahara, Arrah, Bihar, India (A=Winter/Annual, B=Summer/Minimum and C=Monsoon/ maximum) (K = 1.234598).

Sl. No.	Parameters	Season / Annual	Standard Value (Si) (BIS)	Ideal value (Ii)	Observed values (Mi)		Sub index (Qi)		OIP Score		CPI Score		Unit weight (Wi)=K/Si	Wi x Qi	
					Seasonal	Annual	Seasonal	Annual	Seasonal	Annual	Seasonal	Annual		Seasonal	Annual
1.	pH	A	7.5	7.0	7.30	7.13	60.0	26.0	1	1	0.97	0.95	0.1646	9.88	4.28
		B	7.5	7.0	7.22	6.78	44.0	144.0	1	1	0.96	0.90	0.1646	7.24	23.70
		C	7.5	7.0	6.96	7.38	108.0	76.0	1	1	0.93	0.98	0.1646	17.78	12.51
2.	DO (mg/L)	A	5	14.6	8.00	7.19	68.84	77.93	4	4	1.60	1.44	0.2469	17.0	19.24
		B	5	14.6	6.84	6.30	80.90	85.17	4	8	1.37	1.26	0.2469	20.0	21.03
		C	5	14.6	6.69	8.10	82.66	68.55	4	4	1.34	1.62	0.2469	20.4	16.92
3.	TA (mg/L)	A	200	0	239.2	256.9	119.6	128.5	4	4	1.20	1.26	0.0062	0.7415	0.7967
		B	200	0	268.2	230.4	134.1	115.2	4	4	1.34	1.15	0.0062	0.8314	0.7142
		C	200	0	267.4	279.3	133.7	139.7	4	4	1.34	1.39	0.0062	0.8289	0.8630
4.	HA (mg/L)	A	200	0	120.2	127.7	60.1	63.8	2	2	0.60	0.64	0.0062	0.3726	0.2992
		B	200	0	135.8	116.4	67.9	58.2	2	2	0.68	0.58	0.0062	0.4210	0.1934
		C	200	0	128.8	137.1	64.4	68.6	2	2	0.64	0.68	0.0062	0.3923	0.3856
5.	TDS (mg/L)	A	500	0	332.9	372.6	66.6	74.5	1	1	0.70	0.75	0.0025	0.1663	0.0748
		B	500	0	421.0	292.6	84.2	58.5	1	1	0.84	0.59	0.0025	0.2105	0.0584
		C	500	0	386.6	429.7	77.3	85.9	1	1	0.77	0.86	0.0025	0.1933	0.0821
6.	Cl^- (mg/L)	A	250	0	18.2	20.9	7.28	8.36	1	1	0.07	0.08	0.0049	0.0357	0.0264
		B	250	0	24.3	17.1	9.72	6.84	1	1	0.10	0.06	0.0049	0.0476	0.0215
		C	250	0	19.2	25.9	7.68	10.4	1	1	0.08	0.10	0.0049	0.0376	0.0331
7.	NO_3^- (mg/L)	A	45	0	12.0	12.4	24.0	24.8	1	1	0.27	0.28	0.0247	0.5928	0.0677
		B	45	0	12.4	11.9	24.8	23.8	1	1	0.27	0.27	0.0247	0.6126	0.0609
		C	45	0	12.7	13.1	25.4	26.2	1	1	0.28	0.25	0.0247	0.6247	0.0873
8.	Sulphate (mg/L)	A	250	0	132.1	140.5	52.8	56.2	1	1	0.53	0.56	0.0049	0.2587	0.2754
		B	250	0	147.2	125.1	58.9	50.0	1	1	0.58	0.50	0.0049	0.2886	0.2450
		C	250	0	145.1	152.9	58.0	61.2	1	2	0.58	0.61	0.0049	0.2842	0.3000
9.	Fluoride (mg/L)	A	1.0	0	1.12	1.20	112.0	120.0	1	1	1.12	1.20	1.2346	138.3	148.2
		B	1.0	0	1.36	1.01	136.0	101.0	2	1	1.36	1.01	1.2346	167.9	124.7
		C	1.0	0	1.16	1.41	116.0	141.0	1	2	1.16	1.41	1.2346	143.2	174.1
10.	BOD (mg/L)	A	5.0	0	1.78	1.77	35.6	35.4	2	2	0.36	0.35	0.4115	14.65	14.56
		B	5.0	0	1.72	0.70	34.4	14.0	2	1	0.34	0.14	0.4115	14.16	05.76
		C	5.0	0	1.82	2.83	36.4	56.6	2	2	0.36	0.57	0.4115	14.98	23.29
		A							1.8	1.8	0.74	0.83		182.0	188.6
		B						Mean	1.9	2.1	0.79	0.65	ΣWQI	220.1	186.5
		C							1.8	2.0	0.75	0.85		190.7	223.4
Average of Overall Pollution Index (OPI), Comprehensive Pollution Index (CPI) and water quality index (WQI) of Ganga River at Barahara, Arrah, Bihar, India									1.82	1.97	0.76	0.78		197.6	199.5

Table 6: Calculation of Overall Pollution Index (OPI), Comprehensive Pollution Index (CPI) and Water Quality Index (WQI) of Sone river, at Sahar, Arrah, Bihar, India (A=Winter/Annual, B=Summer/Minimum and C=Monsoon/maximum) (K = 1.234598).

Sl. No.	Parameters	Season / Annual	Standard Value (Si) (BIS)	Ideal value (Ii)	Observed values (Mi)		Sub index (Qi)		OPI Score		CPI core		Unit weight (Wi)=K/Si	Wi x Qi	
					Seasonal	Annual	Seasonal	Annual	Seasonal	Annual	Seasonal	Annual		Seasonal	Annual
1.	pH	A	7.5	7.0	7.38	7.19	76.0	20.0	1	1	0.98	0.96	0.1646	12.51	3.292
		B	7.5	7.0	7.34	6.88	68.0	124.0	1	1	0.98	0.92	0.1646	11.19	20.41
		C	7.5	7.0	6.91	7.42	118.0	84.0	1	1	0.92	0.99	0.1646	19.40	13.83
2.	DO (mg/L)	A	5	14.6	7.91	7.14	69.51	82.71	4	4	1.58	1.43	0.2469	17.16	20.42
		B	5	14.6	6.68	6.18	94.31	96.54	4	4	1.34	1.23	0.2469	23.28	23.84
		C	5	14.6	6.89	8.02	80.56	68.48	4	4	1.38	1.60	0.2469	19.89	16.91
3.	TA (mg/L)	A	200	0	237.7	254.5	118.8	127.3	4	4	1.19	1.27	0.0062	0.7366	0.7893
		B	200	0	263.6	234.3	131.8	117.2	4	4	1.32	1.17	0.0062	0.8172	0.7266
		C	200	0	262.1	274.8	131.0	137.4	4	4	1.31	1.37	0.0062	0.8122	0.8579
4.	HA (mg/L)	A	200	0	122.9	128.2	61.5	64.1	2	2	0.61	0.64	0.0062	0.3813	0.3974
		B	200	0	133.4	117.8	66.7	58.9	2	2	0.67	0.59	0.0062	0.4135	0.3652
		C	200	0	130.8	135.9	65.4	67.9	2	2	0.66	0.68	0.0062	0.4055	0.4210
5.	TDS (mg/L)	A	500	0	360.8	404.0	72.2	80.8	1	1	0.72	0.81	0.0025	0.1805	0.2020
		B	500	0	456.2	321.8	91.2	64.4	1	1	0.91	0.64	0.0025	0.2280	0.1615
		C	500	0	412.7	468.4	82.5	93.7	1	1	0.82	0.94	0.0025	0.2663	0.2343
6.	Cl^- (mg/L)	A	250	0	18.32	21.54	7.33	8.62	1	1	0.07	0.08	0.0049	0.0359	0.0422
		B	250	0	25.21	17.54	10.1	7.02	1	1	0.10	0.07	0.0049	0.0495	0.0344
		C	250	0	19.93	26.68	7.97	10.7	1	1	0.08	0.11	0.0049	0.0391	0.0524
7.	NO_3^- (mg/L)	A	45	0	12.24	12.72	24.5	25.4	1	1	0.27	0.25	0.0247	0.6052	0.6274
		B	45	0	12.73	12.14	25.5	24.3	1	1	0.28	0.27	0.0247	0.6298	0.6002
		C	45	0	13.20	13.31	26.4	26.2	1	1	0.29	0.26	0.0247	0.6521	0.6471
8.	Sulphate (mg/L)	A	250	0	135.0	144.4	54.0	57.8	1	1	0.54	0.58	0.0049	0.2646	0.2832
		B	250	0	152.2	129.5	60.9	51.8	2	1	0.61	0.52	0.0049	0.2984	0.2538
		C	250	0	147.4	157.8	59.0	63.1	4	2	0.59	0.64	0.0049	0.2891	0.3092
9.	Fluoride (mg/L)	A	1.0	0	1.13	1.22	113.0	122.0	1	2	1.13	1.22	1.2346	139.5	150.6
		B	1.0	0	1.37	1.01	137.0	101.0	1	1	1.37	1.01	1.2346	169.1	124.6
		C	1.0	0	1.14	1.43	114.0	143.0	1	2	1.14	1.43	1.2346	140.7	176.5
10.	BOD (mg/L)	A	5.0	0	1.46	2.88	29.2	57.6	1	4	0.29	0.42	0.4115	12.02	23.70
		B	5.0	0	3.54	1.01	70.8	20.2	4	1	0.71	0.20	0.4115	29.13	08.31
		C	5.0	0	3.49	4.91	69.8	98.2	4	4	0.70	0.98	0.4115	28.72	40.41
		A							1.70	2.10	0.74	0.78		183.4	200.4
		B						Mean	2.10	1.70	0.83	0.66	ΣWQI	235.1	172.4
		C							2.30	2.20	0.79	0.90		211.2	250.1
Average of Overall Pollution Index (OPI), Comprehensive Pollution Index (CPI) and water quality index (WQI) of Sone river, at Sahar, Arrah, Bihar, India									2.03	2.00	0.79	0.78		209.9	207.6

Table 7: Calculation of Overall Pollution Index (OPI), Comprehensive Pollution Index (CPI) and Water Quality Index (WQI) of Gangi river at Arrah, Bihar, India (A=Winter/Annual, B=Summer/Minimum and C=Monsoon/maximum) (K = 1.234598).

Sl. No.	Parameters	Season / Annual	Standard Value (Si) (BIS)	Ideal value (Ii)	Observed values (Mi)		Sub index (Qi)		OPI Score		CPI Score		Unit weight (Wi)=K/Si	Wi x Qi	
					Seasonal	Annual	Seasonal	Annual	Seasonal	Annual	Seasonal	Annual		Seasonal	Annual
1.	pH	A B C	7.5 7.5 7.5	7.0 7.0 7.0	7.50 7.42 6.94	7.22 6.68 7.58	100.0 84.0 112.0	44.0 164.0 116.0	1 1 1	1 1 2	1.00 0.99 0.93	0.96 0.89 1.11	0.1646 0.1646 0.1646	16.46 13.83 18.44	7.24 26.99 19.09
2.	DO (mg/L)	A B C	5 5 5	14.6 14.6 14.6	7.70 6.51 6.52	6.91 6.00 7.80	72.14 94.87 94.74	82.43 97.47 71.89	4 4 4	4 8 4	1.54 1.30 1.30	1.38 1.20 1.04	0.2469 0.2469 0.2469	17.81 23.42 23.39	20.45 24.06 17.75
3.	TA (mg/L)	A B C	200 200 200	0 0 0	236.6 263.0 263.2	254.7 231.4 279.3	118.3 131.5 131.6	127.4 115.7 139.6	4 4 4	4 4 4	1.18 1.32 1.32	1.27 1.16 1.40	0.0062 0.0062 0.0062	0.7335 0.8153 0.8159	0.7899 0.7173 0.8655
4.	HA (mg/L)	A B C	200 200 200	0 0 0	125.3 137.0 134.6	131.7 120.5 141.0	62.6 68.5 67.3	65.8 60.3 70.5	2 2 2	2 1 2	0.63 0.69 0.67	0.66 0.60 0.71	0.0062 0.0062 0.0062	0.3881 0.4247 0.4173	0.4080 0.3739 0.4371
5.	TDS (mg/L)	A B C	500 500 500	0 0 0	383.3 478.3 433.2	424.9 343.5 486.2	76.7 95.7 86.6	85.0 68.7 97.2	1 1 1	1 1 1	0.77 0.96 0.87	0.85 0.69 0.97	0.0025 0.0025 0.0025	0.1918 0.2393 0.2165	0.2125 0.1718 0.2430
6.	Cl^- (mg/L)	A B C	250 250 250	0 0 0	18.70 25.80 20.70	21.98 17.30 27.40	7.48 10.3 8.28	8.79 6.92 11.0	1 1 1	1 1 1	0.07 0.10 0.08	0.09 0.07 0.11	0.0049 0.0049 0.0049	0.0367 0.0287 0.0406	0.0431 0.0339 0.0539
7.	NO_3^- (mg/L)	A B C	45 45 45	0 0 0	12.24 12.63 13.00	12.66 12.16 13.29	24.5 25.3 26.0	25.3 24.3 26.6	1 1 1	1 1 1	0.24 0.25 0.26	0.25 0.24 0.27	0.0247 0.0247 0.0247	0.0605 0.0625 0.0642	0.6249 0.6002 0.6570
8.	Sulphate (mg/L)	A B C	250 250 250	0 0 0	136.6 154.6 147.3	145.5 130.9 157.9	54.6 61.8 58.9	58.2 52.4 63.2	1 2 1	4 1 4	0.55 0.62 0.59	0.58 0.52 0.63	0.0049 0.0049 0.0049	0.2675 0.3028 0.2886	0.2852 0.2568 0.3097
9.	Fluoride (mg/L)	A B C	1.0 1.0 1.0	0 0 0	1.15 1.36 1.15	1.22 1.00 1.42	115.0 136.0 115.0	122.0 100.0 142.0	1 2 1	1 1 1	1.15 1.36 1.15	1.22 1.00 1.42	1.2346 1.2346 1.2346	142.0 167.9 149.8	150.6 123.5 175.3
10.	BOD (mg/L)	A B C	5.0 5.0 5.0	0 0 0	2.48 4.57 5.52	4.11 2.02 5.95	49.6 91.4 110.4	82.2 40.4 119.0	2 4 4	4 2 4	0.50 0.90 1.10	0.82 0.40 1.19	0.4115 0.4115 0.4115	20.41 37.61 45.43	33.82 16.62 48.97
		A B C						Mean	1.8 2.2 2.0	2.3 2.1 2.4	0.79 0.85 0.83	0.81 0.68 0.87	ΣWQI	192.1 245.2 238.9	214.5 193.3 263.7
Average of Overall Pollution Index (OPI), Comprehensive Pollution Index (CPI) and water quality index (WQI) of Gangi river at Arrah,, Bihar, India									2.0	2.27	0.82	0.77		225.4	223.8

Table 8: Comparison of values of different Physico-Chemical parameters of water of Ganga river (R1) V/S Sone river (R2) V/S Gangi river (R3) at Arrah.

Parameters	Ganga river (R1) V/S Sone river (R2) V/S Gangi river (R3)				Parameters	Ganga river (R1) V/S Sone river (R2) V/S Gangi river (R3)			
	Seasonal		Annual			Seasonal		Annual	
	Column wise (d.f. c=2)	Row wise (d.f. r=2)	Column wise (d.f. c=2)	Row wise (d.f. r=2)		Column wise (d.f. c=2)	Row wise (d.f. r=2)	Column wise (d.f. c=2)	Row wise (d.f. r=2)
WT (^{0}C)	0.1816^{NS}	59.98**	11.95^{NS}	343.9***	pH	2.811^{NS}	42.02**	13.61*	164.6***
DO (mg/L)	7.321*	152.7***	199.0***	7160.0***	TA (mg/L)	12.81*	601.6***	0.1281^{NS}	264.8***
HA (mg/L)	5.751^{NS}	51.96**	27.94**	543.7***	TDS (mg/L)	268.8***	888.7***	347.1***	2443.0***
Chloride (mg/L)	11.28*	408.0***	5.376^{NS}	532.0***	Nitrate (mg/L)	18.17**	120.1***	115.8***	2022.0***
Sulphate (mg/L)	10.43*	134.8***	154.9***	3734.0***	Fluoride (mg/L)	2.971^{NS}	276.1***	2.0^{NS}	1922.0***
OIP core	7.617*	8.766*	5.842^{NS}	0.859^{NS}	CPI Score	18.00**	20.00**	2.693^{NS}	3.251^{NS}
WQI score	8.877*	7.164*	3.808^{NS}	25.15**					

(*=Significant, **=Moderately Significant, ***= Highly Significant, NS=Not significant).

Table 9: Classification of Water category based on Overall Pollution Index (OPI) (Sargoankar and Deshpande, 2003; modified after BIS, 2012: IS-10500).

Category	Class Index	pH	DO (mg/L)	BOD (mg/L)	HA (mg/L)	TA (mg/L)	TDS (mg/L)	Cl^- (mg/L)	Nitrate (mg/L)	Turbidity	F^- (mg/L)	SO_4^{-2} (mg/L)
Excellent	0-1	6.5–7.5	9.5-10.5	1.5	75	75	500	150	20	5	1.2	150
Good (Acceptable)	1-2	6.0–6.5 and 7.5–8.0	8.5-11.5	3	150	150	1500	250	45	10	1.5	250
Slightly polluted	2-4	5.0–6.0 and 8.0–9.0	6.5-12.5	6	300	300	2100	600	50	100	2.5	400
Polluted	4-8	4.5–5.0 and 9.0–9.5	3.0-15.5	12	500	500	3000	800	100	250	6.0	1000
Heavily polluted	8-16	<4.5 and >9.5	<3.0 and >15.5	24	>500	>500	>3000	>800	200	>250	>6.0	>1000

Table 10: Classification of Water category based on Comprehensive Pollution Index (CPI)

Sl. No.	Water Category	Comprehensive Pollution Index (CPI)	Classification of water	Sl. No.	Water Category	Comprehensive Pollution Index (CPI)	Classification of water
1.	Category 1	0 to 0.20	Clean	2.	Category 2	0.21 to 0.40	Sub-clean
3.	Category 3	0.41 to 0.80	Qualified (Slightly polluted)	4.	Category 4	0.81 to 1.00	Basically qualified (Moderately polluted)
5.	Category 5	1.01 to 2.00	Polluted	6.	Category 6	≥ 2.01	Seriously (heavily) polluted

Table 11: Classification of Water category based on Water Quality Scale (WQI).

Sl. No.	Water Category	Mohanty (2004)	Ramakrishnaiah (2009)	Yadav et al, (2010)	Sl. No.	Water Category	Mohanty (2004)	Ramakrishnaiah (2009)	Yadav et al, (2010)
1.	Excellent	<50	<50	0-25	2.	Good (Acceptable)	50-100	50-100	26-50
3.	Poor	100-200	100-200	51-75	4.	Very poor	200-300	200-300	76-100
5.	Unsuitable for drinking	>300	>300	>100					

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