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RESEARCH

Impact of Domestic and Industrial Effluent Disposal on Physicochemical Characteristics of River Malin at Najibabad City, India

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Abstract

The current study aimed to assess the health of the Malin River situated in Najibabad city, India by analyzing several physicochemical parameters. The main objective was to evaluate the impact of industrial and domestic wastewater on the river's health. The study was conducted over six months, from January to June 2023, at four different locations along the river. To calculate the water quality index (WQI), the data was further processed, and Pearson correlation was utilized. Except for site 1, most of the analyzed physicochemical parameters exceeded the Bureau of Indian Standards (BIS) limit, as indicated by the results. The utilization of river Malin water for irrigation, laundry, and vegetable cleaning may pose a health hazard to the public due to high contamination levels at the points where industrial (site 2) and domestic (site 3) effluents continuously mix with the river water. The water quality at all locations is deemed unsuitable for consumption due to a WQI score greater than 100. There are strong positive correlations between total dissolved solids (TDS) and other studied parameters, except for dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and turbidity. This suggests the presence of inorganic pollutants concerning organic pollutants. Wastewater treatment facilities are necessary along river coasts to conserve river flora and fauna, as well as water quality, to safeguard human and river health.

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Statement of Sustainability: The Malin River flows through agricultural and residential areas of Najibabad city, India. Unfortunately, there is no treatment facility along this section of the river, so nearby towns and cities directly discharge their untreated household wastewater into it. Despite the fact that untreated solid and liquid waste is dumped into the river, people still use the Malin River water for agriculture and washing vegetables and clothing. There is a clear correlation between the health of the Malin River and the well-being of the organisms living along its path. To improve the river's health, it is urgently necessary to construct a solid and liquid waste treatment facility and conduct awareness campaigns along the river stretch.

1. Introduction

Water is a crucial natural resource for human survival, constituting around 70% of human body weight and 97% of plants. The presence of water on Earth makes human life possible (Adimalla and Venkatayogi 2018; Suvarna et al., 2018; Ahamad et al., 2023a). Although approximately 70% of the Earth's surface is covered with water, 97% of it is saline, rendering it unusable, especially in impoverished nations like India. Only 3% of the Earth's water is freshwater, with 2% of that being frozen in glaciers, 3% being surface water, and the remaining 0.6% being groundwater. Surface water can be found in rivers, lakes, ponds, and streams. Rivers, in particular, have been historically significant to human societies, with many civilizations emerging around their banks (Dadhich et al., 2017; Bhutiani et al., 2018; Kumar et al., 2018; Kamboj and Kamboj, 2019). Perennial rivers have water available throughout the year, while non-perennial or seasonal rivers only have water during the rainy season. Most rivers can be classified as either perennial or non-perennial. Both types of rivers are equally important as they serve various purposes such as industrial processes, drinking, irrigation, and more (Singh and Mathur, 2005; Sharma et al., 2014). Unlike other countries, rivers in India are not managed effectively despite their importance (Suthar et al., 2009; Bhutiani et al., 2018; Tyagi et al., 2020).

Untreated or partially treated liquid and solid waste from homes and businesses are disposed of in these river bodies, altering their physicochemical characteristics due to the high concentration of organic waste and specific heavy metals. The fast industrialization and urbanization resulted in an enormous amount of waste and sediments generated. The quantity and quality of freshwater resources in these rivers are under strain because a significant portion of garbage is disposed of in them (Phiri et al., 2005; Wang et al., 2007; Singh and Singh, 2007; Rizvi et al., 2015). The microbial population uses dissolved oxygen (DO) in these water bodies to break down organic waste, leading to a DO deficit in the rivers. This deficit causes stress on river wildlife, which can ultimately lead to their death. These bodies of water can become eutrophic due to various circumstances. Surface water features such as ponds, lakes, rivers, and streams can transform into grazing land through a variety of processes (Jain et al., 2005; Phiri et al., 2005; Kannel et al., 2007; Khadse et al., 2008; Purkait et al., 2009). Laws and policies regulate the generation and treatment of solid and liquid waste, but their effectiveness is hindered by ignorance, lack of resources, and insufficient technical know-how. Environmental regulations must be effectively used to manage surface water bodies in developing nations. The following studies support this imperative: Al-Hussaini et al. (2018), Khan et al. (2020), Mishra et al. (2021), and Sharma et al. (2021). The contamination of surface water bodies is a topic of discussion among scientific groups due to the impact of industry and urbanization on their survival. While most rivers are self-cleaning, they have a limited capacity to absorb solid, industrial, household, and agricultural waste. Due to the constant dumping of increasing volumes of waste, rivers have lost their ability to self-clean (Singh and Kumar, 2017; Shil et al., 2019; Ioele et al., 2020). Therefore, it is crucial to regularly monitor surface water bodies. This study evaluates the water quality of the Malin River using physicochemical criteria.

2. Materials and Methods

2.1. Study Area

The Malin River, a non-perennial tributary of the Ganga, originates in the Kotdwar region of Uttarakhand, India (Figure 1 and Table 1). During summer, the river usually runs dry. The Malin River is formed by the confluence of several mountain springs in the Garhwal region. It covers an area of 400 km^2 and flows through two districts, Pauri Garhwal and Bijnor, before joining the Ganga at Ravalli Ghat. Malin is the primary source of water for irrigation in the river's adjacent areas. The Malin River carries untreated wastewater from Najibabad City. Farmers use the river water to wash their vegetables, and washermen use it to wash their clothing.

Table 1. Sampling sites and their geo-coordinates.

Site Number	Site Name	Geo-coordinates
1	Mohmmad Taharpur Village (Control site)	29.678814 N 78.429726 E
2	Jaswantpur Village	29.651666 N 78.406037 E
3	Mirpur Dargu Village	29.645102 N 78.387497 E
4	Puranpur Garhi Village	29.638239 N 78.351620 E

2.2. Sampling and Analysis

Water samples were collected monthly for six months (January 2023 to June 2023) from designated sampling sites. The samples were placed in prewashed 2-L plastic containers and pH was measured on-site. Subsequently, the specimens were transported to the laboratory for examination of residual parameters. Conventional techniques (Khanna and Bhutiani, 2008; APHA, 2012) were used to examine all chosen physicochemical parameters (Table 2).

2.3. Calculation of Water Quality Index (WQI)

To enhance the general public's comprehension of complex water quality data, a single, straightforward digit is used as an index. The Weighted Arithmetic Index approach, as described by Cude (2001) and Brown et al. (1970), was used, employing TDS, turbidity, pH, BOD, COD, hardness, chloride, nitrate, and sulphate values (Table 3).

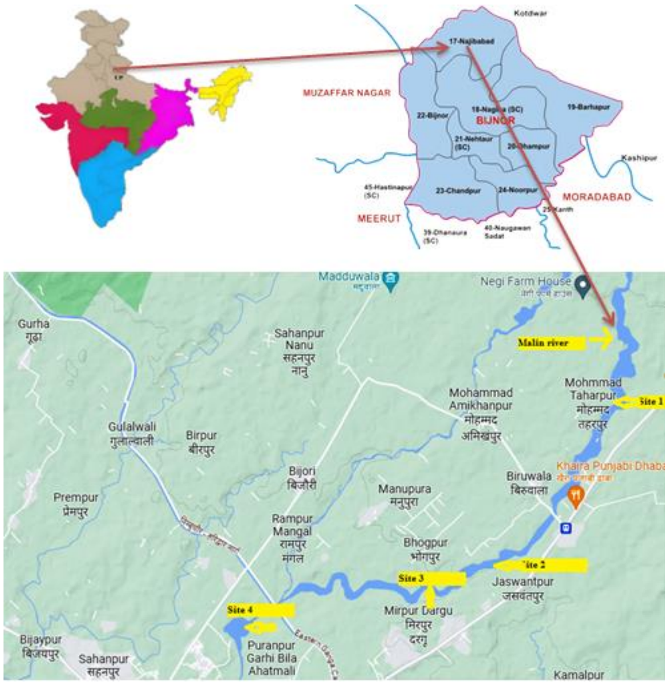

Figure 1. Showing the sampling sites (Source: Google Earth).

Table 2. Parameters analyzed and their methodology with instrument details.

Parameters	Abbreviations	Methodology used / Instruments used
pH	-	With the help of a pH meter (Company name: EI, Model no: EI 112)
EC (µS/cm)	Conductivity	With the help of a Microprocessor based conductivity meter (Company name: ESICO, Model no: ESICO 1601)
TDS (mg/L)	Total Dissolved Solids	With the help of a Microprocessor based TDS meter (Company name: Global Instruments, Model no: 065 G)
Turbidity (NTU)	-	With the help of a Turbidity meter (Company name: EI, Model no: EI 331)
DO (mg/L)	Dissolved Oxygen	Winkler's Iodometric method
BOD (mg/L)	Biochemical Oxygen Demand	Winkler's Iodometric method
COD (mg/L)	Chemical Oxygen Demand	Reflux method
Cl (mg/L)	Chloride	Argenotmetric method
SO_4^{2-} (mg/L)	Sulphate	Spectrophotometric method
NO_3^- (mg/L)	Nitrate	Spectrophotometric method
PO_4^{3-} (mg/L)	Phosphate	Spectrophotometric method

Table 3. Steps used for WQI calculation.

Step	Description
1	The proportionality constant 'K' is calculated by summing the inverse of the standard values of all selected parameters.
2	The unit weight of each parameter was calculated by dividing the value of 'K' by the standard values of each parameter, as shown in the given equation. $$Wi = \frac{K}{Xi}$$
3	The equation provided was used to calculate the total unit weight of each parameter. $$\sum W = W1 + W2 + W3 \ldots Wn$$ Where, W1, W2 and so on are the unit weight of selected parameters.
4	The quality rating was calculated using the following equation, which takes into account the observed value (Vobserved) and the ideal value (Videal): $$Qi = \frac{(Vobserved - Videal)}{(Vstandard - Videal)} \times 100$$
5	Finally, WQI was calculated by using the following equation: $$WQI = \frac{\Sigma QiWi}{\Sigma Wi}$$

2.4. Data analysis

M.S. Office Excel (2010; Microsoft Corp., USA) was utilized to analyze the specific parameters collected during the analytical procedure and estimate the range, mean value, and standard deviation (SD).

3. Results and Discussion

The results of selected physicochemical parameters of all the studied sites are given in Table 4.

3.1. Total Dissolved Solids (TDS)

The amount of mostly inorganic salts, including bicarbonates, chlorides, sulphates, potassium, sodium, magnesium, calcium, and minor amounts of organic materials dissolved in water is referred to as TDS. It is important to note that TDS and EC are directly proportional. TDS is a determining factor for water's palatability. Site 1 had the lowest TDS reading (492.50±13.16 mg/L), while site 2 had the highest (620.75±6.72 mg/L). The average TDS reading in the river was 562.96 mg/L±54.09. All sites, except for site 1, had TDS levels higher than the Bureau of Indian Standards (BIS) threshold of 500 mg/L. The study assessed the water quality of the Malin River during both winter and summer seasons. The elevated TDS readings during the dry seasons may be attributed to the lack of rainfall and faster rate of evaporation (Rahman et al., 2021). The study period, which ran from January to June, revealed that the majority of the non-perennial river was in a tranquil state, resulting in steady TDS readings. Higher TDS values in irrigation exacerbate soil salt issues, leading to decreased productivity (Chandra et al., 2011). The lower TDS readings in this study, compared to Ahmed et al. (2012), who found TDS in the range of 1990-5800 mg/L, may be due to the limited number of industries and anthropogenic activities along the river stretch.

Bhutiani et al. (2017) reported a similar range of TDS in the Hindon River in Ghaziabad. Also, Bhutiani et al. (2019) noted a comparable range of TDS (400.0-1006.5 mg/L) in the Ganga River near Haridwar, which is significantly impacted by STP's wastewater disposal. Joseph and Jacob (2010) reported TDS readings in the 400–800 mg/L range in the Pennar River in Kerala. Mishra and Kumar (2021) found that the TDS value in the Narmada River ranged from 24 to 442 mg/L, which is lower than the values reported in the current study. Rahman et al. (2021) recorded TDS readings ranging from 519.66 to 782.08 mg/L in the Turag River in Bangladesh.

Table 4. Average values of physicochemical parameters at different sites of Malin River (n=6).

Site/Parameters	Site 1	Site 2	Site 3	Site 4	Min	Max	Average ± SD
TDS (mg/L)	492.50±13.16	620.25±6.72	554.33±10.23	585.00±9.19	492.50	620.00	562.96±54.09
EC (μS/cm)	735.07±19.64	925.37±10.03	827.36±15.27	873.13±13.71	735.07	925.37	840.24±80.74
Turbidity (NTU)	13.67±2.16	45.84±1.44	29.16±0.51	33.59±0.58	13.67	45.84	30.56±13.29
pH	7.17±0.03	6.91±0.05	7.06±0.05	7.12±0.08	6.91	7.17	7.07±0.11
DO (mg/L)	6.07±0.35	1.68±0.42	3.87±0.67	2.81±0.40	1.68	6.07	3.61±1.87
BOD (mg/L)	3.15±0.39	14.94±2.46	7.15±0.63	8.21±0.40	3.15	14.94	8.36±4.90
COD (mg/L)	53.68±2.37	103.81±6.64	65.54±2.91	71.37±1.26	53.68	103.81	73.60±21.44
Hardness (mg/L)	180.46±3.54	290.23±5.29	208.96±3.44	237.35±2.34	180.46	290.23	229.23±46.81
Chloride (mg/L)	33.43±0.82	56.26±1.13	38.28±0.43	47.39±1.81	33.43	56.26	43.84±10.10
Nitrate (mg/L)	4.23±0.43	6.79±0.26	5.27±0.20	5.80±0.16	4.23	6.79	5.52±1.06
Sulphate (mg/L)	22.53±1.72	29.02±0.10	26.04±0.30	32.11±0.27	22.53	32.11	27.42±4.10

3.2. Electrical Conductivity (EC)

Electrical conductivity (EC) is the ability of water to transmit electrical current through an aqueous solution. Ahmed et al. (2023b) define EC as a measure of a dissolved material's capacity to carry electricity from one pole to another. The river's average EC value was 840.24±80.74 μS/cm, with the lowest value observed at site 1 (735.07±19.64 μS/cm) and the highest at site 2 (925.37±10.03 μS/cm). Our results are in agreement with those of Bhutiani et al. (2018). Chandra et al. (2011) investigated the impact of various water physicochemical properties on crops. The authors noted that EC values below 98.6 μS/cm are suitable for irrigation, as higher EC values hinder plant water uptake. Although Malin River water is also used for irrigation, we found that the EC values exceeded 98.6 μS/cm, which is detrimental to plant health. Rahman et al. (2021) recorded EC values ranging from 728.75 to 1980.0 μS/cm in the Turag River in Bangladesh. The larger range of EC values in the Turag River may be due to seasonal variations in water quality.

3.3. Turbidity

Water clarity is measured by turbidity, which is caused by the presence of ions and salts in a suspended state. The amount of suspended solids present directly affects turbidity (Bhutiani et al., 2016; Ruhela et al., 2020; Bojago et al., 2023). Additionally, river water turbidity can result from weathering, runoff from unclean roadways and agricultural fields, and soil erosion (Gupta et al., 2017; Khan et al., 2021; Roy et al., 2021). The average turbidity of the river was measured at 30.56±13.29 NTU. Site 1 had the lowest turbidity of all the sites (13.67±2.16 NTU), while site 2 had the highest turbidity (45.84±1.44 NTU). Turbidity readings exceeded the BIS (5 NTU) limit at every site. High turbidity levels can harm the aquatic ecosystem by reducing light penetration, which lowers photosynthetic activity in aquatic plants and decreases the dissolved oxygen level in the water (Simeon et al., 2019). According to Central Pollution Control Board (CPCB) guidelines, the water quality of Malin River is classified as category E due to its turbidity levels, making it unsuitable for drinking, bathing, or irrigation. Ling et al. (2016) reported that the Malaysia Bakun hydroelectric dam downstream of the Balui River has caused an increase in turbidity values ranging from 40 to 74.5 NTU due to the dam's rapid water release. The accelerated flow of water causes soil erosion and resuspension of settled particles, which increases the amount of suspended solids in the water and raises its turbidity. Similarly, Rahman et al. (2021) found that the Turag River in Bangladesh had turbidity readings in the same range (28–37 NTU).

3.4 pH

The acidity or alkalinity of a solution is determined by its pH, which is calculated as the negative logarithm of the hydrogen ion concentration (Roy et al., 2021). pH is a critical factor in all types of aquatic systems, as it determines the nature and outcome of processes occurring within them (Ahmed et al., 2012; Matta et al., 2017; Ahamad et al., 2023b). The river's average pH was 7.07±0.11. Site 2 had the lowest pH of all sites (6.91±0.05), while site 1 had the highest (7.17±0.03). The pH levels at all sites were within the BIS range (6.5-8.5). These results are consistent with Ahmed et al. (2012), which reported a pH range of 7.6 to 8.2 for the Kshipra River's water quality. Ling et al. (2016) found the pH level in Malaysia's Balui River to be between 6 and 7.7. Simeon et al. (2019) recorded the pH of Silver River to be between 7.06 and 7.14. Our study found the pH range of the Malin River to be slightly acidic at site 2 and neutral at all other sites. This may have been caused by the dumping of sugar mill effluent. Mishra and Kumar (2021) observed the pH of the Narmada River to be neutral to somewhat alkaline, with a pH range between 7.1 and 8.8. Khan et al. (2021) reported that the pH values of the Ganga and its tributaries ranged from 6.6 to 8.7. The alkaline characteristics of river bodies may be attributed to the presence of bicarbonate ions.

3.5. Dissolved Oxygen (DO)

The concentration of DO is affected by the amount of organic compounds in the water, photochemical processes, and microbial oxidation activity. Ahmed et al. (2012) also noted that DO values are influenced by the temperature of the surrounding water body and air. The presence of dissolved oxygen in water is essential for supporting various forms of aquatic life. The balance of oxygen in a body of water is a crucial factor in determining the impact of waste discharges (Kumar et al., 2018). The average DO value in the river was 3.61±1.87 mg/L, with the lowest value recorded at site 2 (1.68 mg/L±0.42) and the highest at site 1 (6.07±0.35 mg/L) among all the sites. Due to the high concentration of organic matter resulting from the mixing of home and industrial wastewater, sites 2 and 4 exhibited extremely low DO values. Microbes that require a significant amount of oxygen to oxidize the large amount of organic materials are responsible for the low DO levels in surface water bodies (Ahmed et al., 2012). According to Gupta et al. (2017), the DO concentrations in the Narmada River in Madhya Pradesh ranged from 4 to 6 mg/L. Ahmed et al. (2012) reported that DO values in the Kshipra River ranged from 0 to 5 mg/L. Ling et al. (2016) found that DO readings downstream of the Balui River in Malaysia, below the Bakun hydroelectric dam, ranged from 4.3 to 9.3 mg/L. The spillway from the dam significantly increased DO downstream. Simeon et al. (2019) recorded the DO of Silver River as ranging from 4.0 to 5.4. Mishra and Kumar (2021) reported DO values in the Narmada River ranging from 5.7 to 8.5 mg/L. The data from our study shows that the Malin River has significantly higher levels of pollution than the Narmada River.

During the winter, the low air temperature slows down the decomposition of organic waste in the river bodies, resulting in an adequate amount of DO in the water. However, in the summer months, the higher temperatures accelerate the decomposition process of organic matter, leading to a significant decrease in DO levels. In addition to temperature, evaporation from the open surfaces of these water bodies accelerates the process of heavy metal buildup and reduces the effects of dilution on their physicochemical and heavy metal properties. The moderate temperature, low evaporation, and high dilution during the rainy season improve the quality of the water in these bodies. However, runoff from agricultural fields and high-speed surface runoff during the rainy season cause soil erosion. These runoffs carry significant amounts of organic matter, sediments, dissolved minerals, and metals, which can counteract the dilution effect and increase most physicochemical parameters.

3.6. Biochemical Oxygen Demand (BOD)

The BOD test is a method used to determine the presence of organic matter in water. Essentially, it measures the amount of oxygen that aquatic microorganisms require to break down biodegradable organic matter in the water body (Sharma et al., 2014; Khan et al., 2021). The average BOD value in the river was 8.36± 4.90 mg/L, with the lowest value recorded at site 1 (3.15± 0.39 mg/L) and the highest at site 2 (14.94± 2.46 mg/L) among all the sites. The impact of residential and industrial wastewater on river quality is apparent from the BOD values. The presence of combined household and industrial waste may have caused the BOD value to increase more than four-fold when the river enters a populated area. Although BOD readings decreased as the river flowed downstream, site 4's BOD values also increased due to mixed household garbage. Simeon et al. (2019) reported that a higher BOD value indicates ongoing microbial activity on available organic matter. Chandra et al. (2011) found that BOD levels in several Indian rivers, including the Gomti, Krishna, Hoogaly, Ganga, Maha Nadi, and Cauveri, ranged from 2 to 8 mg/L. Bhutiani et al. (2019) reported a BOD range of 2.4-6.2 mg/L in the heavily impacted stretch of the Ganga River in Haridwar due to STP's effluent disposal. Before this region, Ruhela et al. (2018) reported a BOD range of 1.24 to 1.96 mg/L. According to CPCB guidelines, the water quality of the Malin River is classified as category E due to its high BOD levels, making it unsuitable for drinking, bathing, or irrigation.

3.7. Chemical Oxygen Demand (COD)

The concentration of organic matter in water, both biodegradable and non-biodegradable, can be measured using COD (Khan et al., 2021). COD is recommended over BOD due to its faster testing time (Sharma et al., 2014). The average COD value in the river was found to be 73.60±21.44 mg/L, with the lowest value recorded at site 1 (53.68±2.37 mg/L) and the highest at site 2 (103.81 mg/L±6.64). As the river flows through residential areas, the COD values increase by 1.22 to 2 times. The river flows through residential areas and carries both domestic and industrial sewage, including sugar mill effluent, after passing through a long stretch of woodland before reaching site 1. This is the reason for the increase in COD readings. The levels of COD and BOD in the river water are affected by the disposal of solid and liquid waste (Rather and Dar, 2020; Ruhela et al., 2020; Ahamad et al., 2023). According to Simeon et al. (2019), the COD of Silver River ranged from 46.5 to 54.3. According to CPCB guidelines, the water quality of Malin River falls under category E, indicating that its COD levels render it unsuitable for drinking, bathing, or irrigation.

3.8. Hardness

Water hardness is caused by the presence of calcium, magnesium, chloride, sulphate, and bicarbonate salts. Water can be classified as either soft, meaning its hardness can be removed by boiling, or hard, meaning its hardness cannot be removed by boiling. The hardness of water affects the growth of aquatic vegetation and fauna in rivers (Ruhela et al., 2022). Site 1 had the lowest hardness (180.46±3.54 mg/L), while site 2 had the highest (290.23±5.29 mg/L). The average hardness in the river was 229.23±46.81 mg/L. Hardness values exceeded the BIS threshold, except for site 1. The higher hardness readings in the Malin River may be due to the water's journey through mountainous regions and mining operations at specific locations. According to Ahmed et al. (2012), the hardness values of the Kshipra River ranged from 321 to 880 mg/L. Our study found lower hardness values compared to Ahmed et al. (2012), which could be due to the limited number of companies along the river stretch resulting in a lower volume of effluents. The reduced hardness levels suggest a lower presence of calcium and magnesium salts in groundwater. Raji et al. (2015) found that the hardness levels in the Sokoto River in Niger ranged from 121.2 to 282.8 mg/L. Similarly, Bhutiani et al. (2017) reported a comparable range of hardness in the Hindon River near Ghaziabad. In the Turag River in Bangladesh, Rahman et al. (2021) also reported hardness levels in the same range (204-328 mg/L).

3.9. Chloride (Cl^-)

Site 1 had the lowest chloride content (33.43±0.82 mg/L), while site 2 had the highest (56.26±1.13 mg/L). The average chloride content in the river was 43.84±10.10 mg/L. All chloride values were below the BIS limit of 250 mg/L. The higher levels of chloride in Malin River water suggest that chlorinated pesticides and household wastewater have been discharged into the river (Gopalkrushna, 2011; Rahman et al., 2021). Chandra et al. (2011) reported chloride concentrations ranging from 8 to 58 mg/L in the Gomti, Krishna, Hoogaly, Ganga, Maha Nadi, and Cauveri rivers in India. Raji et al. (2015) found chloride levels ranging from 35 to 100 mg/L in the Sokoto River in Niger. Bhutiani et al. (2017) observed comparable chloride ranges in the Hindon River in Ghaziabad. Tyagi et al. (2020) reported chloride concentrations in the Ganga River near Rishikesh that were significantly lower than our results.

3.10. Nitrate (NO_3^-)

Agricultural runoff and the breakdown of plant matter are the main factors that influence the nitrogen content of surface water bodies. Nitrate, a biomarker of organic pollution, is sourced from fertilizers, atmospheric precipitation, crop residues, decomposing organic waste, and septic tanks (Shakerkhatibi et al., 2019; Khan et al., 2021). The river's average nitrate content was 5.52±1.06 mg/L, with the lowest nitrate recorded at site 1 (4.23±0.43 mg/L) and the highest at site 2 (6.79±0.26 mg/L). Although the nitrate concentrations were within the BIS limit of 45 mg/L, it is possible that the higher nitrate values were due to the rivers flowing past agricultural areas. For instance, Joseph and Jacob (2010) found nitrate levels ranging from 0.5 to 8.8 mg/L in the Pennar River in Kerala. Simeon et al. (2019) measured the DO levels in the Silver River and found them to range from 4.2 to 5.7. They concluded that the nitrate in the river was due to runoff from neighbouring farms, rather than human activity.

3.11. Sulphate (SO_4^{2-})

The presence of sulphate in surface water is caused by the use of fertilizers high in sulphate and the disposal of household and commercial waste. The excess concentration of sulphate in the research area indicates high levels of industrial activity and anthropogenic causes. Site 1 had the lowest sulphate concentration (22.53±1.72 mg/L) out of all the locations, while site 4 had the highest concentration (32.11±0.27 mg/L). Sulphate levels were found to be below the BIS limit of 200 mg/L at all locations. The higher sulphate concentrations at site 4 may be due to the dumping of residential garbage from the entire city of Najibabad. When sulphate concentrations exceed 1000 mg/L in an aquatic environment, it is an indication that certain metals, such as iron (Fe) and lead (Pb), are present (Simeon et al., 2019). However, the sulphate readings in this study are much lower than 1000 mg/L, which suggests that Pb and Fe may not be present in the river water. Ahamad et al. (2023) also recorded the same range of sulphate levels (26 to 32 mg/L) in surface water bodies, such as Dal and Nigeen lakes.

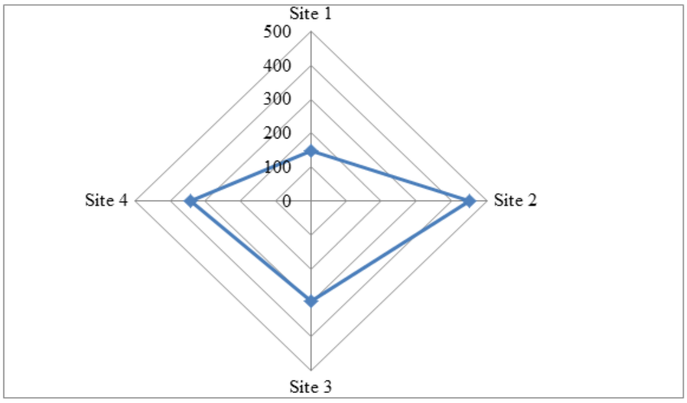

Figure 2. WQI values at all the sampling sites of river Malin.

3.12. Water quality index (WQI)

Figure 2 displays the WQI values for each site. Water quality is classified as excellent (WQI=0–25), good (WQI=26–50), poor (WQI=51–75), extremely poor (WQI=76–100), and unfit for drinking (WQI=>100) according to Chaterjee and Raziuddin (2002). The WQI presents water quality in a format that is easy for the general public to understand. The WQI values for sites 1 and 2 were determined to be the minimum (148.2145) and maximum (450.5812), respectively. All of the water quality at the sites was deemed unsuitable for human consumption based on WQI values. Despite being less crowded and polluted than other sites, the control site (site 1) was still considered polluted due to the mixing of home sewage. The river becomes increasingly contaminated as it flows into densely inhabited areas (sites 2, 3, and 4), and during the summer months, it appears to have a slow or non-existent flow. Site 2 has a lower population than sites 3 and 4. However, it was determined to be extremely polluted due to the mixing of sugar mill wastewater. Turbidity was designated as a criterion parameter at each site because higher subindex values indicated greater suspended solids and ion concentration in the river. Mishra and Kumar (2021) reported that the water quality of the Narmada River falls into the same category, making it unfit for human consumption.

3.13. Pearson correlation coefficient

Table 5 presents the Pearson correlation coefficient between the average values of several parameters measured at different sites. The correlation coefficient describes the relationship between the values of various parameters and shows the impact of changing the value of one parameter on the value of another. Except for DO, BOD, COD, and turbidity, TDS had a significant positive correlation ($r>0.8491$) with most of the parameters investigated in this study. This indicates that the river's pollution was caused mainly by inorganic salts rather than organic salts. The values of EC and other parameters exhibited a similar relationship. The levels of turbidity in river water have a high positive correlation ($r>0.8467$) with all parameters except pH, TDS, EC, DO, and sulphate. This suggests that both organic and inorganic ions contribute to the turbidity. Additionally, there is a strong positive correlation ($r>0.8589$) between COD levels and the values of hardness, chloride, sulphate, and nitrate, indicating that calcium and magnesium salts are influencing COD levels.

Table 5. Pearson correlation coefficient between the different physicochemical parameters of river Malin.

Parameters	TDS	EC	Turbidity	pH	DO	BOD	COD	Hardness	Chloride	Nitrate	Sulphate
TDS	1										
EC	1	1									
Turbidity	0.6626	0.6626	1								
pH	0.9640	0.9640	0.4424	1							
DO	0.3295	0.3295	0.1356	0.3872	1						
BOD	0.5113	0.5113	0.9678	0.2752	-0.1049	1					
COD	0.8491	0.8491	0.9241	0.6945	-0.2586	0.8786	1				
Hardness	0.9478	0.9478	0.8503	0.8366	0.2895	0.7532	0.9714	1			
Chloride	0.9259	0.9259	0.8764	0.8002	0.2650	0.7842	0.9759	0.9963	1		
Nitrate	0.9585	0.9585	0.8467	0.8501	0.2874	0.7335	0.9576	0.9967	0.9915	1	
Sulphate	0.9782	0.9782	0.7243	0.9159	0.3374	0.5665	0.8589	0.9519	0.9448	0.9649	1

4. Conclusion

The study concluded that except for site 1, the values of TDS, turbidity, and hardness exceeded the BIS limit. The water quality of the river deteriorated steadily as it flowed through the residential districts. The study revealed the significant impact of industrial and residential wastewater discharges on the water quality of the Malin River. This poses a potential health risk to the community as the river water is used for irrigation, laundry, and vegetable washing. Najibabad, located in the Bijnor district, is one of the fastest-growing Tehsils. Over the past decade, the city has undergone significant expansion, particularly along the riverbank. This expansion has led to the construction of hospitals, marriage halls, markets, and colonies. As a result of these development initiatives, both the amount of residential wastewater produced and the population density of the city have increased. Wastewater treatment facilities are necessary along river coasts to conserve river flora and fauna, as well as water quality, to safeguard human and river health.

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