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Water quality assessment of Dudhganga river using water quality index and anthropogenic activities

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ABSTRACT

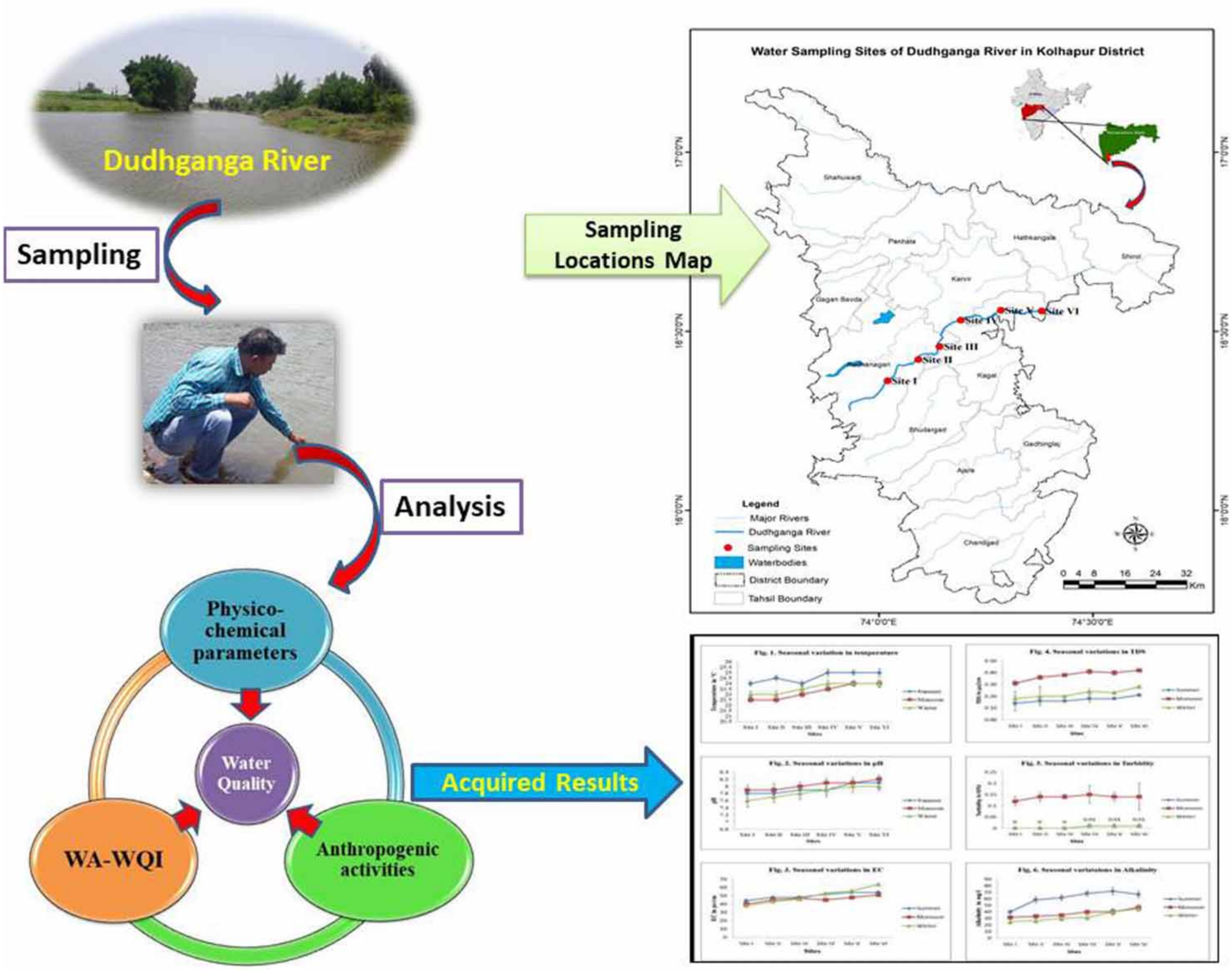
The primary goal of this study is to analyze magnitude of water quality of Dudhganga River seasonally and temporally using physico-chemical parameters, Weighted Arithmetic Water Quality Index (WA-WQI) and anthropogenic activities of Kolhapur District, Maharashtra. Six sampling locations of Dudhganga River (sites I to VI) were selected for sampling and analysis. In seasonal analysis, higher values of water parameters like pH (8.2), TDS (0.42 μs/cm), turbidity (0.14 NTU), DO (6.24 mg/l), nitrate (7.56 mg/l) and phosphate (1.78mg/l) were reported in monsoon season. Temperature, alkalinity and hardness were noted maximum values (25 °C, 66.67 mg/l and 12.67 mg/l) during summer season. However, EC was reported maximum (64 μs/cm) in winter season. Results of WA-WQI revealed that water quality index ranged from 14.90 to 24.26 all sampling sites. The values of WA-WQI were reported higher at downstream locations like IV, V, and VI, than upstream sites I, II, and III. Along Dudhganga River various human activities were substantial contributors for declining the river water quality. The acquired results suggest that water quality status is close to becoming contaminated and unsafe for domestic and human use. Such contaminated water also poses risks to plants and animals that make up the aquatic ecosystem.

Key words: anthropogenic activities, Dudhganga River, Kolhapur (Maharashtra), physicochemical parameters, WQI

HIGHLIGHTS

- Dudhganga River is a lifeline for all the living community of the Kolhapur district
- Due to human interferences, the overall condition or health of rivers is badly affected.
- The contaminated water is unsafe for human use.
- Through this study the ecologically sensitive habitats we can identify.
- This study will help to define some probable management and monitoring remedies.

GRAPHICAL ABSTRACT



INTRODUCTION

The ecological status and quality of the river is significantly influenced by changing climatic conditions (e.g. floods, droughts) and human activities (e.g. pollution and habitat degradation). According to literature, the loss of freshwater biodiversity is mainly due to human related activities like habitat degradation, networking river fragmentation (Sarker *et al.* 2019; Sarker 2021) water diversions and construction of dams (Gao *et al.* 2022). Moreover, the water resources are significantly impaired by pollution due to human activities (Gibbs 2000), hydrological cycle and climate change (Sarker 2022). The human activity produces considerably negative impacts on the riverine basin, leading to deterioration in water quality and making it unfit for inhabiting flora and fauna. Moreover, the degraded water quality is also unsafe for human consumption and irrigation purposes. According to Govorushko (2007) the anthropogenic activities have huge negative consequences on river ecosystems. Very recently authors like Soomro *et al.* (2023a, 2023b, 2023c) concluded that human activities are the chief source of freshwater pollution and declining riverine water quality. According to Soomro *et al.* (2024) the trace elements have toxicant impact on water quality and fish populations of Kunhar River in Pakistan.

Anthropogenic activities like agricultural practices and industrial activities create a serious impact on the natural environment (Kang *et al.* 2004). These authors also concluded that the extreme human activities are responsible for loss of vegetation, gradual soil salinization and desertification. Recent literature reported that the discharge of wastewater (e.g., brine) degrades water quality and thus water cannot be directly used for potable water (via desalination) and industrial applications (Panagopoulos 2022, 2023; Panagopoulos & Giannika 2022).

According to Williams (1987) significant variation in salinity may affect the diversity of invertebrates, vertebrates, aquatic plants, and riparian vegetation. Microbial contamination is one of the issues of water pollution which leads to waterborne disease (Karaboze *et al.* 2003) and deterioration of water quality (Standard Methods 1998). Norman *et al.* (2006) concluded that each human activity has a potential cyclical and cascading effect on water quality and quantity along hydrologic pathways. Dudhganga River is considered as a lifeline for all communities and developing sectors of Kolhapur District in Maharashtra, India. After looking through the various literature, we came to know that no work has been done on the water quality of the Dudhganga River. At present, human activity has also increased significantly along the Dudhganga River, impacting the water quality through different processes. So, there is an urgent need to analyze the water quality and forecast the present water status of the Dudhganga River. The outcomes of this study may be helpful in executing suitable management of human activities and maintaining the water resource. Hence, considering the importance and health condition of the river we have concentrated on evaluating the Dudhganga River water quality and documenting the anthropogenic activities that have resulted in the degradation of the water quality.

MATERIALS AND METHODS

Study area

Dudhganga River is one of the main tributaries of Krishna River in western India. It originates in the Western Ghats of Maharashtra's Sindhudurg district, flows eastward for 69 km through Kolhapur District, and joins the Krishna River in Kallol Yedur, Karnataka (Figure 1) (Government of Maharashtra Water Resources Department 2015).

We visited the six Dudhganga River sampling locations between October 2018 and February 2020. Selection of sites was done on the basis of the major influence of humans and their activities in and around the Dudhganga River. The distance between two sampling sites was kept to about 8–10 km. Six sampling stations in total were chosen for collection of water samples; they were designated on maps as S-I, S-II, S-III, S-IV, S-V, and S-VI. Site I is Kalamwadi; Site II is Sarawade; Site III is Walwe; Site IV is Bachani; Site V is Vandur; and Site VI is Sulkud (Figure 1).

Physicochemical parameters analysis

Water samples were collected from six sampling stations of Dudhganga River (Figure 1) during three distinct seasons: winter (November–December), summer (March–April) and monsoon (July–August). Water samples were collected in cleaned dissolved oxygen bottles without bubbles from the midstream sites at a depth of 20–30 cm. Ten important physicochemical parameters of water samples were estimated for water quality analysis: temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, alkalinity, dissolved oxygen (DO), hardness, nitrate and phosphate (Table 1).

Parameters like temperature, pH, EC and TDS of water samples were measured *in situ* using digital pen-type pH, EC and TDS meters (Model-AM-P-TEM/EC/TDS and Model-AM-P-PH) from Aquasol. Turbidity of water was measured by turbidity meter (Model-EQ-811) using Standard Methods (2005). The alkalinity and hardness of water samples were estimated and tested according to standard titration methods described by Trivedy & Goyal (1986) and Standard Methods (2005). Dissolved oxygen of water samples was measured by the Winkler methods as described by Trivedy & Goyal (1986) and Standard Methods (2005). Spectrophotometric analysis (Model-EQ-821) was applied to estimate the nitrate by phenol disulphonic acid method and phosphates was estimated by the stannous chloride method as described by Trivedy & Goyal (1986) and Standard Methods (2005). All water parameters were analyzed in triplicate and the average value of three analyses is represented in results with standard deviation.

WQI analysis

The water quality index of Dudhganga River was calculated using the formula described by Brown *et al.* (1972). This formula is based on weights of various water parameters. Therefore, the weighted arithmetic water quality index (WA-WQI) relies on weighting of each water parameter according to its importance. The mathematical formula of WA-WQI is as follows:

$$\mathrm{WA-WQI} = \frac{\sum WnQn}{\sum Wn}$$

Brown *et al.* (1972) have categorized the WA-WQI status numerical ranges into five classes: excellent (0–25), good (26–50), poor (51–75), very poor (76–100) and unsuitable for drinking (above 100).

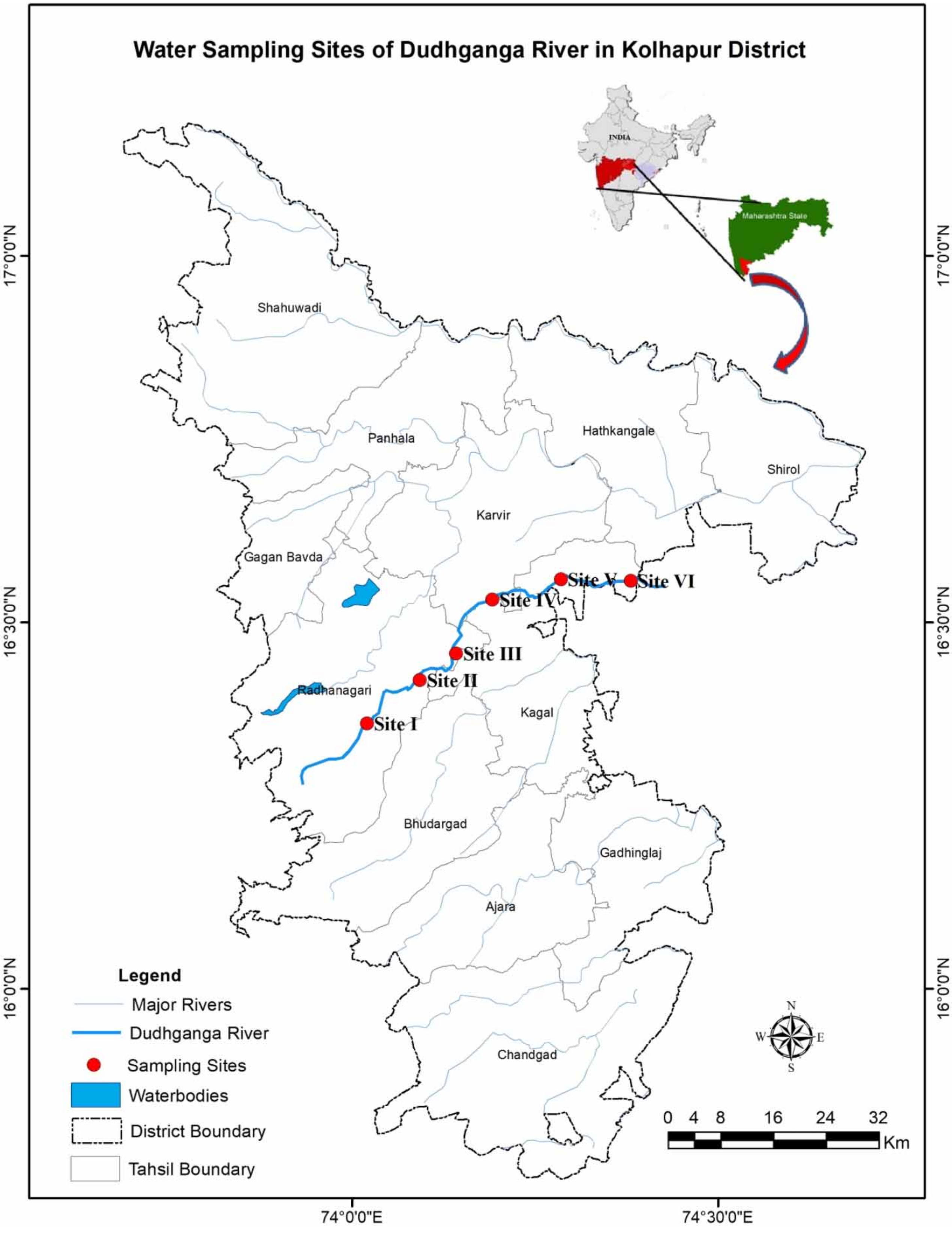


Figure 1 | Map showing the sampling sites of Dudhganga River. *Source*: https://mrsac.gov.in.

Table 1 | Physicochemical parameters and their analytical methods

Water parameters	Analytical method	Unit	Analysis
Temperature	Temperature probe	°C	In-situ (measured in the field)
pH	pH probe		
Electrical conductivity	EC probe	μs/cm	
Total dissolved solids	TDS probe	μs/cm	
Hardness	Titration	mg/l	
Dissolved oxygen	Titration	mg/l	
Alkalinity	Titration	mg/l	
Turbidity	Turbidity meter	NTU	Ex-situ (measured in the laboratory)
Nitrate	Spectrophotometer	mg/l	
Phosphate	Spectrophotometer	mg/l	

Note: μs/cm = microsiemens/centimeter, NTU = nephelometric turbidity unit.

Anthropogenic study

Land-use modifications due to anthropogenic activities reflect the ecological health status of the river. Anthropogenic activities modify the natural riverine basin and land cover types (Gao *et al.* 2019). The various human-made intrusions or anthropogenic activities in and around the Dudhganga were noted monthly.

RESULTS AND DISCUSSION

Physicochemical parameters

The spatial and temporal analysis of the physical and chemical parameter values of the present study are presented in Table 2 and Figures 2–11.

Temperature

In the current study, the summer had the highest temperature (25 $\pm$ 0.38 °C), while the monsoon season had the lowest temperature (22.5 $\pm$ 0.28 °C) (Figure 2). The water temperature rose from upstream to downstream (site I to site VI) in all seasons. The cloud-free climate during summer was responsible for the increase in water temperature whereas during monsoon the mixing of cold rainwater by river runoff reduced the water temperature. Agrahari & Kushwaha (2012) state that characteristics such as solar radiation intensity, water level, current velocity, and atmospheric conditions may be in charge of temperature variation.

pH

The mean pH values varied according to seasons. In the summer, monsoon, and winter, the river water's pH ranged from 7.8 $\pm$ 0.12 to 8.1 $\pm$ 0.16, 7.9 $\pm$ 0.12 to 8.2 $\pm$ 0.12, and 7.6 $\pm$ 0.18 to 8.0 $\pm$ 0.12 respectively (Figure 3). In every season, site VI had the highest pH value and site I the lowest pH. The normal pH range of surface water is 6.5–8.5 while the maximum limit for water used for irrigation and aquaculture purposes is pH 6.5–8.0 (DoE 1997). In this study, highest pH values were reported in monsoon season (7.9 $\pm$ 0.12 to 8.2 $\pm$ 0.12) while lowest pH was noted during winter season (7.6 $\pm$ 0.18 to 8.0 $\pm$ 0.12). However, Rahman *et al.* (2021) have reported highest pH during winter and lowest in summer season for the Turag River in Bangladesh. pH is also raised by the microbial breakdown of organic waste (Venkatesharaju *et al.* 2010).

Electrical conductivity (EC)

According to Table 2, the EC values varied from 44 $\pm$ 0.20 to 54 $\pm$ 0.28 μs/cm in the summer, 40 $\pm$ 0.22 to 51 $\pm$ 0.12 μs/cm in the monsoon, and 38 $\pm$ 0.20 to 64 $\pm$ 0.26 μs/cm in the winter. The present study reported the lowest values of EC in winter season from site I (38 $\pm$ 0.20) and site II (43 $\pm$ 0.18) while in monsoon season from site IV (45 $\pm$ 0.19), V (48 $\pm$ 0.18) and VI (51 $\pm$ 0.12) (Figure 4). The lowering of EC values in Dudhganga River may be due to the addition of runoff water to the riverine system during monsoon and post-monsoon season. Rahman *et al.* (2021) also quoted the same conclusion on lowest

Table 2 | Spatial and temporal variations in physicochemical parameters of Dudhganga River

Site		Temp. (°C)	pH	EC (μs/cm)	TDS (μs/cm)	Turbidity (NTU)	Alkalinity (mg/l)	Oxygen (mg/l)	Hardness (mg/l)	Nitrate (mg/l)	Phosphate (mg/l)
Site I	Summer	24 ± 0.24	7.8 ± 0.12	0.44 ± 0.20	0.14 ± 0.06	0.00 ± 0.0	40 ± 3.42	5.70 ± 0.47	6.67 ± 0.72	2 ± 0.04	0.40 ± 0.04
	Monsoon	22.5 ± 0.28	7.9 ± 0.12	0.40 ± 0.22	0.31 ± 0.02	0.12 ± 0.02	31.67 ± 2.78	5.64 ± 0.72	4 ± 0.42	4.67 ± 0.22	0.98 ± 0.28
	Winter	23 ± 0.24	7.6 ± 0.18	0.38 ± 0.20	0.18 ± 0.02	0.00 ± 0.0	25 ± 3.48	5.24 ± 0.62	6 ± 0.48	3 ± 0.22	0.40 ± 0.18
Site II	Summer	24.5 ± 0.26	7.8 ± 0.15	0.48 ± 0.29	0.16 ± 0.02	0.00 ± 0.0	58.33 ± 4.62	4.57 ± 0.42	7.33 ± 0.62	2 ± 0.02	0.27 ± 0.12
	Monsoon	22.5 ± 0.32	7.9 ± 0.17	0.45 ± 0.21	0.36 ± 0.02	0.14 ± 0.02	33.33 ± 2.92	5.77 ± 0.40	4 ± 0.36	5.44 ± 0.56	1.42 ± 0.18
	Winter	23 ± 0.26	7.8 ± 0.15	0.43 ± 0.18	0.20 ± 0.02	0.00 ± 0.0	26.67 ± 3.88	5.10 ± 0.35	6 ± 0.88	2.78 ± 0.18	0.44 ± 0.16
Site III	Summer	24 ± 0.24	8.1 ± 0.10	0.48 ± 0.16	0.16 ± 0.01	0.00 ± 0.0	61.67 ± 4.22	5.24 ± 0.47	8 ± 1.01	2.44 ± 0.22	0.40 ± 0.10
	Monsoon	23 ± 0.24	8.1 ± 0.12	0.47 ± 0.20	0.38 ± 0.01	0.14 ± 0.04	35 ± 2.42	6.12 ± 0.32	4.67 ± 0.48	6 ± 0.49	1.38 ± 0.08
	Winter	24 ± 0.26	7.9 ± 0.16	0.46 ± 0.12	0.20 ± 0.01	0.00 ± 0.0	30 ± 3.22	5.68 ± 0.41	8 ± 0.75	3.33 ± 0.28	0.67 ± 0.26
Site IV	Summer	25 ± 0.32	8.0 ± 0.18	0.52 ± 0.12	0.18 ± 0.01	0.01 ± 0.01	68.33 ± 4.42	5.10 ± 0.32	9.33 ± 1.12	2.67 ± 0.26	0.53 ± 0.18
	Monsoon	23.5 ± 0.32	8.0 ± 0.12	0.45 ± 0.19	0.41 ± 0.02	0.15 ± 0.04	40 ± 2.78	6.18 ± 0.38	6 ± 0.47	6.78 ± 0.24	1.69 ± 0.12
	Winter	24 ± 0.22	8.1 ± 0.10	0.63 ± 0.26	0.24 ± 0.02	0.01 ± 0.01	31.67 ± 4.32	5.92 ± 0.47	6 ± 0.32	3.78 ± 0.42	0.89 ± 0.28
Site V	Summer	25 ± 0.26	8.1 ± 0.14	0.54 ± 0.26	0.18 ± 0.01	0.01 ± 0.01	71.67 ± 5.42	5.42 ± 0.38	10 ± 1.46	1.67 ± 0.02	0.53 ± 0.18
	Monsoon	24 ± 0.22	8.1 ± 0.14	0.48 ± 0.18	0.40 ± 0.02	0.14 ± 0.02	40 ± 4.78	6.18 ± 0.32	5.33 ± 0.52	7.22 ± 0.42	1.73 ± 0.08
	Winter	24 ± 0.24	8.1 ± 0.17	0.68 ± 0.20	0.23 ± 0.01	0.01 ± 0.01	40 ± 3.42	5.71 ± 0.42	8 ± 0.72	4.22 ± 0.52	0.98 ± 0.18
Site VI	Summer	25 ± 0.38	8.1 ± 0.16	0.54 ± 0.28	0.21 ± 0.01	0.01 ± 0.01	66.67 ± 5.02	5.76 ± 0.32	12.67 ± 1.40	2.72 ± 0.22	0.53 ± 0.22
	Monsoon	24 ± 0.30	8.2 ± 0.12	0.51 ± 0.12	0.42 ± 0.01	0.14 ± 0.06	46.67 ± 4.28	6.24 ± 0.38	6 ± 0.48	7.56 ± 0.42	1.78 ± 0.04
	Winter	24 ± 0.32	8.0 ± 0.12	0.64 ± 0.26	0.28 ± 0.01	0.01 ± 0.01	45 ± 4.22	5.86 ± 0.48	8 ± 0.86	4.67 ± 0.59	0.98 ± 0.22

Note: All values are the mean of three observations with ± standard deviation; EC = electrical conductivity, TDS = total dissolved solids, μs/cm = microsiemens/centimeter, NTU = nephelometric turbidity unit.

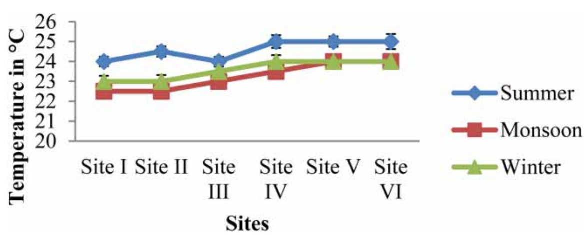


Figure 2 | Seasonal variation in temperature.

values of EC from Turag River. From site I to site VI, the EC values showed a slight increase moving downstream. Increased household activity and high agricultural waste runoff are the causes of the higher EC value in riverine water. According to published research, ions and nutrient concentrations affect water's electrical conductivity (Agrahari & Kushwaha 2012).

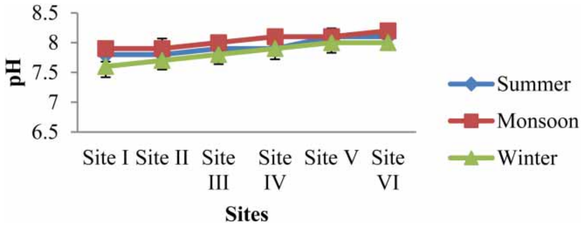


Figure 3 | Seasonal variations in pH.

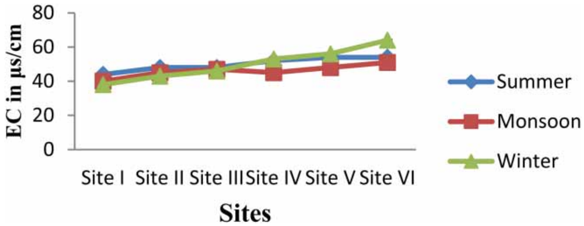


Figure 4 | Seasonal variations in EC.

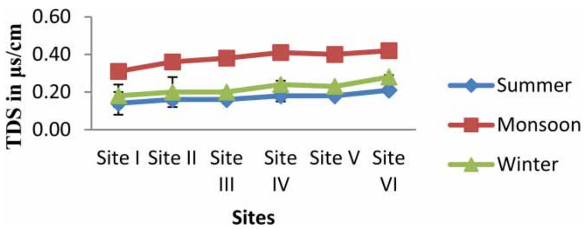


Figure 5 | Seasonal variations in TDS.

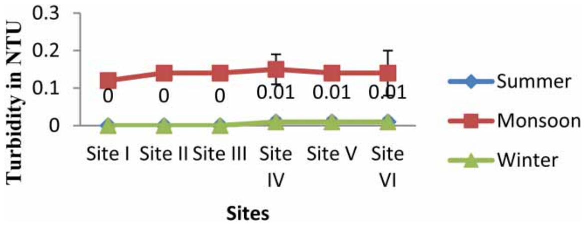


Figure 6 | Seasonal variations in turbidity.

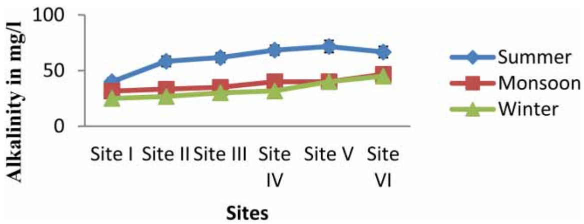


Figure 7 | Seasonal variations in alkalinity.

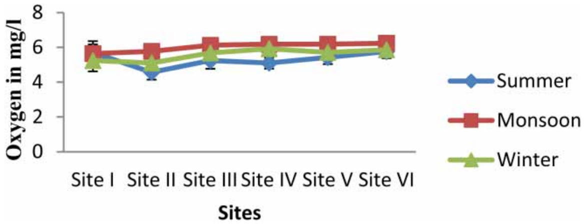


Figure 8 | Seasonal variations in oxygen.

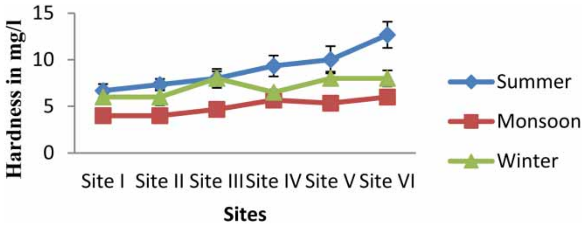


Figure 9 | Seasonal variations in hardness.

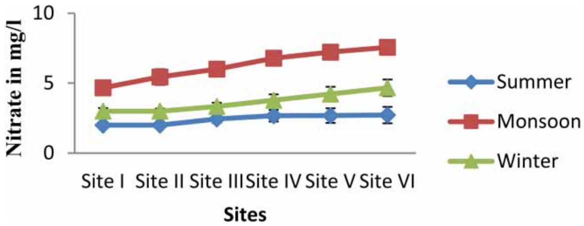


Figure 10 | Seasonal variations in nitrate.

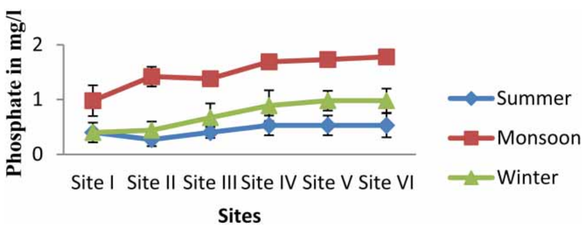


Figure 11 | Seasonal variations in phosphate.

Total dissolved solids (TDS)

The TDS mean values of collected water samples of all site locations were within the range of 0.31 ± 0.22 to $0.42 \pm 0.18\,\mu s/cm$ during the monsoon, 0.18 ± 0.22 to $0.28 \pm 0.10\,\mu s/cm$ in the winter and from 0.14 ± 0.06 to $0.28 \pm 0.10\,\mu s/cm$ in the summer (Figure 5). All values of TDS are reported within the permissible limit (DoE 1997). Because of the discharges of domestic wastewater, sites IV through VI had the highest values of TDS. Those water bodies with the maximum concentration of total dissolved solids are responsible for the deterioration of the water quality, making it unfit for human consumption (Mahor 2011). According to Olomukoro *et al.* (2022) human activity like car washing is responsible for higher values of TDS at different locations of Orogodo River, Nigeria.

Turbidity

The turbidity values in this study varied greatly between 0 and 0.14 NTU across all sampling locations. During the monsoon season, the mean turbidity value was within the range of 0.12 ± 0.02 to 0.14 ± 0.06 NTU from site I to site VI. In spatial variation, the sampling sites IV to VI were reported to have negligible values of turbidity (0.01 ± 0.01 NTU) in winter (Figure 6). Conversely, at every sampling site, turbidity values of zero were reported in summer. The monsoon season high turbidity value was defined by the maximum amount of runoff rainwater entering the system and incorporating colloidal materials such as clay, slit, organic, and inorganic materials. However, Rahman *et al.* (2021) found a contrasting value of turbidity from Turag River with respect to the present study; they noted a higher turbidity value in summer than the monsoon season.

Alkalinity

Highest values of alkalinity were recorded during summer season at all sampling stations and values ranged between 40 ± 3.32 mg/l and 66.67 ± 5.02 mg/l. Winter season showed the lowest values of alkalinity at all six sampling stations within the range of 25 ± 3.48 mg/l to 45 ± 4.22 mg/l. Whereas, the alkalinity values ranged between 31.67 ± 2.78 mg/l and 46.67 ± 4.28 mg/l in monsoon season (Figure 7). The values of alkalinity increased significantly as one descended from site I to site VI. Chandra *et al.* (2011) claimed that water with a high concentration of alkalinity was unfit for residential use. It may be assumed that anthropogenic activities like vehicle washing, clothes washing and bathing may have effects on the alkalinity of riverine water (Olomukoro *et al.* 2022).

Dissolved oxygen (DO)

The highest level of dissolved oxygen was reported during monsoon season; DO fluctuated from 5.64 ± 0.72 to 6.24 ± 0.38 mg/l from site I to site VI (Figure 8). In winter, moderate values of dissolved oxygen were reported at site I to site VI, 5.24 ± 0.62–5.86 ± 0.48 mg/l. The summer season had the lowest dissolved oxygen values across all sites when compared to the other seasons. The values during summer season ranged within 5.70 ± 0.47–5.76 ± 0.32 mg/l. The acquired values of dissolved oxygen progressively declined from site I to site IV. The occurrence of submerged microphytes and riparian vegetation may responsible for the declining dissolved oxygen level of Dudhganga River at the downstream sampling locations. Hasan *et al.* (2019) stated the floating and submerged microphytes may decrease the DO level. Movement of water also has a negative effect on the dissolved oxygen levels of riverine ecosystems (Rahman *et al.* 2021).

The influx of wastewater and sewage, and domestic activities like washing clothes, vehicles, animals, bathing etc. would be responsible for the declining dissolved oxygen level of the river. Research by Whitehead *et al.* (2018) and Uddin & Jeong (2021) concluded that the municipal wastes and industrial wastes are responsible for the reduced oxygen concentration of water. Besides, agricultural runoff or waste is also entering river water and lowering the water quality. Iqbal *et al.* (2006) stated that the addition of sewage waste results in water quality decline by lowering the oxygen level.

Hardness

According to Unni (1985), total hardness was used to evaluate the level of domestic pollution in water bodies. In the context of seasons and sampling locations, the hardness values in this study were reported in the opposite order than the values of dissolved oxygen. From site I to site VI, the maximum hardness was measured in the summer (6.67 ± 0.72 to 12.67 ± 1.40 mg/l), followed by the winter (6.0 ± 0.48 to 8.0 ± 0.86 mg/l) and the monsoon (4.0 ± 0.42 to 6.0 ± 0.48 mg/l) seasons (Figure 9). However, the research of Tahmina *et al.* (2018) observed highest values of total hardness in winter season, but Rahman *et al.* (2021) found similar lowest values of total hardness in monsoon season from Turag River. Agrahari & Kushwaha (2012) found a positive correlation between the amount of sewage dumped into water bodies and the water's hardness.

Nitrate

Higher values of nitrate are positively correlated with domestic activities, and the addition of sewage and agricultural runoff in water bodies. In the present study, the nitrate values were maximum during monsoon season (4.67 ± 0.22–7.56 ± 0.42 μg/l), followed by winter season (3.0 ± 0.22–4.67 ± 0.59 μg/l). However, the lowest values of nitrate were reported (2.0 ± 0.04–2.72 ± 0.22 μg/l) during summer season from site I to site VI (Figure 10). The main source of nitrate in aquatic bodies is the organic substances which come through sewage and industrial wastes (Agrahari & Kushwaha 2012). According to Shrimali & Singh (2001) the concentration of nitrate in aquatic bodies is due to anthropogenic activities, use of chemical fertilizers and dumping of domestic sewage wastes.

Phosphate

Extensive use of fertilizer and detergents, organic manure and wastes of animals and humans result in heavily loading phosphorus into water bodies (Ali *et al.* 2018; De Girolamo *et al.* 2019). In the present study, a similar trend of phosphate concentration was reported to that of nitrate with respect to seasons and sites. The maximum concentration of phosphate was reported in monsoon and the values ranged from 0.98 ± 0.48 to 1.78 ± 0.04 μg/l, followed by winter season (0.4 ± 0.42–0.98 ± 0.50 μg/l) and summer season (0.4 ± 0.04–0.53 ± 0.62 μg/l) (Figure 11). The higher concentration of phosphate mean value in monsoon season is due to high inputs of nutrients from nearby farmlands through runoff of rainwater. The same kind of result was reported by Isiuku & Enyoh (2020) that the higher level of phosphate concentration is reported to be due to runoff from farmlands in proximity to the water bodies.

Correlation matrix analysis of physicochemical parameters

The correlation matrix (r) values of all water parameters are displayed in Table 3. Water temperature had not shown any positive correlation with any other water parameters, whereas there was a strong negative correlation with nitrate ($r = -0.93$) and negative relationship with oxygen ($r = -0.52$). pH exhibit a strong positive correlation with EC ($r = 0.73$), TDS ($r = 0.89$), alkalinity ($r = 0.77$), hardness ($r = 0.73$), and phosphate ($r = 0.72$). pH has a negative correlation with water parameters like oxygen ($r = -0.15$) and nitrate ($r = -0.05$).

Likewise, the EC showed a positive strong correlation with TDS ($r = 0.91$), turbidity ($r = 0.90$), and alkalinity ($r = 0.95$). However, EC also recorded negative correlation with oxygen ($r = -0.60$) and with nitrate ($r = -0.05$). Strong correlations were found between TDS and turbidity ($r = 0.79$), alkalinity ($r = 0.88$), and hardness ($r = 0.89$). TDS also reported negative correlation with water parameters like oxygen ($r = -0.48$) and nitrate ($r = -0.35$). Turbidity shows significantly strong correlation with alkalinity ($r = 0.75$), hardness ($r = 0.84$) and phosphate ($r = 0.89$), and negative correlation with oxygen ($r = -0.29$) and nitrate ($r = -0.19$). Alkalinity showed strong correlation with hardness ($r = 0.70$), but a negative correlation with oxygen ($r = -0.67$) and nitrate ($r = -0.01$). The dissolved oxygen did not show any noticeable relationship with any parameter. On the other hand, hardness showed positive correlation with phosphate ($r = 0.75$) and a negative relationship with nitrate ($r = -0.40$). Nitrate was negatively correlated with phosphate ($r = -0.08$). Rahman *et al.* (2021) also got similar results that there is no positive correlation of temperature with the rest of the water parameters. Barakat *et al.* (2016) found that turbidity had a strong correlation with both ammonia and total suspended solids, while DO had a strong correlation with nitrate. The anthropogenic activities such as domestic and agriculture activities including urbanization and industrialization can contribute to a decline in the WQI of river water (Azha *et al.* 2023).

Table 3 | Correlation matrix of water parameters of Dudhganga River (Pearson correlation coefficients (r))

	Temp. (°C)	**pH**	**EC (μs/cm)**	**TDS (μs/cm)**	**Turbidity (NTU)**	**Alkalinity (mg/l)**	**Oxygen (mg/l)**	**Hardness (mg/l)**	**Nitrate (mg/l)**	**Phosphate (mg/l)**
Temp. (°C)	1.00									
pH	0.30	1.00								
EC	0.42	0.73	1.00							
TDS	0.60	0.89	0.91	1.00						
Turbidity (NTU)	0.30	0.62	0.90	0.79	1.00					
Alkalinity (mg/l)	0.32	0.77	0.95	0.88	0.75	1.00				
Oxygen (mg/l)	−0.52	−0.15	−0.60	−0.48	−0.29	−0.67	1.00			
Hardness (mg/l)	0.56	0.73	0.78	0.89	0.84	0.70	−0.33	1.00		
Nitrate (mg/l)	−0.93	−0.05	−0.18	−0.35	−0.19	−0.01	0.27	−0.40	1.00	
Phosphate (mg/l)	0.13	0.72	0.71	0.71	0.89	0.56	0.12	0.75	−0.08	1.00

Note: EC = electrical conductivity, TDS = total dissolved solids, μs/cm = microsiemens/centimeter, NTU = nephelometric turbidity unit; figures in bold indicate significant correlation.

Weighted Arithmetic Water Quality Index (WA-WQI)

Generally, the physicochemical parameters analysis and their values will not be sufficient to identify the actual quality of water bodies; therefore, water quality indices have been used to estimate the quality status of water (CCME 2002; Krishan *et al.* 2015). WQI is a potent tool for forecasting the deteriorating level of water (Azha *et al.* 2023). Water quality indices are based on comparison of water parameters to standards which give a final value for water quality (Bharati & Katyal 2011).

The current study found that the Dudhganga River's WQI varied noticeably from upstream to downstream across the sampling locations. From site I to site VI, the WQI varied from 14.90 to 24.26 (Table 4). Due to values of the WQI being below the standard value (<25), Dudhganga WQI is denoted as excellent and right now is suitable for drinking purposes (Table 4). However, the WQI was gradually increasing from upstream to downstream sites, and the highest WQI was noted at site VI (24.26). This value depicts that the water quality decreases towards the downstream, indicating that the water parameters are significantly varying due to human activities downstream. Barakat *et al.* (2016) reported similar results that downstream sites of Oum Er-Rbia River in Morocco were more polluted due to discharging of urban waste. The domestic and agricultural activities are the key factors for the declining WQI of Dudhganga River. Azha *et al.* (2023) reached the same conclusion that domestic and agriculture activities are contributing to the decline in the WQI of river water. Similarly, Azha *et al.* (2023) declared that agriculture waste had degraded the water quality of Batu Pahat River in Malaysia. According to Anani & Olomukoro (2021) a higher value of WQI of water is not ideal for drinking.

Anthropogenic activity

We have documented substantial human activity near the Dudhganga River in our current study. The decline in aquatic diversity, productivity, and quality may be attributed to these activities. The anthropogenic activities are discussed below (see also Table 5 and Figure 12 (images a–k)).

Domestic activities

The Dudhganga River is severely affected by various domestic activities like washing, bathing, cleaning of clothes, washing vehicles and domestic animals which are frequently carried out in and around the riverine habitat (Figure 12, images a–d). These activities are responsible for releasing the soap nutrients and organic content in water while washing vehicles releases oil and grease directly into river water. Clothes washing and bathing activities are enhancing the nutrients and organic concentration in the river basin. Danha *et al.* (2014) reported that the increased nutrient level promotes rampant algal and weed growth. Similarly, Rai *et al.* (2020) reported that the vehicle washing contaminates the river water by adding oil and grease and sulfate which significantly degrade water quality and affect benthic macro-invertebrate assemblage structure.

Disposing of waste and sewage water

The primary cause of declining water quality and productivity is the release of untreated sewage and household waste into rivers (Figure 12, image e). It contains all household waste, including garbage from the kitchen, bathrooms, and drains, which are dumped into the river untreated. The majority of municipal waste, or toilet waste, is made up of human waste, which also contains some harmful substances and pathogens. All of these wastes have the potential to give water an unpleasant, strong odor and turn it into something unsafe to drink. According to Weiner (2013) water quality of any aquatic body mainly depends on its usage, i.e. drinking and irrigation.

Table 4 | Water quality index (WA-WQI) and status (Brown *et al.* 1972)

Water quality index (range)	Water quality status	WQI of Dudhganga River	Water quality status of Dudhganga River
0–25	Excellent	Site I (14.90)	Excellent
26–50	Good	Site II (16.80)	
51–75	Poor	Site III (22.32)	
76–100	Very poor	Site IV (22.42)	
>100	Unfit for consumption	**Site V (24.27)**	
		Site VI (24.26)	

Note: Bold WQI values are highest in study area.

Table 5 | Sampling sites and anthropogenic activities

Sampling site	Name of sampling site	GPS locations	Stream type	Possible anthropogenic activities (activities are reported on large scale)
I	Kalamwadi	16°21′48.3″N 74°01′27.7″E	Upstream	Domestic activity, agricultural practices
II	Sarawade	16°25′15.0″N 74°05′32.8″E	Upstream	Domestic activity, agricultural practices, slaughter waste, Ganesh idols immersion and holy or religious waste (*nirmalya*), bridge and construction activity, dumping and releasing waste and sewage water
III	Walwe (K)	16°29′00.9″N 74°08′54.6″E	Midstream	Domestic activity, industrial activity, agricultural practices
IV	Bachani	16°31′50.8″N 74°11′30.0″E	Midstream	Domestic activity, agricultural practices, slaughter waste, dumping and releasing waste and sewage water
V	Vandur	16°33′29.8″N 74°17′06.3″E	Downstream	Domestic activity, agricultural practices, encroachment of habitat and fragmentation, Ganesh idols immersion and holy or religious waste (*nirmalya*)
VI	Sulkud	16°33′25.3″N 74° 22′47.7″E	Downstream	Domestic activity, agricultural practices

Agricultural practices

Farmers use a variety of pesticides and herbicides, as well as highly synthetic and organic fertilizers, to cultivate crops along the banks of riverine habitat. Water's physical, chemical, and biological characteristics may change as a result of fertilizer, pesticide, and herbicide runoff or untreated agricultural waste in riverine basins (images f–g). Due to excessive use of pesticide and fertilizers the riverine water is unsafe for fish and other organism as well (Lake Champlain Basin Program 1998). Synthetic pesticide may cause gill dysfunction in fishes (Moore *et al.* 2008). Azha *et al.* (2023) concluded that agriculture sector waste may degrade the water quality of Batu Pahat River. Substantial increase in agricultural activity may have undesirable impacts on the water ecosystem (Li *et al.* 2022).

Bridge and construction activity

In the present study, we reported the bridge construction and bridge repairing activities at sites II (Sarawade), IV (Bachane), and in regions like Nadi Kinara between sites IV and V (Figure 12, image h). The natural hydrological river regime may be altered by this construction activity. River flow, water level and volume of water may show adverse effects due to construction activity and possibly lead to changes in the riverine basin. It was noted that runoff from the construction site of the bridge contributed a significant amount of nutrients and sediments to the river flow. Additionally, this activity causes sedimentation and turbidity in the riverine ecosystem. Anthropogenic activity like construction activity and land-use cover in and around the river may be accelerating the deteriorating quality of water bodies (Pacheco & Fernandes 2016).

Encroachment of habitat and fragmentation

From the perspective of the aquatic ecosystem, this may be of greater concern because humans are acquiring riverine habitat for personal use. Most riverine habitats are used for cultivation of crops which leads to physical disturbances of the riverbed. Construction activities were reported at some of sampling stations like site I (Sarawad) and site II (Walwe) as construction of temples, wells, washing places etc. along the side of the riverine bed (Figure 12, image i).

Ganesh idols immersed and holy or religious waste (*nirmalya*)

Religious activities have a significant negative impact on riverine water. Large-scale, enthusiastic celebrations are held for annual religious events like *Durga Puja* and the Ganesh festival. Following the festivities, the idols of Durga Devi and Ganesh are submerged in river water, along with its *nirmalya* (Figure 12, images j–k). A result of these activities are certain non-biodegradable materials, such as plaster of Paris idols, plastics, oils, decorative items, suspended solids, paints with varnish, cement, lime, and other ingredients. These substances, both biodegradable and non-biodegradable, have the potential to lower the quality of riverine water, making it unsuitable for irrigation and human consumption. According to a few

Figure 12 | Anthropogenic activities reported in and around Dudhganga River. (a) Washing clothes, (b) washing animals, (c) washing vehicles, (d) bathing, (e) releasing and dumping drainage waste, (f) agricultural runoff in river water, (g) agricultural practices and drainage water, (h) bridge and construction activity, (i) encroachment on habitat, (j) immersion of Ganesh idol, (k) *nirmalya* waste, (l) slaughter waste.

researchers the idol immersion in water bodies during Ganesh festival and *Durga Puja* may degrade the water quality and grossly polluted the riverine habitat (Dhote & Dixit 2011; Bhat *et al.* 2012).

Slaughter waste

Slaughter waste like sheep or goat hairs, fowl feathers, blood and visceral waste from slaughter houses were directly or indirectly added to the riverine environment (Figure 12, image l). According to Elemile *et al.* (2019) the waste from slaughter houses may create substantial environmental and public health hazards including affecting the water quality. According to Gao *et al.* (2019), animal husbandry can significantly affect natural environmental resources.

Industrial waste

In this study, two sugar factories were located near Dudhganga River. One sugar factory was located at Farale near to Kalamwdi and another at Bidri. Neither factory was directly discharging effluents and other waste like bagasse, molasses, effluent, wastewater etc. that are generated from the industry. However, the wastewater from cooling towers, molasses and other chemical waste were indirectly added to the riverine basin. This waste may enhance the turbidity, reduce the oxygen level of riverine water, and ultimately alter the water quality. According to Rahim & Mostafa (2021) the waste generated from sugar industries contains toxic chemicals which mainly affect the fish, crops, and human health as well.

CONCLUSIONS

The study concluded that all physicochemical parameters are considerably increased from upstream sampling stations to downstream stations along the Dudhganga River.

- In seasonal analysis, higher values for pH (7.9 – 8.2), TDS (0.31 – 0.42 μs/cm), turbidity (0.12 – 0.14 NTU), DO (5.64 – 6.24 mg/l), nitrate (4.67 – 7.56 mg/l) and phosphate (0.98 – 1.78 mg/l) were reported in monsoon season.
- On the other hand, the water parameters temperature (24 – 25 °C), EC (44 – 54 μs/cm), alkalinity (40 – 66.67 mg/l) and hardness (6.67 – 12.67 mg/l) exhibited maximum concentrations during summer season.
- The Dudhganga River's WQI ranges from 14.90 to 24.26 at sampling sites I to VI. The status of WQI in the present study is categorized as excellent.
- However, the present values of WQI gradually increase from upstream to downstream. Therefore, this value indicates that water quality is leading towards a deterioration in the water quality status.
- Highest significant values of water parameters and human activities are cumulatively responsible for reducing the water quality of Dudhganga River. Moreover, this condition may have adverse impacts on flora, fauna and productivity of the riverine ecosystem.

On the basis of the results of the present study, the water quality of Dudhganga River is more or less contaminated and water is not suitable for human consumption or domestic use unless it is processed, and is also unsafe for inhabitant aquatic flora and fauna.

RECOMMENDATIONS

Finally, this study suggests that all point sources of contamination of the river should be lowered, and anthropogenic activities in and around the river minimized. On the other hand, proper and effective management practices and improvement of domestic, organic, and industrial wastes is required to lower the accumulation of pollutants in Dudhganga River. This study recommended that regular monitoring and further analysis is needed to know the current status of the river. Additionally, with the help of conservationists and policymakers, mitigation plans and threshold limits can be developed to improve the river water quality to safeguard the aquatic ecosystem and a healthy environment for future generations.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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