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ASSESSMENT OF THE PHYSICOCHEMICAL PROPERTIES OF THE HALDA RIVER, BANGLADESH

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Abstract: Water quality in any water body is dependent on its physicochemical properties, the knowledge of which is necessary to maintain the suitability of the environment for aquatic organisms. In Bangladesh, the Halda River, a valuable spawning ground for the Indian major carp species is currently believed to be under threat due to anthropogenic and environmental causes. To identify the physicochemical properties of this river, eleven physical and chemical parameters were under investigation for 24 months, from January, 2017 to December, 2018, at three selected stations on the river. The average and range values of the investigated parameters were: 27.70±1.25 °C and 22.52–30.77 °C for water temperature, 24.96±6.11 cm and 15.33–35.33 cm for transparency, 114.36±14.42 µS/cm and 54.67–162.17 µS/cm for electrical conductivity (EC), 50±10 ppm and 30–70 ppm for total dissolved solids (TDS), 7.46±0.14 and 7.1–7.7 for pH, 6.17±0.88 mg/L and 4.30–10.07 mg/L for dissolved oxygen (DO), 13.14±2.41 mg/L and 7.49–43.29 mg/L for free carbon dioxide (fCO_2), 7.71±1.15 mg/L and 4.41–11.62 mg/L for calcium (Ca^{++}), 32.76±5.17 mg/L and 17.83–46.33 mg/L for total hardness (TH), 47.10±12.47 mg/L and 36.17–55 mg/L for total alkalinity (TA), and 1.38±0.38 mg/L and 0.72–2.43 mg/L for biochemical oxygen demand (BOD_5). Significant positive relationships between transparency and EC ($r=0.78$, $P<0.01$), EC and TH ($r=0.96$, $P<0.001$), EC and TDS ($r=0.92$, $P<0.001$), EC and Ca^{++}($r=0.87$, $P<0.001$), TDS and TH ($r=0.86$, $P<0.001$), Ca^{++} and TH ($r=0.87$, $P<0.001$), and Ca^{++} and TDS ($r=0.86$, $P<0.001$) have been observed. Physicochemical properties indicated that the level of pollution of the Halda River water was low, which made it suitable for aquatic organisms and acceptable for domestic and agricultural purposes.

Keywords: physicochemical parameters, pollution, water quality, monthly and seasonal variation, Halda River

ОЦЕНКА ФИЗИКО-ХИМИЧЕСКИХ СВОЙСТВ РЕКИ ХАЛДА, БАНГЛАДЕШ

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Аннотация. Физико-химические свойства любого полезного водного объекта важно знать, чтобы поддерживать его экосистему в состоянии, благоприятном для жизни водных организмов. Состояние реки Халда в Бангладеш, которая является важным нерестилищем для основных видов индийских карпов, находится под угрозой из-за воздействия антропогенных и экологических факторов. Для определения текущего состояния качества воды реки Халда на трех выбранных станциях были исследованы 12 физико-химических параметров за 24-месячный период с января 2017 по декабрь 2018 г. Средние и интервальные значения исследованных параметров были следующими: температура воды — 27,70±1,25 (22,52–30,77) °C, прозрачность — 24,96±6,11 (15,33–35,33) см, электропроводность (EC) — 114,36±14,42 (54,67–162,17) мкСм/см, общее количество растворенных твердых веществ (TDS) — 50±10 (30–70) частей на миллион, pH — 7,46±0,14 (7,1–7,7), растворенный кислород (DO) — 6,17±0,88 (4,30–10,07) мг/л, свободный диоксид углерода (fCO_2) — 13,14±2,41 (7,49–43,29) мг/л, кальций (Ca^{++}) — 7,71±1,15 (4,41–11,62) мг/л, общая жесткость (TH) — 32,76±5,17 (17,83–46,33) мг/л, общая щелочность (TA) — 47,10±12,47 (36,17–55) мг/л и биохимическая потребность в кислороде (BOD_5) — 1,38±0,38 (0,72–2,43) мг/л. Значимая положительная зависимость наблюдалась между температурой воздуха и температурой воды ($r=0,87$, $P<0,001$), прозрачностью и электропроводностью ($r=0,78$, $P<0,01$), электропроводностью и общей жесткостью ($r=0,96$, $P<0,001$), электропроводностью и общим количеством растворенных твердых веществ ($r=0,92$, $P<0,001$), электропроводностью и кальцием ($r=0,87$, $P<0,001$), общим количеством растворенных твердых веществ и общей жесткостью ($r=0,86$, $P<0,001$), кальцием и общей жесткостью ($r=0,87$, $P<0,001$) и кальцием и общим количеством растворенных твердых веществ ($r=0,86$, $P<0,001$). Физико-химические свойства указывают на то, что уровень загрязнения воды в р. Халда низкий, благодаря чему она пригодна для обитания водных организмов и может использоваться в бытовых и сельскохозяйственных целях.

Ключевые слова: физико-химические параметры, загрязнение, качество воды, месячные и сезонные колебания, река Халда

INTRODUCTION

The tidal River Halda, located in the southeastern region of Bangladesh, is well known as an important natural spawning ground of the Indian major carp species [1]. Eighty-three species of finfish and ten species of shellfish inhabit this river [2]. From prehistoric times, river waters are used for transport, agriculture and drinking purposes, as well as in drainage systems. With the advent of time, industrial development, modern agriculture, and urbanization led to the production of large amounts of solid and liquid pollutants, which are discharged into the rivers. Thus, most of the rivers of this planet face environmental issues threatening the lives of fish and other aquatic organisms inhabiting them. The water quality and productivity of aquatic ecosystems are critically dependent on the influence of various physical and chemical factors. Fish survival, diversity, and growth can be affected by the abnormal physical, chemical, and biological properties of water [3]. Pollution directly affects the quality of river waters, which may harm aquatic organisms and render the water unfit for agricultural and domestic uses. Polluted water is the source of diseases, has an adverse effect on the soil, and is also unable to sustain life [4]. Due to inherent health risk, contaminated and polluted water is unsuitable for drinking, as well as for domestic and sometimes even agricultural purposes [5]. It is believed that the Halda River is currently adversely affected by the discharge of poultry industrial waters, household wastes from the local Upazila towns (Fatikchari, Nazirhat, Raozan, and Hathazari), crop field agrochemicals, industrial effluents from Chittagong Asia Paper Mill, oil wastes from Beijing Power Plant, and some industrial

pollutants of town area entering the river through various canals [1]. Beside that, alteration of the Halda River habitat is also done by the construction of sluice gates, rubber dam, weir dam for increasing crop production and loop cutting for controlling severe river bank erosion [6]. It is essential to know the physicochemical properties of the Halda River water to protect the aquatic environment and manage its quality in order to sustain proper carp spawning and keep the water safe for drinking after its adequate treatment and also for using in irrigation, for household and other purposes. Earlier, a few notable research works covering some parts of the River Halda were done on the limnology of the surface water [1, 7–13], but long-term study covering the entire river has not yet been conducted. A very recent study by Islam et al. [1] only covered the suitability of the water for drinking purposes. So, the present study was being carried out for two years to determine the water quality of the entire river covering all fishing, spawning, and navigable areas and to identify the effect of water quality on fish and other aquatic organisms. These findings might be helpful to fishery biologists, environmentalists, planners, and decision-makers for taking mitigation measures to minimize water pollution if so required and increasing public awareness; among other things, they could also facilitate maintaining the quality of water required for proper carp spawning and sustain the environment for other aquatic organisms.

MATERIALS AND METHODS

Sampling site

The Halda River, one of the important tributaries of the tidal River Karnaphuli, originates in the Batnatali Hill Ranges in the Chattogram Hill Tracts and enters Chattogram District. After traversing 88 km, the river finally meets the River Karnaphuli (270 km long) at Mohara point, one kilometer north of Kalurghat Bridge. Physicochemical properties of the Halda River were investigated at three sampling stations selected from upstream to downstream at a reasonable distance from each other—namely, Station-1 (upstream at Nazirhat), Station-2 (mid-stream at Satterghat), and Station-3 (downstream at Modunaghat), which covered the entire fishing (40 km) and carp spawning (15 km) area of the Halda River (Table 1, Fig. 1).

Sample collection and analysis

Eleven physicochemical parameters (water temperature, transparency, TDS, EC, pH, DO, free CO_2, Ca^{++}, total hardness, total alkalinity, and BOD_5) were analyzed using sub-surface water samples collected in nine 250 ml and six 500 ml amber glass bottles at three sampling stations during the time range from 9.00 am to 11.00 am at regular monthly intervals for two years [14]. Table 2 shows the methods of analysis of water characteristics. MS Excel 2013 was used for statistical analysis and graphical representation of the data.

RESULTS AND DISCUSSION

Water temperature

Water temperature is one of the most important factors in the aquatic environment since it influences both physicochemical and biological processes [15]. During two-year investigation period, the lowest average value of water temperature (21.9 °C) was recorded in January at Station-3, while the highest (31.4 °C) was observed in May at Station-1 and in August at Station-2 (Tables 3–5). In the Halda River, the total average value of water temperature was the lowest (22.52±1.11 °C) in December and the highest (30.77±2.54 °C) in May (Fig. 2A). An almost similar pattern of water temperature was recorded in the Halda River in 1977–1978 (about four decades ago) by Patra and Azadi [9, 10], and the same pattern of it was observed in the Buriganga River in recent years [16, 17]. The average seasonal value of water temperature was the lowest (23.77±3.25 °C) in the winter season at Station-3, whereas the highest one (30.40±2.63 °C) fell on the monsoon season and was observed at Station-1 (Fig. 3A). In the Halda River, the total average seasonal value of water temperature was lowest (24.46±3.20 °C) during the winter season and highest (29.88±1.11 °C) during the monsoon season (Table 6). These findings more or less coincide with the data collected in other rivers [18–20]. The present result was found to be within the permissible limit of water temperature recommended by Bhumik et al. [21]. The variation in water temperature could also be related to the temperature of atmosphere and weather conditions.

Transparency

Transparency is an important parameter for water quality monitoring. The lowest transparency (12.5 cm) was recorded in July at Station-2 and the highest transparency (44.5 cm) was recorded in December at Station-1 (Tables 3, 4). In the Halda River, the total average value of water transparency was lowest (15.33±1.41 cm) in July and highest (35.33±0.47 cm) in December (Fig. 2B). More or less similar pattern

Table 1. Sampling sites, sample code, geographical location and assessment for three stations

Таблица 1. Участки отбора проб, код выборки, географическое положение и оценка трех станций

Sampling station Станция отбора проб	Sampling code Код выборки	Distance Расстояние	Latitude Широта	Longitude Долгота	Assessment Оценка
Nazirhat Назирхат	Station-1 Станция-1	20 km from Station-2 20 км от Станции-2	22°37'59.38"N	91°47'32.71"E	No significant pollution sources except agricultural lands Без существенных источников загрязнения, кроме земель с/х назначения
Satterghat Саттергхат	Station-2 Станция-2	20 km from Station-3 20 км от Станции-3	22°30'48.05"N	91°50'45.60"E	No significant pollution sources except agricultural lands Без существенных источников загрязнения, кроме земель с/х назначения
Modunaghat Модунагхат	Station-3 Станция-3	5 km from the Halda River mouth 5 км от устья р. Халда	22°26'2.55"N	91°52'16.82"E	Direct discharge of industrial effluents through various canals/tributaries Непосредственный слив промышленных сточных вод через различные каналы/притоки

of fluctuations was observed by other authors [9, 20]. The low transparency is the result of heavy influx of sediments, silts, debris, organic and inorganic suspended particles during the monsoon month (July). The average seasonal value of water transparency was lowest (18.50±2.54 cm) during the post-monsoon season at Station-2 and highest (39.67±5.02 cm) during the winter season at Station-1 (Fig. 3B). In the Halda River, the total average seasonal value of water transparency was lowest (19.56±1.51 cm) during the post-monsoon season and highest (30.89±4.50 cm) during the winter season (Table 6). These findings showed similarities with the results obtained by Patra and Azadi [8]. The present study found transparency to be within the permissible limit as reported by Rahman [22]. Transparency showed a significant positive relationship with EC ($r=0.78$, $P<0.01$), TDS ($r=0.67$, $P<0.05$), and TH ($r=0.66$, $P<0.05$) (Table 7).

Electrical conductivity (EC)

Electrical conductivity is the water capability to transmit electric current and serves as a tool to assess the purity of water [23]. The lowest average value of EC (42 µS/cm) was recorded at Station-1 in July and the highest one (179 µS/cm) was observed at the same station in March (Table 3). In the Halda River, the total average value of EC was lowest (54.67±12.26 µS/cm) in July and highest (162.17±4.48 µS/cm) in March (Fig. 2C). It showed close similarities with the findings of different authors [9, 24]. The average seasonal value of EC was lowest (70.83±29.90 µS/cm) during the monsoon season at Station-2 and highest (155.17±26.11 µS/cm) during the pre-monsoon season at the same station (Fig. 3C). In the Halda River, the total average seasonal value of EC was lowest (78±22.40 µS/cm) during the monsoon season and

Fig. 1. Outline map of the River Halda showing three sampling stations (big round yellow mark), namely Halda St-1 (Nazirhat), Halda St-2 (Satterghat), and Halda St-3 (Modunaghat) [12]

Рис. 1. Карта-схема р. Халда с тремя станциями отбора проб (большая круглая желтая метка), i. e. Халда Ст-1 (Назирхат), Халда Ст-2 (Саттергхат) и Халда Ст-3 (Модунгхат) [12]

Table 2. Methods of analysis used for different physicochemical parameters of the Halda River water
Таблица 2. Методы анализа различных физико-химических параметров воды реки Халда

Parameters Параметры		Equipment & methods of analysis Оборудование и методы анализа	Measured Измерено
Physical Физические	Water temperature (°C) Температура воды (°C)	Mercury thermometer (Taylor Rochester, NY, USA) Ртутный термометр (Taylor Rochester, Нью-Йорк, США)	At the sampling stations На станциях отбора проб
	Transparency (cm) Прозрачность (см)	Secchi disc (20 cm diameter) Диск Секки (20 см диаметром)	
	EC (μS/cm) Электропроводность (мкСм/см)	EC meter (EC 4DIGIT, HM Digital, China) Измеритель электропроводности воды (EC 4DIGIT, HM Digital, Китай)	
	TDS (ppm) Общее количество растворенных твердых веществ (частей на миллион)	Digital TDS meter (Dist. 2, HANNA Instruments, Italy) Электронный измеритель минерализации воды (Dist. 2, HANNA Instruments, Италия)	
Chemical Химические	pH	pH meter (pHep HANNA Instruments, Italy) Измеритель щелочности воды (pHep HANNA Instruments, Италия)	
	DO (mg/L) Растворенный кислород (мг/л)	Azide modification of iodometric method [14] Модификация йодометрического метода с применением азида [14]	In the laboratory within 6 hours В лаборатории не позднее 6 часов с момента взятия
	Free CO_2 (mg/L) Свободный CO_2 (мг/л)	Titrimetric method using 0.0454N sodium carbonate as titrant [14] Титриметрический метод с применением карбоната натрия 0,0454N в качестве титранта [14]	
	Calcium (mg/L) Кальций (мг/л)	EDTA titrimetric method [14] Титриметрический метод с применением ЭДТА [14]	
	Total hardness (mg/L) Общая жесткость (мг/л)	EDTA titrimetric method [14] Титриметрический метод с применением ЭДТА [14]	
	Total alkalinity (mg/L) Общая щелочность (мг/л)	Titrimetric method using standard H_2SO_4 as titrant [14] Титриметрический метод с применением стандартной H_2SO_4 в качестве титранта [14]	
	BOD_5 (mg/L) $БПК_5$ (мг/л)	Analysed after 5-day incubation period [14] Проанализировано после пятидневного инкубационного периода [14]	

highest (147.61±23.22 μS/cm) during the pre-monsoon season (Table 6). The lowest EC could result from the dilution of effluents during the monsoon season; it increases in water current densities. The highest EC values may have been caused by the leaching of minerals from agricultural fertilizers, drainage of mixed waste waters from various urban facilities into the river along with effluents from adjoining industries and sewage waters during the pre-monsoon season. This result was compliant with the findings of different authors for various water bodies [16, 17, 19, 25]. In the present study, electrical conductivity was found to be below the permissible limit of 350 μS/cm [26]. Electrical conductivity showed a significant positive

Table 3. Average values of different physicochemical parameters at the Station-1 on the Halda River from January, 2017 to December, 2018

Таблица 3. Средние значения различных физико-химических параметров Станции-1 на р. Халда с января 2017 по декабрь 2018 г.

Parameters Параметры	January Январь	February Февраль	March Март	April Апрель	May Май	June Июнь	July Июль	August Август	September Сентябрь	October Октябрь	November Ноябрь	December Декабрь
Water temperature (°C) Температура воды (°C)	23	25.75	27.55	29	31.4	31.1	28.7	30.2	29.25	26.25	28	22.55
Transparency (cm) Прозрачность (см)	39	30	29.5	25.5	28.5	23	19	16	17	23	35.5	44.5
EC (µS/cm) Электропроводность (мкСм/см)	151	159.5	179	105	90.5	80.5	42	71.5	79	78	119	152.5
TDS (ppm) Общее количество растворенных твердых веществ (частей на миллион)	60	75	75	40	40	40	30	25	25	30	50	65
pH	7.5	7.4	7.2	7.0	7.2	7.1	7.3	7.3	7.5	7.6	7.7	7.4
DO (mg/L) Растворенный кислород (мг/л)	12.2	5.35	8.05	6.05	5.95	5.4	5.7	5.55	5.85	7.05	9.5	7.5
fCO_2 (mg/L) Свободный CO_2 (мг/л)	12.98	6.49	9.49	13.98	11.49	10.99	39.45	7.49	11.49	8.99	8.49	7.99
Calcium (mg/L) Кальций (мг/л)	11.70	10.42	10.82	6.41	5.61	4.81	7.62	4.81	5.61	4.41	11.22	9.21
Total hardness (mg/L) Общая жесткость (мг/л)	37	46.5	42.5	27	25.5	20.5	14.5	27.5	31.5	26	39.5	43
Total alkalinity (mg/L) Общая щелочность (мг/л)	50	50	47.5	49	54	42	52.5	56	37	49	43.5	50
BOD_5 (mg/L) $БПК_5$ (мг/л)	2.4	1.7	3.9	1.7	1.95	0.7	0.95	1.5	0.8	0.85	0.5	2.6

Table 4. Average values of different physicochemical parameters at the Station-2 on the Halda River from January, 2017 to December, 2018

Таблица 4. Средние значения различных физико-химических параметров Станции-2 на р. Халда с января 2017 по декабрь 2018 г.

Parameters Параметры	January Январь	February Февраль	March Март	April Апрель	May Май	June Июнь	July Июль	August Август	September Сентябрь	October Октябрь	November Ноябрь	December Декабрь
Water temperature (°C) Температура воды (°C)	23.2	25.85	27.7	30.5	31.1	30.45	28.75	31.4	29.75	27.65	29	23.05
Transparency (cm) Прозрачность (см)	27	35	22	24.5	28	24	12.5	18.5	21	16	23	34
EC (µS/cm) Электропроводность (мкСм/см)	163	174	166	125.5	97.5	70.5	44.5	75	79.5	92.5	127.5	164.5
TDS (ppm) Общее количество растворенных твердых веществ (частей на миллион)	60	80	80	50	50	30	35	25	30	35	55	65
pH	7.5	7.4	7.4	7.1	7.1	7.6	7.3	7.4	7.6	7.8	7.7	7.8
DO (mg/L) Растворенный кислород (мг/л)	9.8	5.75	9.35	5.3	4.15	5.25	4.35	4.85	4.75	7.25	7.5	7.25
fCO_2 (mg/L) Свободный CO_2 (мг/л)	10.99	9.49	10.49	14.98	11.98	11.49	49.46	7.99	7.49	9.99	8.49	7.49
Calcium (mg/L) Кальций (мг/л)	11.51	12.02	11.22	6.81	5.21	4.01	4.01	4.01	5.61	5.21	10.42	10.01
Total hardness (mg/L) Общая жесткость (мг/л)	44	53	47.5	30.5	23.5	20.5	15.5	26	22	27	42	42
Total alkalinity (mg/L) Общая щелочность (мг/л)	43.5	41.5	49	43.5	54.5	40	44.5	50.5	38	36.5	43	46.5
BOD_5 (mg/L) $БПК_5$ (мг/л)	1	1.6	1.2	1.15	1.7	0.85	1.2	0.2	0.55	2.05	0.85	1.15

Table 5. Average values of different physicochemical parameters at the Station-3 on the Halda River from January, 2017 to December, 2018

Таблица 5. Средние значения различных физико-химических параметров Станции-3 на р. Халда с января 2017 по декабрь 2018 г.

Parameters Параметры	January Январь	February Февраль	March Март	April Апрель	May Май	June Июнь	July Июль	August Август	September Сентябрь	October Октябрь	November Ноябрь	December Декабрь
Water temperature (°C) Температура воды (°C)	21.9	24.9	26.85	27.55	29.8	29.2	28.45	30.2	29.05	28.8	27.45	21.95
Transparency (cm) Прозрачность (см)	27	25.5	29.5	21.5	31.5	20.5	14.5	27.5	22.5	14.5	20.5	27.5
EC (μS/cm) Электропроводность (мкСм/см)	129	146	141.5	132	110	89	77.5	111.5	86	107.5	140	159.5
TDS (ppm) Общее количество растворенных твердых веществ (частей на миллион)	50	55	65	55	40	35	45	45	30	35	60	55
pH	7.7	7.6	7.4	7.5	7.6	7.8	7.5	7.5	7.7	7.8	7.8	7.8
DO (mg/L) Растворенный кислород (мг/л)	8.2	5.05	7	3.65	4.85	4.4	2.85	4	4.15	5.25	6.65	6.2
fCO_2 (mg/L) Свободный CO_2 (мг/л)	11.99	8.99	10.99	16.48	11.99	14.48	40.95	10.49	7.99	10.99	10.99	6.99
Calcium (mg/L) Кальций (мг/л)	11.20	12.42	10.02	8.42	7.21	4.41	5.61	4.41	6.01	6.41	10.02	8.80
Total hardness (mg/L) Общая жесткость (мг/л)	40	39.5	40	40	32	23	23.5	26.5	27	31	41.5	41
Total alkalinity (mg/L) Общая щелочность (мг/л)	43.5	57	52.5	44	56.5	48	56.5	51.5	33.5	42.5	42.5	56
BOD_5 (mg/L) $БПК_5$ (мг/л)	1.1	1.6	2.2	0.95	2.35	1	1.3	1.55	0.8	0.9	1.2	1.55

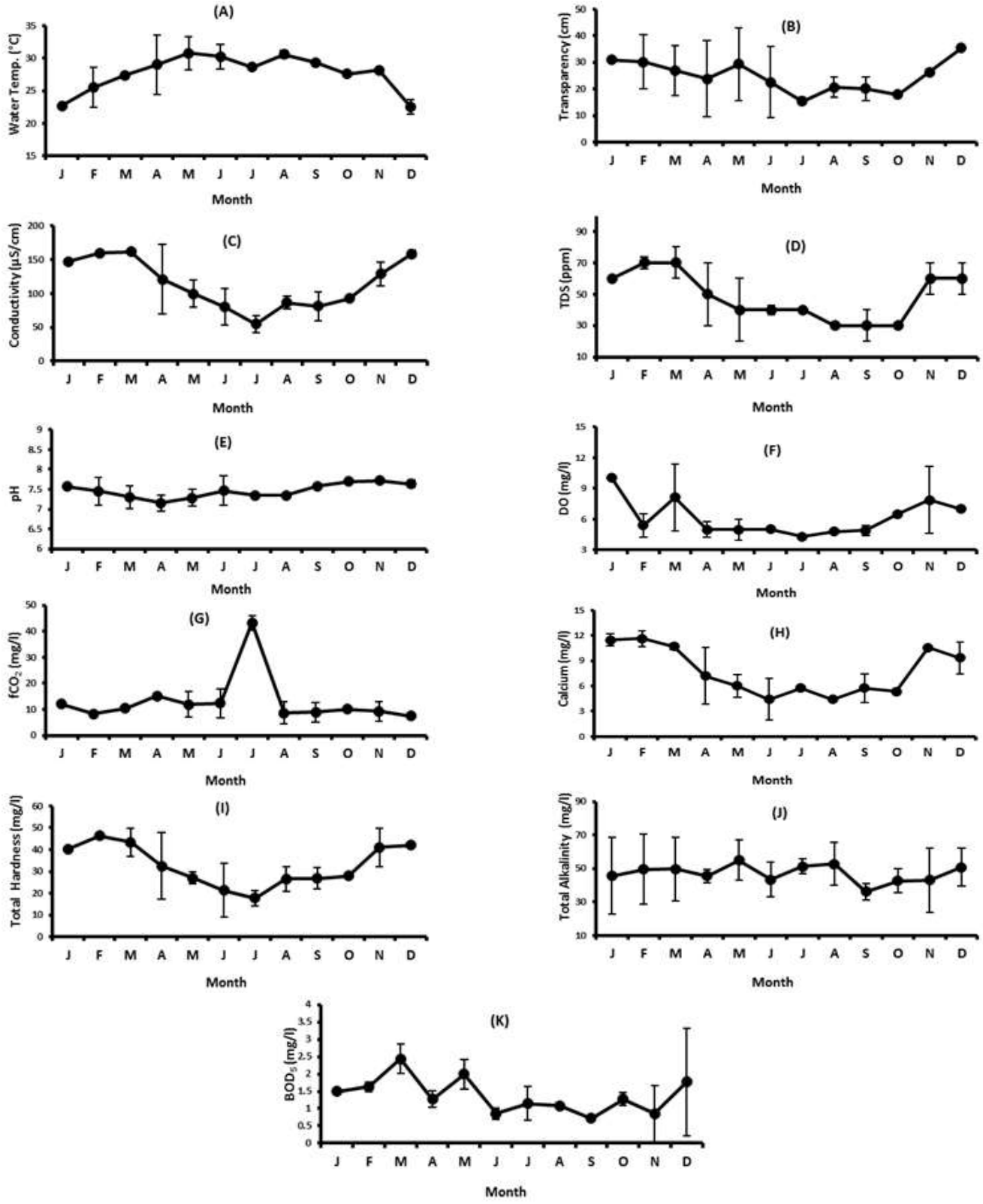

Fig. 2. Monthly variation of the average values (±SD) of various physicochemical parameters—(A) water temperature, (B) transparency, (C) electrical conductivity, (D) TDS, (E) pH, (F) DO, (G) fCO_2, (H) calcium, (I) total hardness, (J) total alkalinity, (K) BOD_5—in the Halda River for the time range from January, 2017 to December, 2018

Рис. 2. Месячное изменение средних значений (±стандартное отклонение) различных физико-химических параметров: (A) температура воды, (B) прозрачность, (C) электропроводность, (D) общее количество растворенных твердых веществ, (E) pH, (F) растворенный кислород, (G) свободный CO_2, (H) кальций, (I) общая жесткость, (J) общая щелочность, (K) $БПК_5$, — в р. Халда с января 2017 по декабрь 2018 г.

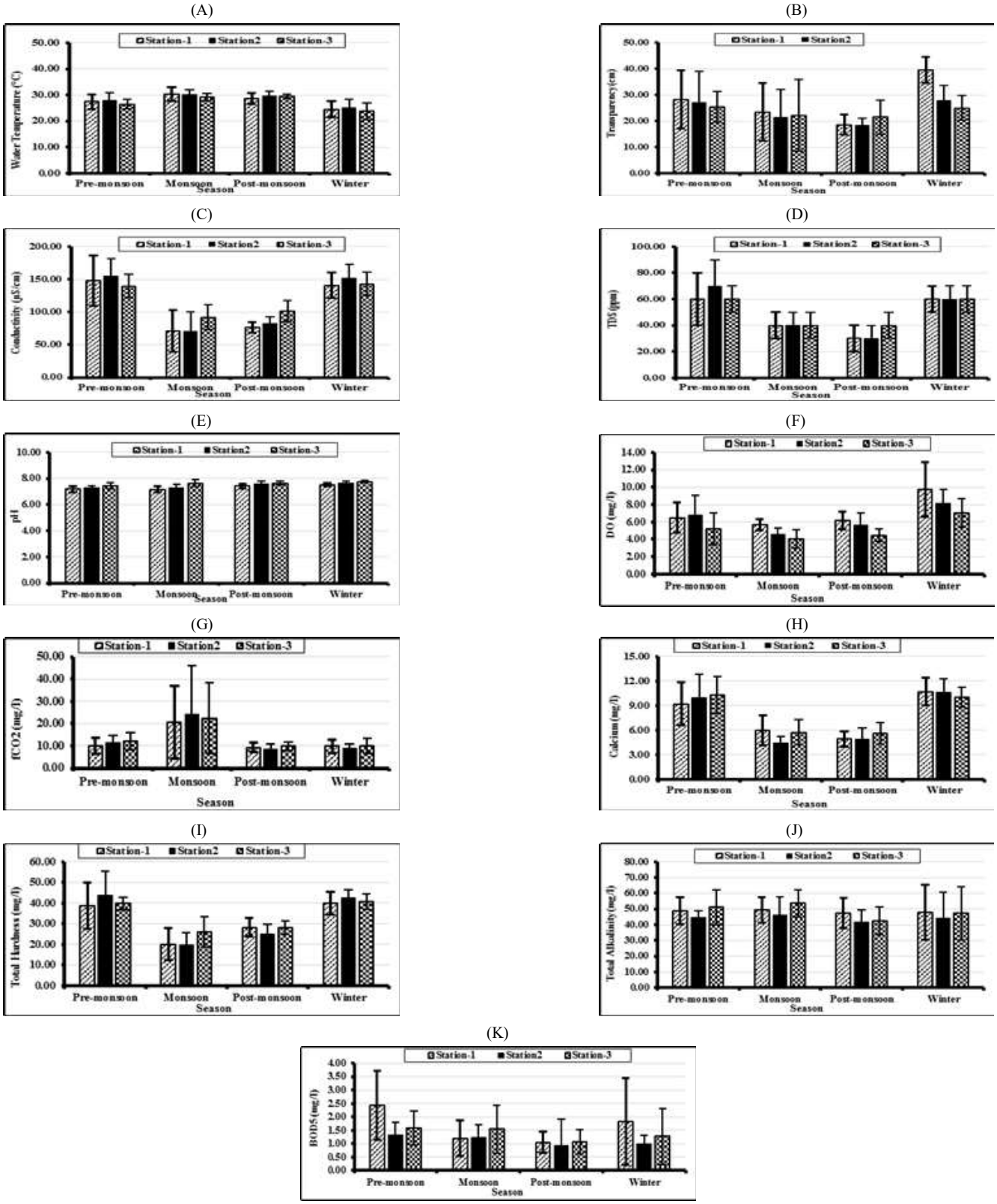

Fig. 3. Seasonal variation of the average values (±SD) of various physicochemical parameters—(A) water temperature, (B) transparency, (C) electrical conductivity, (D) TDS, (E) pH, (F) DO, (G) fCO_2, (H) calcium, (I) total hardness, (J) total alkalinity, (K) BOD_5—in the Halda River for the time range from January, 2017 to December, 2018

Рис. 3. Сезонное изменение средних значений (±стандартное отклонение) различных физико-химических параметров: (A) температура воды, (B) прозрачность, (C) электропроводность, (D) общее количество растворенных твердых веществ, (E) pH, (F) растворенный кислород, (G) свободный CO_2, (H) кальций, (I) общая жесткость, (J) общая щелочность, (K) $БПК_5$, — в р. Халда с января 2017 по декабрь 2018 г.

Table 6. Total seasonal variation of various physicochemical parameters in the Halda River from January, 2017 to December, 2018

Таблица 6. Общее сезонное изменение различных физико-химических параметров в р. Халда с января 2017 по декабрь 2018 г.

Parameters Параметры	Pre-monsoon (February–April) Предмуссонный (февраль–апрель)	Monsoon (May–July) Муссонный (май–июль)	Post-monsoon (August–October) Послемуссонный (август–октябрь)	Winter (November–January) Зимний (ноябрь–январь)
Water temperature (°C) Температура (°C)	27.29±1.76	29.88±1.11	29.17±1.52	24.46±3.20
Transparency (cm) Прозрачность (см)	27±3.17	22.39±7.00	19.56±1.51	30.89±4.50
Conductivity (μS/cm) Электропроводность (мкС/см)	147.61±23.22	78±22.40	86.72±5.62	145.11±15.15
TDS (ppm) Общее количество растворенных твердых веществ (частей на миллион)	60±10	40±0.00	30±0.00	60±0.00
pH	7.30±0.15	7.37±0.09	7.54±0.18	7.64±0.07
DO (mg/L) Растворенный кислород (мг/л)	6.17±1.71	4.77±0.40	5.41±0.96	8.31±1.59
fCO_2 (mg/L) Свободный CO_2 (мг/л)	11.26±3.51	22.47±18.03	9.21±0.69	9.60±2.26
Ca^{++} (mg/L) Ca^{++} (мг/л)	9.84±2.32	5.39±0.86	5.17±0.69	10.45±1.07
TH (mg/L) Общая жесткость (мг/л)	40.72±7.28	22.06±4.63	27.17±0.73	41.11±0.84
TA (mg/L) Общая щелочность (мг/л)	48.22±2.36	49.83±5.95	43.83±8.31	46.50±3.98
BOD_5 (mg/L) $БПК_5$ (мг/л)	1.78±0.60	1.33±0.60	1.02±0.28	1.37±0.47

relationship with TH (r=0.96, P<0.001), TDS (r=0.92, P<0.001), Ca^{++} (r=0.87, P<0.001), and transparency (r=0.78, P<0.01) (Table 7).

Total dissolved solids (TDS)

TDS is the direct measurement of dissolved particles in the water sample. The lowest average value of TDS (25 ppm) was recorded at Stations 1 and 2 in August and September, and the highest value of TDS (80 ppm) was recorded at Station-2 in February and March (Tables 3, 4). In the Halda River, the total average value of TDS was lowest (30±10 ppm) in September and highest (70±10 ppm) in March (Fig. 2D). The average seasonal value of TDS was lowest (30± 10 ppm) during the post-monsoon season at Stations 1 and 2 and highest (70±20 ppm) during the pre-monsoon season at Station-2 (Fig. 3D). In the Halda River, the total average seasonal value of TDS was lowest (30±0.00 ppm) during the post-monsoon season

Table 7. Correlation between various physicochemical parameters in the Halda River for the time range from January, 2017 to December, 2018

Таблица 7. Корреляция между различными физико-химическими параметрами р. Халда с января 2017 по декабрь 2018 г.

Parameters	Water temperature Температура воды	Transparency Прозрачность	EC Электропроводность	pH	DO Растворенный кислород	fCO_2 Свободный CO_2	Ca^{++}	TDS Общее кол-во растворенных твердых веществ	TH Общая жесткость	TA Общая щелочность	BOD_5 $БПК_5$
1	2	3	4	5	6	7	8	9	10	11	12
Water temperature Температура воды	1	-0.16	-0.51	-0.34	-0.56	0.15	-0.58	0.43	-0.46	-0.05	-0.13
Transparency Прозрачность		1	0.78**	-0.11	0.41	-0.38	0.55	0.67*	0.66*	0.20	-0.42
EC Электропроводность			1	-0.28	0.53	-0.51	0.87***	0.92***	0.96***	-0.30	0.54
pH				1	0.34	-0.31	-0.27	-0.38	-0.26	-0.41	-0.28
DO Растворенный кислород					1	-0.26	0.60*	0.42	0.44	-0.23	0.10
fCO_2 Свободный CO_2						1	-0.22	0.27	-0.50	-0.19	-0.13
Ca^{++}							1	0.86***	0.87***	-0.16	0.33
TDS Общее количество растворенных твердых веществ								1	0.86***	0.32	0.52

Table 7 (finished)

Таблица 7 (окончание)

1	2	3	4	5	6	7	8	9	10	11	12
TH Общая жесткость									1	-0.26	0.50
TA Общая щелочность										1	-0.47
BOD_5 $БПК_5$											1

Note: Level of significance — ***=P<0.001, **=P<0.01, *=P<0.05

Примечание: Уровень значимости — ***=P<0,001, **=P<0,01, *=P<0,05

and highest (60±10 ppm) during the pre-monsoon and winter seasons (Table 6). These findings showed close similarities with the observations in the Buriganga and Dhaleshwari Rivers [17, 24]. With the increasing temperature during the pre-monsoon season, organic matter undergoes the process of mineralization faster, which leads to the increase in the TDS values.

In the present study, TDS was found to be far below the standard limit of 1000 ppm [27]. TDS showed a significant positive relationship with EC ($r=0.92$, $P<0.001$), TH ($r=0.86$, $P<0.001$), Ca^{++} ($r=0.86$, $P<0.001$), and transparency ($r=0.67$, $P<0.05$) (Table 7).

pH

pH is the measure of the intensity of acidity or alkalinity and the concentration of H^+ ions in water. The lowest average value of pH (7.0) was recorded at Station-1 in April and the highest one (7.8) at Station-2 in October and December and at Station-3 in June, October to December (Tables 3–5). In the Halda River, the total average value of pH was lowest (7.1±0.21) in April and highest (7.7±0.02) in November (Fig. 2E). This pattern showed similarities with the records of Islam et al. on the Padma River [20]. The average seasonal value of pH was lowest (7.2±0.23) during the monsoon season at Station-1 and highest (7.7±0.10) during the winter season at Station-3 (Fig. 3E). In the Halda River, the total average seasonal value of pH was lowest (7.30±0.15) during the pre-monsoon season and highest (7.64±0.07) during the winter season (Table 6). This result closely coincided with the findings of different authors [9, 24, 28]. The high pH value may result from the increased influx of bicarbonates and carbonates of calcium and magnesium from waste waters, coming mainly from urban and industrial facilities. However, the lower value of pH during the pre-monsoon season can be attributed to the accumulation of free CO_2 and higher respiration of organisms at higher temperature. The pH value identified by the present study was found to be within the permissible limit (6.6–8.5) of pH [26, 27, 29]. The water of the Halda River ranges from slightly acidic to alkaline and is suitable for the sustaining of fish and other aquatic organisms (Table 7).

Dissolved oxygen (DO)

The lowest average value of DO (2.8 mg/L) was recorded at Station-3 in July and the highest one (12.2 mg/L) was at Station-1 in January (Tables 3, 5). In the Halda River, the total average value of DO was lowest (4.30±0.28 mg/L) in July and highest (10.07±0.00 mg/L) in January (Fig. 2F). These data showed close similarities with the findings of other authors [20, 30]. The possible reason of the decreased values of DO (2.8 mg/L) might be the decomposed matter and other effluents carried by heavy flood runoff at the Station-3 area in July, which is also the furthest one downstreams and thus becomes a mixing zone for all upstream discharges and various waste waters coming to the river from a range of sources through different feeds. The average seasonal value of DO was lowest (4.03±1.05 mg/L) during the monsoon season at Station-3 and highest (9.73±3.13 mg/L) during the winter season at Station-1 (Fig. 3F). In the Halda River, the total average seasonal value of DO was lowest (4.77±0.40 mg/L) during the monsoon season and highest (8.31±1.59 mg/L) during the winter season (Table 6). The higher value indicative of the winter season may be caused by the low surface water temperature and atmospheric temperature. Cold water has a high capability for holding oxygen. The lowest value of DO could be associated with the direct discharge of municipal sewage and industrial effluents containing organic matter through the different tributaries of the Halda River during the monsoon season. Therefore, consequent biodegradation of organic matter and decay of vegetation at higher temperature leads to consumption of oxygen from water. The results of the present study were very close to the data collected by the other authors [9, 13, 20]. The standard value of DO for a water body capable of sustaining aquatic organisms is 5 mg/L [26, 27, 29]. The DO level in the Halda River was found to be suitable for all aquatic organisms. DO showed a positive relationship with Ca^{++} ($r=0.60$, $P<0.05$) (Table 7). A similar significant positive relationship for the Halda River was also reported by [9]. It could be attributed to the seasonal circulation of calcium in the water.

Free CO_2 (fCO_2)

Free CO_2 is an important chemical indicator of water pollution. The lowest average value of fCO_2 (6.49 mg/L) was recorded at Station-1 in February and the highest one (49.46 mg/L) was observed at Station-2 in July (Tables 3, 4). In the Halda River, the total average value of fCO_2 was lowest (7.49±0.71 mg/L) in December and highest (43.29±2.83 mg/L) in July (Fig. 2G). The average seasonal value of fCO_2 was lowest (8.49±2.47 mg/L) during the post-monsoon season at Station-2 and highest (24.31±21.79 mg/L) during the monsoon season at Station-2 (Fig. 3G). In the Halda River, the total average seasonal value of fCO_2 was lowest (9.21±0.69 mg/L) during the post-

monsoon season and highest (22.47±18.03 mg/L) during the monsoon season (Table 6). The results of the present study were more or less similar to the findings of the other authors [9, 28]. Boyd (1982) suggested that free CO_2 between 5–10 mg/L is good for fish health and fish culture [31]. The free CO_2 level in the Halda River was found to be within the acceptable limit with the exception of a sudden devastating flood which occurred during the monsoon season in July, 2018, covered the both banks of the river and continued for about 10 days, which led to decomposition of all the wild plants and cultivated crops. Thus, a large amount of organic matter was decomposed, which resulted in the production of a high amount of fCO_2 in the Halda River during the monsoon month of July only.

Calcium (Ca^{++})

The lowest average value of calcium (4.01 mg/L) was recorded at Station-2 in June to August and the highest amount (12.42 mg/L) was found at Station-3 in February (Tables 4, 5). In the Halda River, the total average value of Ca^{++} was at its lowest (4.41± 0.19 mg/L) in June and August and highest (11.62± 0.94 mg/L) in February (Fig. 2H). These results aligned with the findings of Patra and Azadi for the Halda River [9, 13]. The average seasonal value of calcium was lowest (4.41±0.80 mg/L) during the monsoon season at Station-2 and highest (10.71± 1.71 mg/L) during the winter season at Station-1 (Fig. 3H). In the Halda River, the total average seasonal value of calcium was at its lowest (5.17± 0.69 mg/L) during the post-monsoon season and at its highest (10.45±1.07 mg/L) during the winter season (Table 6). Similar findings were also recorded in the Halda River by Patra and Azadi and Azadi et al. [8, 13]. Calcium concentration in the Halda River was found to be below the standard level of 36 mg/L [26]. Calcium showed a significant positive relationship with TH ($r=0.87$, $P<0.001$), EC ($r=0.87$, $P<0.001$), DO ($r=0.60$, $P<0.05$), and TDS ($r=0.86$, $P<0.001$) (Table 7).

Total hardness (TH)

Average monthly fluctuations of TH are shown in Fig. 2I. The lowest average value of total hardness (14.5 mg/L) was recorded at Station-1 in July and the highest one (53 mg/L) was observed at Station-2 in February (Tables 3, 4). In the Halda River, the total average value of TH was lowest (17.83±3.54 mg/L) in July and highest (46.33±0.00 mg/L) in February (Fig. 2I). Similar data were also recorded in the Nabaganga River [28]. The average seasonal value of total hardness was lowest (19.83±5.80 mg/L) at Station-2 during the monsoon season and highest (43.67±11.84 mg/L) at Station-2 during the pre-monsoon season (Fig. 3I). In the Halda River, the total average seasonal value of total hardness was at its lowest (22.06±4.63 mg/L) during the monsoon season and highest (41.11±0.84 mg/L) during the pre-monsoon season (Table 6). These findings were more or less compliant with the results obtained by the other authors [20, 25, 32]. Total hardness is found to be minimal during the monsoon season, which may be due to dilution factor and the process in which some of the half-bound carbon (HCO_3) gets channelized into its bound form (CO_3), thus resulting in low bicarbonate values. The highest value of TH during the pre-monsoon season can be attributed to a decrease in water volume and an increase in the rate of water evaporation. According to WHO [33], the water of the Halda River is soft and suitable for aquatic organisms. Total hardness showed a significant positive relationship with EC ($r=0.96$, $P<0.001$), Ca^{++} ($r=0.87$, $P<0.001$), TDS ($r=0.86$, $P<0.001$), and transparency ($r=0.66$, $P<0.05$) (Table 7).

Total alkalinity (TA)

Fig. 2J shows the monthly average variation of TA in the Halda River. The lowest average value of total alkalinity (33.5 mg/L) was recorded at Station-3 in September and the highest total alkalinity (57 mg/L) was recorded at the same station in February (Table 5). In the Halda River, the total average value of TA was lowest (36.17±4.95 mg/L) in September and highest (55±12.26 mg/L) in May (Fig. 2J). These results aligned with the data on TA collected in other rivers [28, 32]. The average seasonal value of total alkalinity was at its lowest (41.67±7.70 mg/L) during the post-monsoon season at Station-2 and at its highest (53.67±8.51 mg/L) during the monsoon season at Station-3 (Fig. 3J). In the Halda River, the total average seasonal value of total alkalinity was lowest (43.83±8.31 mg/L) during the post-monsoon season and highest (49.83± 5.95 mg/L) during the monsoon season (Table 6). The highest value of total alkalinity recorded at Station-3 during the monsoon season was caused by a high rate of decomposition which releases CO_2 resulting in the addition of carbonate and bicarbonate ions, hence increasing alkalinity level. The TA of the Halda River was found to be far below the permissible limit of 500 mg/L (Table 7).

Biochemical oxygen demand (BOD_5)

The BOD_5 value indicates the pollution contributed by biodegradable organic matter coming from various

pollution sources [34]. Fig. 2K shows the average monthly variation of BOD_5 in the Halda River, whereas Tables 3–5 indicate the monthly variation of lowest and highest values of BOD_5, and Fig. 3K presents the seasonal variation of BOD_5 station by station. The lowest average value of BOD_5 (0.2 mg/L) was recorded at Station-2 in August and the highest BOD_5 (3.9 mg/L) was recorded at Station-1 in March (Tables 3, 4). In the Halda River, the total average value of BOD_5 was lowest (0.72±0.02 mg/L) in September and highest (2.43±0.42 mg/L) in March (Fig. 2K). Similar results were also reported by different authors [19, 28]. The average seasonal value of BOD_5 was at its lowest (0.93±0.98 mg/L) during the post-monsoon season at Station-2 and at its highest (2.43±1.28 mg/L) during the pre-monsoon season at Station-1 (Fig. 3K). In the Halda River, the total average seasonal value of BOD_5 was lowest (1.02±0.28 mg/L) during the post-monsoon season and highest (1.78±0.60 mg/L) during the pre-monsoon season (Table 6). These records complied with the data on BOD_5 reported by the other authors [24, 30]. Sometimes BOD_5 value in the Halda River was found to exceed the permissible limit (≤2 mg/L) [27, 35]. It might be caused by the higher rate of decomposition of organic matter during heavy organic discharges; the lower value observed during the post-monsoon season could be attributed to the dilution in the concentration of dissolved organic matter and decrease in temperature.

CONCLUSION

All investigated physicochemical parameters indicate that the water of the Halda River has a low level of pollution and thus is capable of supporting aquatic organisms and spawning of carp. When used for drinking purposes, the water should undergo treatment, which is presently being implemented. No direct discharge of the waste water from poultry industry should happen without its prior treatment, which also holds for local urban wastes, industrial pollutants and other contaminants (liquid or solid) drained into the Halda River; it is crucial for preventing the deterioration of water quality in the future. As it is indicative of a tidal river, there is a flushing of water in the Halda River happening twice daily and protecting its water from any sort of pollution. In this regard, there should also be conducted an awareness program aimed at the people belonging to various demographic groups.

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