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Assessment of Seasonal Variation in Water Quality and Water Quality Index of Tattekere Lake, Bangalore, India

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Abstract
Wetlands are transition zones on the planet that play an important role in nutrient dynamics and primary productivity. Bangalore and its urban agglomerations have many artificial wetlands developed for various hydrological purposes to meet the needs and water requirements of the city. The wetlands of Bangalore are subject to anthropogenic pressures, primarily due to the continuous discharge of wastewater, which has altered the chemical integrity of the wetlands. The current study was conducted to evaluate seasonal variations in physicochemical parameters of water quality and to calculate the water quality index of Tattekere Lake in Bangalore. Tattekere Lake, one of the largest lakes in Bangalore, Karnataka, India, originates in the central Gottigere area and traverses several major agricultural areas as well as various companies that receive enormous wastewater from various sources. Water samples were collected from four locations and analyzed for pH, electrical conductivity, TDS, dissolved oxygen, nitrate, BOD, total hardness, Ca, Mg, chlorides and alkalinity using standard methods. Seasonal variations in water quality measurements were recorded and compared to norms, and water pollution status was also examined.

Introduction

Currently, surface water pollution has received much attention globally. Natural process and anthropogenic activities, like hydrological features, climate change, precipitation, agricultural activities, and wastewater discharge from industries, are the main reason for worsening of surface water quality [1–3]. Nonetheless, rivers and/or lakes have also been used for cleaning and dumping purposes. This practices more prominent in developing countries, mostly in India, China, Africa etc. Rivers are one of the aquatic environments most prone to pollution due to their extensive flow that transports industrial, municipal, and agricultural wastes through the runoff [4]. Natural processes (precipitation and weathering) as well as anthropogenic activities such as domestic sewage, industrial pollution, and agricultural operations all have a significant impact on the quality of surface water in diverse locations. Domestic sewage and industrial wastewater discharge are point sources of pollution, but agricultural pollution is a nonpoint source of pollution that varies seasonally based on the climatic conditions of each region [5]. The pollutant concentration in river water varies seasonally due to variations in precipitation [6]. Nutrients in surface water have been linked mostly to land use activities [7]. As a result of anthropogenic activities, both point and nonpoint pollution sources enrich surface water with nutrients.

While animal manure and inorganic fertilizers used in agricultural fields are nonpoint sources of pollution that help to enrich the aquatic environment with nutrients, municipal wastewater and industrial wastewater are the main sources of nutrient pollution in the aquatic environment [8]. Due to their toxicity, persistence, and bioaccumulation effect on the ecosystem, heavy metal pollution of surface water is the primary concern [9]. A river can receive heavy metals from a variety of sources, both natural and man-made. The amount of heavy metals in rivers is typically negligible in clean areas and primarily results from soil and rock weathering [10]. Raw industrial wastewater from factories, mining activities, sewage, and agrochemicals from agricultural areas are the main anthropogenic sources of heavy metal in rivers [10][11]. Tattekere Lake, one of the major lakes in Bangalore, Karnataka, India, which originates from the central Gottigere area, crosses different extended agricultural farms as well as various industries that receive large effluents from different sources. In the country, all of the prevailing industries and main town (Bangalore) with in the upper watershed have no proper treatment plants resulting in polluting the river [12,13]. Previously, there has not been any work on spatial and seasonal variation in physicochemical parameters and heavy metal in Tattekere Lake. The aim of this study was therefore to evaluate the level of different physicochemical parameters and heavy metals in terms of space and season in Tattekere Lake.

Materials and methods

Study area

The Tattekere Lake is the most important lake in Bangalore, India and serves as home to 9.2 million inhabitants. The lake rises on the central Gottigere area, Bangalore and crosses different extended agricultural farms as well as various industries that receive large effluents from different sources. The total length of the main course is some 50 km surrounding.

Water sampling

Sampling strategy was designed to cover a wide range of physiochemical parameters and heavy metals at sampling sites in Tattekere Lake. Water sampling was carried out on seasonal basis, namely during dry season (March–May, 2020) and rainy season (June–August, 2020). A total of 48 water samples were collected from eight sampling stations (24 samples during rainy season and 24 during dry season). Sampling, preservation, and transportation of the water samples to the laboratory were as per standard method [14].

Analysis of water samples

The samples were analyzed for 19 parameters, namely water temperature (WT), pH, electrical conductivity (EC), turbidity, nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonia nitrogen (NH_4-N), total nitrogen (TN), total phosphorus (TP), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), iron (Fe), zinc (Zn), copper (Cu), lead (Pb), chromium (Cr), Cadmium (Cd), and nickel (Ni). pH was measured on the sampling sites by pH meter model 370. WT and EC were also determined in the field using conductivity meter model CON 2700. All other parameters were determined in the laboratory following standard protocols [14]. TN (persulfate digestion method), NO_3-N (cadmium reduction method), NO_2-N (diazotization method), NH_3-N (Nessler method), TP (persulfate digestion followed by ascorbic acid method), COD (dichromate reactor digestion method) were analyzed by HACH DR/2400, whereas Fe, Zn, Cu, Pb, Cr, Cd, and Ni were analyzed using graphite atomic absorption spectrometer. Each analysis was performed in triplicate, and the mean value was taken. The analytical data quality was guaranteed through the implementation of laboratory quality assurance and quality control methods, including the use of standard operating procedures, calibration with standards, analysis of reagent blanks, recovery of known additions, and analysis of replicates.

Statistical analysis

Statistical analysis was performed by SPSS version 16.0 to calculate average mean, standard deviation, and Pearson's correlation (*r*) value to show the degree of physicochemical and metal association in river water. The ANOVA test (level of significance $\alpha = 0.05$) was employed to understand the spatial and seasonal variation in the physico-chemical and heavy metal concentrations.

Result and discussion

Seasonal and spatial variation in physicochemical parameters

The concentration of physicochemical parameters in dry and wet season of Tattekere Lake is shown in Tables 1 and 2. During the study period, water temperature in Tattekere Lake showed some seasonal variation and ranged from 19.1 to 23.6 °C. As expected, water temperature was the highest during dry seasons and the lowest during wet seasons. The highest average water temperature values were recorded at site 7 during both dry season (23.01 °C) and wet season (21.9 °C). The reason might be there has been drinking water treatment plant at sampling station 7 so that the wastewater which drains from the treatment plant makes the river water temperature rise. There is no significant variation in water temperature among the sampling sites ($p > 0.05$), while there was a significant difference in seasonal mean concentration of water temperature ($p < 0.05$). The mean water temperature value (22.2 °C) in the present study was higher than the average value (16.7 °C) in Tinishu Akaki River, Ethiopia [15], but it was substantially lower than the mean water temperature value (25.65 °C) in Upper Awash River, Ethiopia [16]. Mean pH values at all sampling stations were slightly acidic to alkaline. The pH ranged from 6.08 to 8.47. Site 6 showed higher pH value (8.45) during the dry season. The lowest pH value (6.08) was found at site 7 in dry season. The lowest pH might be the sludge from drinking treatment plant mainly aluminum sulfate which lowers the pH of the river water. The deposition of sediment at Koka reservoir (site 6) is responsible for pH elevation. There is a significant variation in mean pH value among the sampling sites in Awash River ($p < 0.05$), while there was no seasonal significant difference in mean pH value in Awash River. The average pH value (7.23) in the present study is lower than the mean value (8.44) reported from Guder River, Ethiopia [17], and in Upper Awash River, Ethiopia (8.33), but higher than the mean pH (6.54) value of Buriganga River, Bangladesh [18], Iguedo River, Edo State, Nigeria (5.65) [19].

The turbidity values in Awash River varied from 29.27 to 159.51 NTU (Tables 1 and 2). The highest mean turbidity values (139.61 NTU) were found at site 2 during wet season because of surface runoff from nearest agricultural land, and the lowest average value (36.4 NTU) of turbidity was recorded at sampling site 6 during dry season. Higher values were recorded during the raining season as compared to the dry season. This could be attributed to run off water from the agricultural farm which carries suspended materials into the river. The soil around Koka area is bare and hence highly susceptible to erosion during rainy seasons. Sampling sites 2, 3, and 4 had higher turbidity levels than the rest of the sampling sites. There is a significant spatial and seasonal variation ($p < 0.05$) in average turbidity value among sampling sites (Table 3). The mean turbidity value in Awash River duringrainy season (121.06 NTU) was substantially higher than the value of turbidity (57 NTU) in Walgamo River, Ethiopia [20], in Gudbahi River, Eastern Tigray, Ethiopia (9.6 NTU) [21].

Table 1 Physicochemical water quality parameters at different locations of the Tattekere Lake during dry season

Parameters	Sampling Station							
	S1	S2	S3	S4	S5	S6	S7	S8
WT (°C)								
Mean	21.57 (1.07)	22.48 (0.9)	22.8 (0.83)	22.06 (1.04)	21.81 (1.17)	21.32 (1.06)	23.01 (0.78)	22.5 (1.03)
Range	Range 20.40–22.50	21.45–23.1	21.86–23.43	20.96–23.03	20.52–22.80	20.19–22.28	22.13–23.60	21.40–23.40
pH								
Mean	7.85 (0.21)	6.69 (0.39)	6.26 (0.11)	6.66 (0.22)	7.85 (0.08)	8.17 (0.24)	6.21 (0.17)	8.06 (0.13)
Range	7.63–8.04	6.28–7.07	6.17–6.38	6.41–6.82	7.76–7.93	7.99–8.45	6.08–6.41	7.92–8.17
EC (μS/cm)								
Mean	331.83 (38.96)	673.12 (47.4)	612.97 (26.18)	529.11 (31.74)	615.43 (96.54)	316.55 (28.25)	732.58 (10.93)	482.52 (29.83)
Range	294.27–372.06	626.68–721.43	589.47–641.19	498.21–561.63	504.72–682.14	286.17–342.02	720.94–742.62	449.07–506.38
Turbidity (NTU)								
Mean	40.07 (5.54)	72.67 (10.65)	64.12 (8.13)	56.43 (5.47)	49.19 (4.69)	36.4 (9.57)	54.48 (4.58)	43.27 (4.88)
Range	34.49–45.57	63.28–84.25	55.82–72.06	50.62–61.49	45.09–54.3	29.27–47.28	50.11–59.25	38.51–48.27
NO_3-N (mg l^{-1})								

Mean	0.8 (0.25)	13.33 (0.96)	27.87 (0.86)	12.5 (0.66)	14.71 (1.14)	2.31 (0.3)	1.86 (0.11)	1.36 (0.13)
Range	0.51–0.98	12.30–14.20	27.10–28.80	11.80–13.10	13.47–15.71	1.98–2.58	1.74–1.96	1.23–1.49
NO2-N (mg l−1)								
Mean	0.24 (0.08)	0.61 (0.02)	0.90 (0.02)	0.26 (0.03)	0.52 (0.06)	0.21 (0.04)	0.29 (0.06)	0.31 (0.04)
Range	0.15–0.31	0.59–0.63	0.87–0.92	0.23–0.28	0.46–0.58	0.18–0.25	0.24–0.35	0.27–0.36
TN (mg l−1)								
Mean	2.28 (0.35)	39.63 (2.1)	83.43 (1.02)	79.40 (0.9)	50.23 (2.15)	8.22 (1.64)	2.90 (0.51)	3.57 (1.24)
Range	2.01–2.68	37.60–41.80	82.52–84.53	78.52–80.32	48.62–52.68	6.57–9.86	2.36–3.37	2.27–4.75
TP (mg l−1)								
Mean	0.08 (0.06)	0.17 (0.04)	0.27 (0.04)	0.19 (0.15)	0.09 (0.04)	0.12 (0.07)	0.04 (0.03)	0.11 (0.02)
Range	0.02–0.15	0.13–0.21	0.25–0.31	0.02–0.29	0.04–0.13	0.05–0.19	0.02–0.07	0.08–0.13
DO (mg l−1)								
Mean	7.47 (0.89)	5.15 (1.27)	4.51 (1.37)	3.62 (0.91)	6.83 (0.51)	7.03 (0.93)	6.29 (1.24)	7.58 (1.25)
Range	6.48–8.21	4.36–6.62	3.32–6.01	3.02–4.67	6.32–7.34	6.09–7.94	5.17–7.62	6.23–8.71
BOD (mg l−1)								
Mean	16.22 (2.42)	41.35 (3.34)	59.23 (0.94)	80.32 (3.64)	38.52 (0.88)	27.13 (4.81)	17.53 (3.25)	19.62 (1.82)
Range	13.69–18.51	37.62–44.07	58.26–60.14	76.29–83.37	37.58–39.33	22.31–31.93	13.85–20.01	17.74–21.37
COD (mg l−1)								
Mean	27.33 (4.45)	72.63 (10.41)	147.98 (2.77)	112.3 (1.32)	53.24 (1.72)	40.5 (3.39)	125.0 (1.11)	35.55 (1.09)
Range	22.85–31.76	61.37–81.89	144.95–150.38	110.86–113.45	51.40–54.82	36.73–43.29	123.77–125.94	34.61–36.75

Table 2 Physicochemical water quality parameters at different locations of the Tattekere Lake during wet season

Parameters	Sampling Station							
	S1	S2	S3	S4	S5	S6	S7	S8
WT (°C)								
Mean	21.23 (1.17)	21 (0.72) 22.00	21.6 (1.06)	20.8 (1.18)	20.6 (1.08)	20.7 (1.44)	21.9 (0.66)	21.4 (0.6)
Range	19.9–22.1	20.2–21.6	20.40–22.40	19.50–21.80	19.40–21.50	19.10–21.90	21.30–22.60	20.80–22.00
pH								

Mean	8.13 (0.20)	6.55 (0.18)	6.71 (0.1)	6.64 (0.06)	7.55 (0.33)	7.73 (0.26)	6.27 (0.19)	8.0 (0.2)
Range	7.92–8.31	6.39–6.74	6.61–6.81	6.60–6.71	7.30–7.92	7.51–8.02	6.14–6.48	7.79–8.19
EC (µS/cm)								
Mean	285.5 (22.37)	589.6 (19.78)	521.73 (25.15)	476.47 (12.69)	279.97 (18.45)	294.53 (20.19)	648.27 (13.25)	577.6 (17.71)
Range	265.4–309.6	572.8–611.4	496.8–547.10	462.6–487.5	261.7–298.6	279.6–317.5	634.8–661.3	563–597.3
Turbidity (NTU)								
Mean	122.8 (12.31)	139.61 (21.02)	138.26 (16.56)	137.37 (20.04)	124.64 (14.91)	95.08 (6.85)	105.83 (16.07)	104.89 (14.97)
Range	110.67–135.28	117.62–159.51	121.28–154.36	115.38–154.60	110.80–140.42	89.17–102.59	94.72–124.26	92.07–121.35
NO3-N (mg l−1)								
Mean	0.48 (0.2)	8.9 (1.61)	13.78 (1.77)	6.35 (1.21)	4.73 (0.56)	2.73 (0.43)	1.18 (0.22)	0.74 (0.12)
Range	0.28–0.68	7.14–10.3	12.17–15.68	5.11–7.53	4.10–5.17	2.25–3.07	0.98–1.42	0.63–0.86
NO2-N (mg l−1)								
Mean	0.11 (0.03)	0.35 (0.07)	0.43 (0.06)	0.19 (0.02)	0.31 (0.03)	0.14 (0.05)	0.15 (0.04)	0.07 (0.01)
Range	0.08–0.15	0.28–0.42	0.37–0.49	0.17–0.2	0.29–0.34	0.09–0.18	0.11–0.2	0.06–0.07
TN (mg l−1)								
Mean	1.22 (0.42)	11.66 (2.65)	17.06 (1.52)	13.43 (0.66)	9.1 (1.49)	17.75 (1.9)	2.61 (0.54)	11.0 (2.98)
Range	0.82–1.65	9.17–14.45	15.32–18.16	12.86–14.15	7.39–10.15	16.14–19.85	2.01–3.07	8.25–14.16
TP (mg l−1)								
Mean	0.05 (0.03)	0.08 (0.05)	0.15 (0.08)	0.18 (0.11)	0.17 (0.08)	0.09 (0.06)	0.07 (0.05)	0.08 (0.04)
Range	0.03–0.08	0.04–0.13	0.06–0.23	0.07–0.28	0.09–0.25	0.04–0.15	0.03–0.12	0.05–0.13
DO (mg l−1)								
Mean	10.82 (2.46)	4.60 (1.46)	4.25 (1.02)	5.12 (1.22)	6.24 (2.55)	6.41 (1.19)	7.27 (1.98)	8.62 (1.71)
Range	8.69–13.51	3.24–6.15	3.27–5.31	4.07–6.45	4.48–9.16	5.39–7.72	5.81–9.53	7.13–10.49
BOD (mg l−1)								
Mean	11.13 (1.92)	14.43 (2.89)	34.09 (1.2)	38.32 (1.5)	17.49 (0.81)	12.81 (1.79)	16.63 (1.65)	13.24 (1.97)
Range	9.14–12.98	11.33–17.04	32.84–35.23	36.62–39.47	16.92–18.41	11.47–14.85	15.19–18.44	11.16–15.08
COD (mg l−1)								
Mean	19.08 (2.79)	48.9 (8.39)	94.1 (7.94)	67.12 (3.79)	29.81 (2.66)	23.38 (4.84)	110.02 (1.71)	21.0 (2.12)
Range	16.13–21.68	41.97–58.23	88.4–103.2	62.85–70.09	27.14–32.47	18.49–28.16	108.93–112	19.43–23.42

Table 3 ANOVA relation of physicochemical parameters at different sampling location and different season								
Parameters	Dry season			Wet season			ANOVA	
	Mean (mg l−1)	Range	SD	Mean (mg l−1)	Range	SD	Spatial	Seasonal
WT	22.2	21.32–23.01	0.6	21.15	20.6–21.9	0.46	NS	SS*
pH	7.23	6.21–8.17	0.84	7.2	6.27–8.13	0.73	SS*	NS
EC	536.76	316.55–732.58	152.33	459.21	279.97–648.27	151.37	SS*	NS*
Turbidity	52.08	36.4–72.67	12.36	121.06	95.08–139.61 *	17.28	SS*	SS
NO3-N	9.34	0.8–27.87	9.56	4.86	0.48–13.78	4.66	SS*	NS
NO2-N *	0.42	0.21–0.9	0.24	0.22	0.07–0.43	0.13	SS*	NS
NH4-N	0.78	0.12–1.41	0.55	0.14	0.05–0.29	0.07	SS*	SS
TN	33.71	2.28–83.43	34.56	10.48	1.2–17.75	6.05	SS*	NS
TP	0.13	0.04–0.27	0.07	0.11	0.06–0.18	0.05	NS	NS
DO	6.25	4.51–7.58	1.18	6.48	3.62–10.82	2.41	SS*	NS
BOD	37.49	16.22–80.32	22.68	19.77	11.13–38.32	10.41	SS*	NS
COD	76.82	27.33–147.98	45.81	51.68	19.08–110.02	35.32	SS*	NS

The NO_3-N concentration varied from 0.28 to 28.8 mg l−1. The highest mean concentration (27.87 mg l^{-1}) of NO_3- N was found at site 3 during dry season because of intensive agricultural activities near to this site and animal manure waste near the river. The lowest average concentration (0.48 mg l−1) of NO_3- N was found at sampling site 1 during wet season. A significant variation in nitrate in the spatial trend was observed ($p <$ 0.05). Nitrate is the most oxidized form of nitrogen found in aquatic environment, and during rainy season, considerable amount of nitrate washed from the agricultural farm and reached to water body through runoff.

The mean concentration of NO_3- N (9.34 mg l−1) in Awash River was higher than the average value (3.74 mg l^{-1}) from Jajrood River, Iran [22], from Vishwamitri River, India (0.06 mg l^{-1}) [22], from Sinos River, Brazil (0.3 mg l^{-1}) [23], but substantially lower than the average NO_3-N concentration (26.93 mg l^{-1}) from Chambal River, Rajasthan, India [24], from Mahanadi River, India (36.2 mg l^{-1}) [25], from Ogun River, Nigeria (35.18 mg l^{-1}) [26].

The NO_2- N concentration varied from 0.06 to 0.92 mg l^{-1}. The highest mean value (0.90 mg l^{-1}) of NO_2-N was reported at sampling site 3 during dry season, while the lowest mean concentration (0.07 mg l^{-1}) was observed at sampling site 8 during wet season.

The mean value (0.42 mg l^{-1}) of NO_2- N concentration in the present study was higher than the average value (0.06 mg l^{-1}) in Tigris River, Turkey [27], and also Elala River, Tigray, Ethiopia (0.11 mg l^{-1}) [28], while it is considerably lower than the average value (1.07 mg l^{-1}) in Awash River, Ethiopia [29].

The measured NH4-N values vary between 0.11 and 1.47 mg l−1 in dry season and between 0.03 and 0.35 mg l−1 in wet season. Site 4 showed higher average values (1.41 mg l^{-1}) during dry season while the lowest NH_4^+ mean value (0.05 mg l^{-1}) was found at site 1 in wet season. There is a significant spatial and seasonal variation ($p < 0.05$) in mean NH_4- N values in Awash River (Table 3). NH4-N is a water-soluble gas that exists at low levels (0.1 mg l^{-1}) in natural waters. NH_4^+ comes from the nitrogen-containing organic material and gas exchange between the water and the atmosphere [30]. It also derives from the biodegradation of waste and from domestic, agricultural, and industrial wastes.

The mean value (0.78 mg l^{-1}) of NH_{4}- N in Awash River was higher than the average value (0.07 mg l−1) from Upper Awash River, Ethiopia [16], Tigris River, Iraq (0.11 mg l^{-1}) [31]. The TN ranged from 0.82 to 84.53 mg l^{-1} (Tables 1 and 2). The highest mean values (83.43 mg l−1) of TN have been noted at sampling site 3 in dry season, and the lowest average concentration (1.22 mg l^{-1}) was found at site 1 during wet season. There is a significant variation in mean TN values among sampling stations ($p < 0.05$); however, there was no seasonal significant difference in average TN concentration in Awash River.
The mean concentration (33.71 mg l^{-1}) of TN in the present study was very similar to the average TN (35.21 mg l^{-1}) in Walleme River, Ethiopia [32], but significantly higher than the mean TN value (2.06 mg l^{-1}) in Tigris River, Turkey (varol et al. 2011), from Xin'anjing River, China (1.55 mg l^{-1}) [33]. The concentration of TP varied from 0.02 to 0.31 mg l−1 in dry season and between 0.03 and 0.28 mg l−1 in wet season. Site 3 showed higher mean values (0.27 mg l^{-1}) during dry season while the lowest average TP value (0.04 mg l^{-1}) was found at site 7 in dry season. There was no a significant spatial and seasonal variation ($p > 0.05$) in average TP values in Awash River (Table 3).
The DO values varied from 3.02 to 13.51 mg l^{-1}. The DO was higher in wet season than in dry season at almost all sites. The low DO values in dry months were possibly due to considerable activities of microorganisms, which consumed appreciable amount of oxygen as a result of metabolizing activities and decay of organic matter. The highest mean values (10.82 51 mg l^{-1}) of DO were observed at site 1 during wet season. The lowest concentration (3.62 mg l^{-1}) of DO was found at site 4 during dry season, which receives agricultural runoff and animal manure wastes near the river. Dissolved oxygen is probably the most important parameter in natural surface water systems for determining the health of aquatic ecosystems [34].
The average value (6.48 mg l^{-1}) of DO in Awash River was very similar to the mean DO value (6.62 mg l^{-1}) from Blue Nile River, Ethiopia, but considerably higher than the mean DO value (1 mg l^{-1}) from Modjo River, Ethiopia, from Mahanadi River, India (4.58 mg l^{-1}) [25], from Ngong River, Kenya (4.35 mg l^{-1}). The concentration of BOD varied from 13.69 to 83.37 mg l−1 in dry season and between 9.14 and 39.47 mg l−1 in wet season. Site 4 showed higher average values (80.32 mg l−1) of BOD during dry season while the lowest average BOD value (11.13 mg l−1) was found at site 1 in wet season (Tables 1 and 2). There was a significant spatial variation ($p < 0.05$) in average BOD values in Awash River, whereas there was no significant seasonal variation ($p > 0.05$) in mean BOD values among the sampling sites (Table 3).
Based on the result of the present study, average BOD value (37.49 mg l^{-1}) was significantly higher than the mean value of BOD (24.23 mg l^{-1}) from Nyabugogo catchment, Rwanda [35], Gudbahri River, Eastern Tigray, Ethiopia (3.88 mg l^{-1}) [36], Rapti River, India (34.33 mg l^{-1}) [37], but lower than the mean value (38.10 mg l−1) of BOD from Nile River, Egypt.
COD in Awash River varied from 16.13 to 150.38 mg l^{-1}. The highest average COD values (147.98 mg l−1) were found at site 3 during dry season because of different agrochemicals' discharge to the river through runoff. The lowest mean value (19.08 mg l−1) of COD was recorded at sampling site 1 during wet season. The average COD values were indicated a significant spatial variation ($p < 0.05$) among the sampling sites, but there was no seasonal variation in mean COD values in Awash River (Table 3). High values of COD indicate waterpollution, which is associated with wastewater discharged from industry or agricultural practices [38].
The mean value (76.82 mg l−1) of COD in Awash River was substantially lower than the average concentration (651 mg l−1) of COD from Modjo River, Ethiopia [39], from Buniganga River, Bangladesh [18].
The covariance matrix of the 12 analyzed variables was calculated from normalized data; consequently, it coincided with the correlation matrix (Tables 4 and 5). Because the eight sampling stations were combined to determine the correlation matrix, the correlation coefficients should be interpreted; however, they are affected simultaneously by spatial and seasonal variation.
There is a strong and positive correlation between (pH and EC, $r = 0.805$), (WT and BOD, $r = 0.774$), (NO3-N and NO2- N, $r = 0.901$), (NO_{3}-N and TN, $r = 0.906$), (NO_{3}-N and TP, 0.830), (NH_{4}-N and TN, $r = 0.876$), (NH_{4}-N and COD, $r = 0.848$), (TN and TP, $r = 0.819$), (TN and COD, $r = 0.941$). A significant negative correlation exists between (WT and turbidity, $r = -0.812$), (WT and DO $r = -0.927$), (TN and BOD, $r = -0.854$) during dry season (Table 4). Strong and positive correlations exist between (WT and BOD, $r = 0.704$), (turbidity and NO3-N, $r = 0.749$), (turbidity and NO_{2}- N, $r = 0.722$), (NO_{3}-N and NO_{2}-N, $r = 0.921$), (NO_{3}-N and BOD, 0.832), (TP and COD, $r = 0.789$). A significant negative correlation exists between (WT and NH_{4}-N, $r = -0.769$) during wet

season. The positive correlation probably indicated that these pollutants came from the same sources that are from agricultural runoff and animal manure.

Table 4 Correlation matrix of the physicochemical parameters during dry season

	pH	WT	EC	Turbidity	NO3-N	NO2-N	NH4-N	TN	TP	BOD	COD	DO
pH	1											
WT	− 0.7517	1										
EC	**0.805307**	− 0.75172	1									
Turbidity	0.649723	− **0.81201**	0.783435	1								
NO3-N	0.311429	− 0.52466	0.453181	0.687205	1							
NO2-N	0.472314	− 0.4814	0.525567	0.7097	**0.9007**	**06**	1					
NH4-N	− 0.1578	− 0.21762	0.205599	0.44498	0.76949	0.488327	1					
TN	0.178033	− 0.51307	0.358213	0.615293	**0.906192**	0.645128	**0.875985**	1				
TP	0.205074	− 0.42186	0.108145	0.569795	**0.829653**	0.698926	0.664038	**0.818915**	1			
BOD	− 0.35475	**0.773919**	− 0.4493	− 0.75	− 0.69888	− 0.44552	− 0.68268	− **0.85397**	− 0.7486	1		
COD	0.085421	− 0.48257	0.233119	0.536053	0.728213	0.391149	**0.848397**	**0.941056**	0.779804	**0.91321**	1	
DO	0.694409	− **0.92761**	0.666149	0.665023	0.63082	0.518756	0.342735	0.630267	0.520033	− 0.7819	0.581778	1

Table 5 Correlation matrix of the physicochemical parameters during wet season

	pH	WT	EC	Turbidity	NO3-N	NO2-N	NH4-N	TN	TP	BOD	COD	DO
pH	1											
WT	− 0.7517	1										
EC	**0.805307**	− 0.75172	1									
Turbidity	0.649723	− **0.81201**	0.783435	1								
NO3-N	0.311429	− 0.52466	0.453181	0.687205	1							
NO2-N	0.472314	− 0.4814	0.525567	0.7097	**0.9007**	**06**	1					
NH4-N	− 0.1578	− 0.21762	0.205599	0.44498	0.76949	0.488327	1					
TN	0.178033	− 0.51307	0.358213	0.615293	**0.906192**	0.645128	**0.875985**	1				
TP	0.205074	− 0.42186	0.108145	0.569795	**0.829653**	0.698926	0.664038	**0.818915**	1			
BOD	− 0.35475	**0.773919**	− 0.4493	− 0.75	− 0.69888	− 0.44552	− 0.68268	− **0.85397**	− 0.7486	1		
COD	0.085421	− 0.48257	0.233119	0.536053	0.728213	0.391149	**0.848397**	**0.941056**	0.7798	**0.9132**	1	

									04	**1**		
DO	0.694409	– **0.92761**	0.666149	0.665023	0.63082	0.518756	0.342735	0.630267	0.520033	–0.7819	0.581778	1

Table 6 Mean concentration of heavy metals during dry season								
Sites	Values	Metal Concentrations (mg l−1)						
		Fe	Zn	Cu	Pb	Cr	Cd	Ni
Site-1	Mean	1.11 ± 0.58	0.74 ± 0.62	0.92 ± 0.62	0.56 ± 0.17	0.36 ± 0.12	0.07 ± 0.02	0.05 ± 0.01
	Range	0.49–1.64	0.35–1.46	0.29–1.52	0.38–0.71	0.26–0.49	0.05–0.09	0.03–0.06
Site-2	Mean	2.17 ± 0.8	1.12 ± 0.78	1.22 ± 0.83	0.70 ± 0.21	0.52 ± 0.2	0.09 ± 0.36	0.08 ± 0.01
	Range	1.42–3.01	0.42–1.96	0.41–2.07	0.52–0.93	0.32–0.71	0.06–0.13	0.06–0.09
Site-3	Mean	2.34 ± 0.92	1.42 ± 1.21	0.88 ± 0.47	0.84 ± 0.43	0.56 ± 0.09	0.13 ± 0.05	0.11 ± 0.04
	Range	1.63–3.38	0.37–2.74	0.35–1.27	0.58–1.34	0.46–0.63	0.09–0.18	0.07–0.15
Site-4	Mean	2.6 ± 1.0	1.22 ± 1.10	1.69 ± 0.96	0.77 ± 0.61	0.99 ± 0.31	0.18 ± 0.07	0.14 ± 0.06
	Range	1.7–3.68	0.23–2.41	0.73–2.65	0.33–1.46	0.65–1.25	0.11–0.25	0.08–0.19
Site-5	Mean	2.73 ± 1.03	1.56 ± 1.27	1.63 ± 1.19	1.36 ± 1.20	1.16 ± 0.35	0.22 ± 0.07	0.12 ± 0.03
	Range	1.85–3.87	0.47–2.95	0.49–2.86	0.58–0.75	0.77–1.43	0.16–0.3	0.09–0.14

Table 6 Mean concentration of heavy metals during wet season								
Sites	Values	Metal Concentrations (mg l−1)						
		Fe	Zn	Cu	Pb	Cr	Cd	Ni
Site-1	Mean	1.11 ± 0.58	0.74 ± 0.62	0.92 ± 0.62	0.56 ± 0.17	0.36 ± 0.12	0.07 ± 0.02	0.05 ± 0.01
	Range	0.49–1.64	0.35–1.46	0.29–1.52	0.38–0.71	0.26–0.49	0.05–0.09	0.03–0.06
Site-2	Mean	2.17 ± 0.8	1.12 ± 0.78	1.22 ± 0.83	0.70 ± 0.21	0.52 ± 0.2	0.09 ± 0.36	0.08 ± 0.01
	Range	1.42–3.01	0.42–1.96	0.41–2.07	0.52–0.93	0.32–0.71	0.06–0.13	0.06–0.09
Site-3	Mean	2.34 ± 0.92	1.42 ± 1.21	0.88 ± 0.47	0.84 ± 0.43	0.56 ± 0.09	0.13 ± 0.05	0.11 ± 0.04
	Range	1.63–3.38	0.37–2.74	0.35–1.27	0.58–1.34	0.46–0.63	0.09–0.18	0.07–0.15
Site-4	Mean	2.6 ± 1.0	1.22 ± 1.10	1.69 ± 0.96	0.77 ± 0.61	0.99 ± 0.31	0.18 ± 0.07	0.14 ± 0.06
	Range	1.7–3.68	0.23–	0.73–	0.33–	0.65–	0.11–	0.08–

			2.41	2.65	1.46	1.25	0.25	0.19
Site-5	Mean	2.73 ± 1.03	1.56 ± 1.27	1.63 ± 1.19	1.36 ± 1.20	1.16 ± 0.35	0.22 ± 0.07	0.12 ± 0.03
	Range	1.85–3.87	0.47–2.95	0.49–2.86	0.58–0.75	0.77–1.43	0.16–0.3	0.09–0.14

Table 8 ANOVA relation of heavy metals at different sampling location and different season

Elements	Dry season			Wet season			ANOVA	
	Mean (mg l^{-1})	Range	SD	Mean (mg l−1)	Range	SD	Spatial	Seasonal
Fe	2.17	1.11–2.73	0.61	3.36	1.82–4.12	0.77	NS	SS*
Zn	0.64	0.46–0.91	0.15	1.14	0.74–1.56	0.3	NS	SS*
Cu	0.7	0.44–1.01	0.20	1.20	0.82–1.69	0.34	NS	SS*
Pb	0.59	0.31–0.83	0.18	0.81	0.41–1.36	0.29	NS	NS
Cr	0.75	0.36–1.16	0.29	0.63	0.3–0.98	0.25	SS*	NS
Cd	0.06	0.03–0.11	0.03	0.13	0.05–0.24	0.07	SS*	SS*
Ni	0.05	0.02–0.09	0.02	0.10	0.03–0.2	0.07	SS*	SS*

NS not statistical significant, *SS* statistical significant *$p < 0.05$

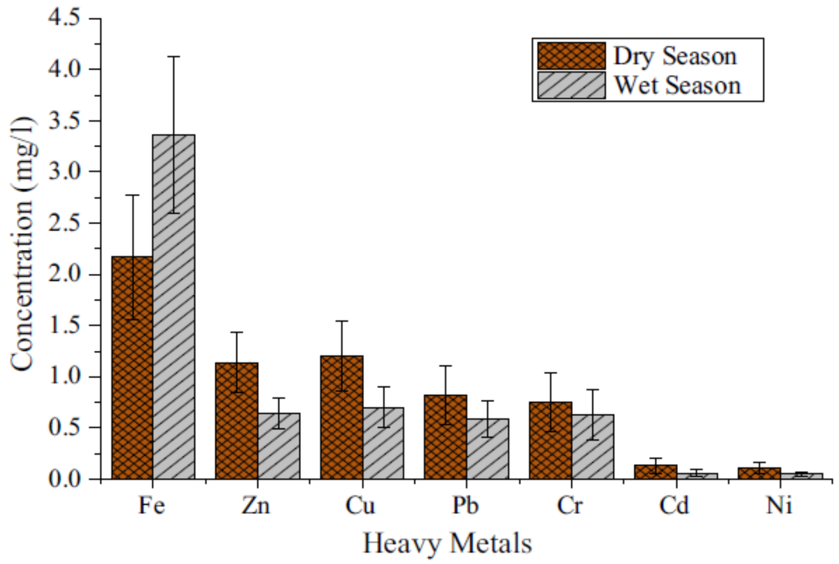

Fig. 1 Heavy metal concentration during dry and wet season

Conclusion

There is a significant spatial and seasonal variation in most of the physicochemical parameters in Tattekere Lake. The concentration of heavy metals during dry season is higher than the wet season except for Fe in which the highest concentration was found during wet season. Buffer zones should be protected in order to control soil and agricultural nutrients from entering to Tattekere Lake. Moreover, industries at the upper stream area should be properly and adequately treat the wastewater before discharging to the Tattekere

Lake and environmental protection agency need to regularly monitor and test the waste water based on the standard guidelines.

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