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ORIGINAL ARTICLE

Status of cyanotoxin contamination and water quality in major irrigational and recreational reservoirs in Sri Lanka

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Abstract

The rapid depletion of water quality in reservoirs is considered as a global ecological and health consequences. Hence, the regular monitoring of water quality status in such reservoirs is mandatory to ensure a safe water supply for the general public. The present study was conducted to evaluate the water quality, contamination status of cyanotoxins, species composition and abundance of phytoplankton in 43 selected major reservoirs in Sri Lanka. The water temperature, pH, Dissolved oxygen (DO), and Electrical Conductivity (EC) were measured at the site and the other water quality parameters, Total Nitrogen (TN), Total Phosphates (TP), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Fluoride, Total Hardness (TH), Chlorophyll-*a* (Chl-*a*), Cyanotoxins; Microcystin-LR (MC-LR), Cylindrospermopsin (CYN), Saxitoxin (SAX), Nodularin (NOD), Anatoxin-a (ANA-a) concentrations and Faecal Coliform were measured following the standard methods. The water temperature, pH, DO, EC, TN, TP, COD, BOD, Fluoride, TH, and Chl-*a* were ranged from 20.5 to 29.7 ℃, 6.5 to 8.8, 2.1 to 7.9 mg/L, 25.6 to 1752 µS/cm, < 0.05 to 3.42 mg/L, < 0.05 to 20.55 mg/L, 10.2 to 220.6 mg/L, 0.6 to 10.6 mg/L, < 0.01 to 0.23 mg/L, 13.67 to 122 mg/L and 0.66 to 48.9 µg/L respectively. Further, each water body was contaminated with at least one algal toxin tested. Overall, MC-LR was the most dominant toxin variant (37%) in the collected water samples compared to CYN (10%), SAX (10%), NOD (10%), and ANA-a (10%). Moreover, 39 reservoirs tested out of 43 recorded fecal coliform greater than 200 (CFU)/100 mL. Among all the selected water bodies, Beira Lake in Colombo was the most polluted recreational water body. Furthermore, in Beira Lake, almost all measured water quality parameters exceeded the standard levels set by the Sri Lanka Standards Institute (SLSI) and the Environmental Protection Agency (EPA), USA for aquatic life. The measured water quality data indicated that most of the reservoirs are polluted, and the overall water quality has deteriorated. It suggests the negative impacts on the ecological balance of the ecosystem and these results indicate the necessity of proper treatment facilities for the reservoirs in Sri Lanka.

Keywords Water quality · Reservoirs · Algal toxins · Cyanobacteria · Fecal coliform

Introduction

Sri Lanka is an island in the Indian Ocean, southeast of the Bay of Bengal, with mean temperatures of 17 ℃ in the central highlands to 27 ℃ in the lowlands (Wijewardena 2021). Four monsoons dominate the rainfall distribution throughout the island: the southwest monsoon, the northeast monsoon, and inter-monsoons prevailing throughout the year. There are two primary climatic regions in Sri Lanka dry zone and the wet zone, based on the availability of rain (Ampitiyawatta et al. 2022). Additionally, many historically significant manmade reservoirs are primarily in the dry zone to collect rainwater for agricultural and recreational uses (Siriwardana et al. 2019). High populations in Sri Lanka

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rely on these water reservoirs to meet their water requirements (Mahagamage et al. 2014). Importantly, most of the urban and suburban human population in Sri Lanka directly consumes the reservoir water without any treatment.

The water requirement in Sri Lanka has gradually increased in recent decades due to the expansion of industrial and agricultural activities (Mahagamage and Manage 2019; Thadshayini et al. 2020). In addition, the direct discharge of untreated wastewater into natural water bodies, and excessive use of nitrogenous fertilizers for agricultural purposes, mainly contribute to the rapid water quality depletion in the reservoirs (Akhtar et al. 2021). The accumulation of excessive nitrate and phosphate in the reservoirs causes serious ecological concerns like eutrophication and increases toxin levels resulting in critical health problems (Bhateria and Jain 2016; Mahagamage et al. 2019). Furthermore, the accumulation of excess nitrate and nitrite ions in water can cause acute and chronic toxicity for both adults and children, leading to conditions such as methemoglobinemia and brain tumors (Karwowska and Kononiuk 2020). In addition, the increased nutrient concentrations in water can boost microalgae growth in tropical countries like Sri Lanka (Kulasoorita 2017; Manage 2019). As a result, cyanobacteria can pose an environmental and health risk to humans by forming dense agglomerations in freshwater habitats that produce and emit harmful cyanotoxins (Van Apeldoorn et al. 2007; Idroos and Manage 2014). Water quality depletion can be caused by metabolites released by cyanobacteria and microalgae degradation, which cause odor and taste problems in freshwater. Another critical aspect of cyanobacteria in drinking water quality is the formation of surface scums before the occurrence of blooms (Spoof et al. 2006). *Anabaena circinalis, Aphanizomenonflos-aquae, Cylindrospermopsis raciborskii*, and *Microcystis aeruginosa*, are among other cyanobacterial strains, that have been reported all over the world as cyanotoxins producers (Manage 2019). Wijewickrama and Manage (2019) documented that toxins can impact other flora and fauna.

The concentration of Chlorophyll-*a* present in a water body is used as a marker to measure the number of microalgae that can be present in that water body which can classify the trophic state of the water. Chlorophyll-*a* concentrations and algal density are higher in water, with high nutrients obtained from the dissolved chemicals. By promoting eutrophication, hypoxia, low DO in bottom waters, and anoxia through increased algal productivity, the increase of nutrients in the surface water bodies poses a hazard to the ecological balance in the water system. Increased nutrient levels commonly result in higher algal productivity, which increases Chlorophyll-*a* concentrations in water (Dahanayake et al. 2016).

Fecal contamination of drinking water is also a significant threat to public health, especially in developing countries. Contaminated drinking water is estimated to cause 485,000 diarrheal deaths yearly (WHO 2019). Further, microalgae can change fecal coliform concentrations in the aquatic system since microalgae are known to supply carbon, compete with fecal coliform for nutrients, modify the water chemistry, shelter fecal coliform from solar radiation, and release toxins and stimulants. Different types of microalgae can have different impacts on fecal coliform survival by altering fecal coliform populations. Microalgae can consequently affect any fecal coliform bacteria-based evaluation of the effectiveness of land-use practices, such as waste management, livestock feeding operations, stormwater control, recreational activities, and conservation practices on microbial water quality. In particular, practices causing or controlling eutrophication may influence microalgal populations and consequently affect the conditions fecal coliform has adapted for survival.

Hence, the mechanisms that underlie the source of water contamination variability are essential to study and monitor to enhance the safety of drinking water and preserve public health (Mahagamage et al. 2014). Further, making decisions about supplying safe water to the public is crucial. Hence, the current study focused on analyzing the water quality of a few critical reservoirs in Sri Lanka concerning nutrient levels, fecal coliform contaminations, algal composition, and various cyanotoxins.

Methodology

Study area and sampling

Water samples were collected from 43 major reservoirs (Fig. 1) in Anuradhapura, Polonnaruwa, Trincomalee, Ampara, Batticaloa, Kurunegala, Matale, Badulla, Hambanthota, Kandy, Nuwara Eliya, and Colombo districts in Sri Lanka during January to September 2021.

Water samples were collected from a 15 cm depth from the surface of the reservoir into pre-cleaned polypropylene bottles and sterilized amber colour glass bottles for chemical and microbial analysis, respectively. Samples were taken for two times from this period Then water samples were transported to the laboratory under cooling conditions (4–8 ℃) and stored in a cold room until analysis. The GPS coordinates were recorded via a hand-held Garmin eTrex 30 GPS receiver at the site. The User categories and climatic zones of the reservoirs sampled in the present study are mentioned in Table 1.

Physico-chemical analysis of water

Water temperature, DO, and water pH levels were measured using an HQD portable multiparameter (HACH–HQ

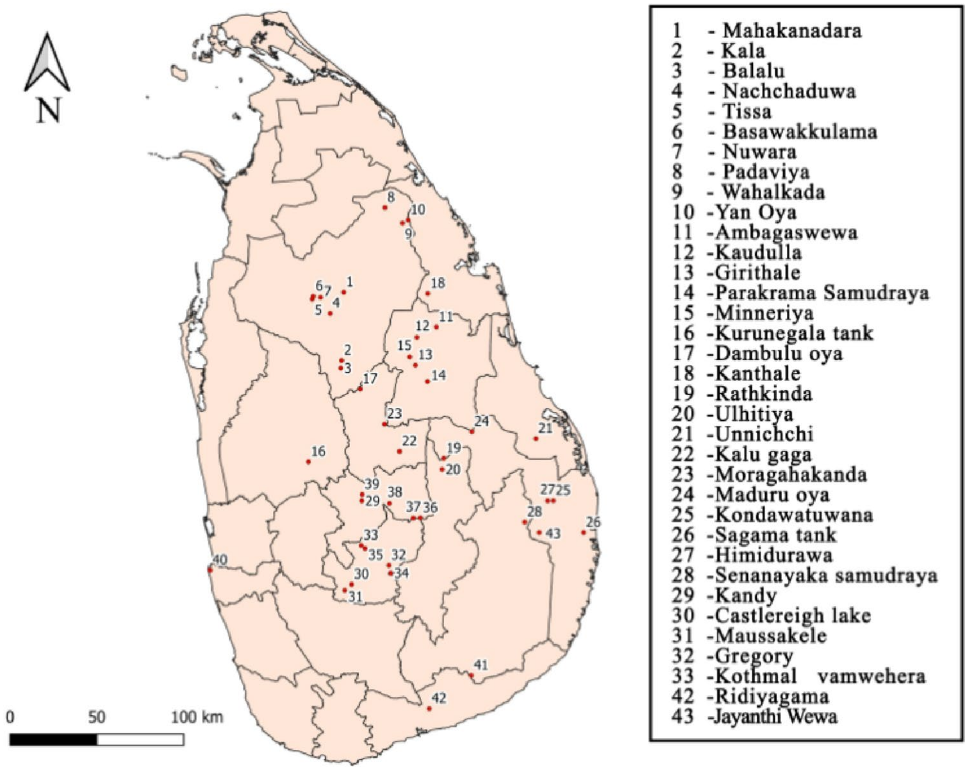

Fig. 1 Geographic locations of the selected major reservoirs in the present study

40D), and TDS, EC, and salinity were recorded using a portable conductivity meter (HACH–Sension EC5) at the site itself. COD was determined by using the closed reflux method where ammonia (as N-NH_3), nitrates (as N-NO_3), nitrite (as N-NO_2), and TP concentrations were measured by using the Spectrophotometric (Spectro UV–VIS Double UVD 2960) methods. The total hardness was determined by using standard methods (APHA 1999). The SPADNS method was used to determine the fluoride in water using the colorimeter (HACH–DR 2700).

Total and fecal coliform analysis

The membrane filtration method was performed to determine the water's total coliform (TC), and *E. coli* counts. An aliquot of 0.1 dm^3 from each water sample was filtered through a 0.45 μm filter paper (Whatman Cat No: 7001 0004, D-47 mm), and then the filter papers were kept on the Membrane Lactose Glucuronide Agar (MLGA) plates. Plates were incubated at 37 °C, and bacterial counts were taken after 18 ± 2 h (SLSI, 2013).

Determination of chlorophyll-a concentration

The Chlorophyll content was extracted from the concentrated algal sample into 10 mL of methanol (98%). The chlorophyll-*a* concentration was determined spectrophotometrically by measuring the absorbance (Optical Density-OD) at 665 nm and 750 nm wavelengths before and after acidification (1% HCl). The resulting absorbance measurements were then applied to a standard equation to detect Chlorophyll-*a* concentrations (Pathmalal et al. 2023; Gunawardana et al. 2022).

Determination of *Cyanobacteria* species composition and abundance

About 100 L of water was filtered through a plankton net (55 μm) to collect phytoplankton samples. Filtered samples were collected into plastic bottles (100 mL), fixed with a 1% final concentration of acidified Lugol's solution, transferred to a measuring cylinder at the laboratory, and allowed to settle for 24 h in the dark. The upper water column was gently drawn off using a Pasteur pipette, leaving a 5–10 mL sample in the cylinder, assuming all microalgae had settled to the bottom (Guiry and Guiry 2014; Sahu, 2013). Identification and enumeration were made using the Sedgewick-rafter counting chamber under the epifluorescence microscope. Cyanobacteria species were identified using a standard algae taxonomic guideline (Moestrup et al. 2009).

Determination of cyanotoxins by using ELISA

Commercially available test kits were used to quantify intracellular and extracellular MC-LR, CYN, NOD, SAX, and ANA-a (Beacon, USA). 25 mL from each water sample was

Table 1 User categories climatic zones of the reservoirs sampled in the present study

Sample no.	Reference no.	Reservoir	District	Climatic regions	Urban and rural matrics	Usage of water
1	MR	Mahakanadara wewa	Anuradhapura	Dry zone	Rural	Irrigation/fishing
2	KR	Kala wewa	Anuradhapura	Dry zone	Rural	Irrigation/fishing
3	B1R	Balalu wewa	Anuradhapura	Dry zone	Rural	Irrigation/fishing
4	N1R	Nachchaduwa	Anuradhapura	Dry zone	Rural	Irrigation/fishing
5	TR	Tissa wewa	Anuradhapura	Dry zone	Rural	Irrigation/drinking/fishing
6	B2R	Basawakkulama wewa	Anuradhapura	Dry zone	Rural	Irrigation/recreation
7	N2R	Nuwara wewa	Anuradhapura	Dry zone	Rural	Irrigation/drinking/fishing
8	PR	Padaviya wewa	Anuradhapura	Dry zone	Rural	Irrigation/fishing
9	WR	Wahalkada wewa	Anuradhapura	Dry zone	Rural	Irrigation/fishing
10	YR	Yan oya	Trincomalee	Dry zone	Rural	Irrigation/fishing
11	R1	Ambagaswewa	Polonnaruwa	Dry zone	Rural	Irrigation
12	R2	Kaudulla	Polonnaruwa	Dry zone	Rural	Irrigation
13	R3	Girithale	Polonnaruwa	Dry zone	Rural	Irrigation
14	R8	Parakrama Samudraya	Polonnaruwa	Dry zone	Rural	Irrigation
15	R5	Minneriya	Polonnaruwa	Dry zone	Rural	Irrigation
16	R4	Kanthale	Trincomalee	Dry zone	Rural	Irrigation
17	R11	Maduruoya	Trincomalee	Dry zone	Rural	Irrigational
18	R16	Kondawatuwana	Ampara	Dry zone	Rural	Irrigation
19	R17	Jayanthi	Ampara	Dry zone	Rural	Irrigation
20	R18	Himidurawa	Ampara	Dry zone	Rural	Irrigation
21	R13	Sagama tank	Ampara	Dry zone	Rural	Irrigation
22	R19	Senanayaka Samudraya	Ampara	Dry zone	Rural	Irrigation
23	R12	Unnichchi	Ampara	Dry zone	Rural	Irrigation
24	R6	Kurunegala tank	Batticaloa	Dry zone	Rural	Irrigation/recreation
25	R7	Dambulu oya	Kurunegala	Intermediate zone	Rural	Irrigation
26	R14	Kalu ganga	Matale	Intermediate zone	Rural	Irrigation/hydroelectricity
27	R15	Moragahakanda	Matale	Intermediate zone	Rural	Irrigation/hydroelectricity
28	R9	Rathkinda	Badulla	Intermediate zone	Rural	Irrigation/drinking
29	R10	Ulhitiya	Badulla	Intermediate zone	Rural	Irrigation/drinking
30	LR	Lunugamwehera	Hambanthota	Intermediate zone	Rural	Irrigation
31	RR	Ridiyagama	Hambanthota	Intermediate zone	Rural	Irrigation
32	R20	Kandy	Kandy	Wet zone	Urban	Irrigation
33	R25	Rantabe	Kandy	Wet zone	Rural	Irrigation/hydroelectricity
34	R26	Randenigala	Kandy	Wet zone	Rural	Irrigation/hydroelectricity
35	R27	Victoria	Kandy	Wet zone	Rural	Irrigation/hydroelectricity
36	R28	Polgolla	Kandy	Wet zone	Rural	Irrigation/hydroelectricity
37	R21	Castlereigh lake	Nuwara Eliya	Wet zone	Rural	Irrigation/recreation
38	R22	Maussakele	Nuwara Eliya	Wet zone	Rural	Irrigation
39	R23	Gregory	Nuwara Eliya	Wet zone	Urban	Irrigation
40	R29	Kothmale	Nuwara Eliya	Wet zone	Rural	Hydroelectricity
41	R30	Kandeela	Nuwara Eliya	Wet zone	Rural	Drinking
42	R24	Upper Kothmale	Nuwara Eliya	Wet zone	Rural	Hydroelectricity
43	R31	Baire	Colombo	Wet zone	Urban	Recreation

frozen and thawed three times to lyse the cells and liberate the intracellular toxin. Each sample was analyzed in triplicate, and the procedure was followed exactly as directed by the manufacturer. In a plate reader, the absorbance of total cyanotoxin was measured at 450 nm (ELISA, USA) (Abeysiri and Manage 2022a, b).

Statistical analysis

The dataset was processed using the Minitab (version 15) statistical software. Principal Component Analysis (PCA) was carried out for 14 physico–chemical parameters and 43 surface water sampling locations. Pearson correlation was performed to compare the association between the water quality parameters in reservoirs (Mahagamage and Manage 2019).

Results

Physico-chemical analysis of water

The pH of all the reservoirs ranged between 6.5 ± 0.2 and 8.8 ± 0.1. The highest pH was recorded from the Beira Lake Colombo, and the lowest was recorded from the Dambulu oya, Kurunegala district. The lowest EC was 25.6 μScm^{-1} recorded from the Kandeela reservoir, and the highest EC was 1862.5 μScm^{-1} in the Nachchaduwa reservoir. The DO of the selected reservoirs ranged between 2.12 and 10.23 mg/L, and the highest and lowest values were recorded at Beira Lake and Gregory Lake, respectively. The highest total inorganic nitrogen, phosphate, COD, and BOD level was recorded at the Beira lake Colombo at 3.42 ± 0.08 mg/L, 20.55 ± 0.07 mg/L, 1220.6 ± 0.2 mg/L and 10.6 mg/L values, respectively. In this study, Chlorophyll-*a* concentrations in the studied water bodies ranged from 0.66 ± 0.0 to 48.9 ± 0.3 mg/L. The highest Chlorophyll-*a* was recorded from Beira Lake, and the lowest was on the Rantabe reservoir (Table 2).

Total and fecal coliform contamination of water

Fecal coliform (*E.coli*) is considered a critical water quality indicator that determines water quality for drinking purposes. According to the recorded CFU values (Table 2) the Rathkida, Ulhitiya, and Kandeela reservoirs were not contaminated with the fecal coliform. However, the fecal coliform count was recorded at more than 200 CFU in 100 mL of water in the reservoirs of Mahakanadara Wewa, Vahalkada Weva, Baire Lake, Polgolla Lake, Castelere Lake, Ridiyagama, Kandy Lake, Maussakele Lake, and Gregory Lake.

Cyanobacteria species composition and abundance

Five different cyanobacteria species were recorded; *Microsystis* sp., *Oscillatoria* sp., *Cylindrspermopsis* sp., and *Anabaena* sp., The *Merismopedia* sp. is the most abundant species in the reservoirs. During the study, the highest abundance of cyanobacteria cell densities was detected in Beira Lake, Colombo (Table 3).

Cyanotoxin contamination

At least one algal toxin (Microcystin-LR (MC-LR), Cylindrospermopsin (CYN), Saxitoxin, Nodularin, and Anatoxin-a) was detected in the 43 reservoirs. 37% of samples were positive for the MC-LR and the highest concentration of MC-LR was recorded in the Beira Lake (3.31 µg/L), where other reservoirs recorded at less than 1 µg/L. In the Anuradhapura district, MC-LR was detected in Basawakkulama and Padaviya reservoirs at 0.10 µg/L, 0.13 µg/L respectively, whereas in Polonnaruwa district; Ambagaswewa and Parkkrma Samudraya reservoirs were at 0.14 µg/L and 0.11 µg/L respectively. In the Badulla district, the Rathkinda reservoir was recorded at 0.10 µg/L MC-LR, and the Moragahakanda reservoir in the Matale district was 0.13 µg/L. Further, Maduru Oya, Jayanthi Wewa, Sagama tank, Senanayake Samudraya, Kandy Lake, Randenigala, Gregory, Kothmale, and Unnichchi reservoirs, MC-LR concentrations recorded at 0.12 µg/L, 0.10 µg/L, 0.10 µg/L, 0.11 µg/L, 0.11 µg/L, 0.10 µg/L 0.18 µg/L, 0.10 µg/L and 0.10 µg/L respectively during the study period. However, MC-LR was not recorded in reservoirs in Trincomalee, Kurunagala and Hambanthota districts. According to the established guidelines by the WHO and Sri Lanka Standard Institute (SLSI), MC-LR in drinking water should be below 1.0 µg/L. Except for the Beria Lake (3.31 µg/L) 15 irrigation tanks were contaminated with MC-LR and the concentrations remained below the WHO and SLSI concentrations given for drinking.

The concentrations of CYN in reservoirs ranged from 0.05 µg/L to 0.07 µg/L during the sampling. Compared to the other districts, high CYN concentrations were recorded in the Anuradhapura district. Further, the highest concentration of saxitoxin was recorded in the Padaviya tank (0.09 µg/L) in the Anuradhapura district following the Beira Lake (0.08 µg/L), Parakkrma Samudraya (0.08 µg/L) and Ulhitiya (0.08 µg/L) respectively. All the recorded saxitoxin concentrations were lower than the drinking guidelines given by the WHO (0.1 µg/L). Nodularin was only detected in four reservoirs, namely, Balalau (0.07 µg/L), Padaviya (0.05 µg/L), Ulhitiya (0.08 µg/L), Uninichchi (0.06 µg/L)and the Anatoxin-a was recorded in Nuwara Wewa (0.17 µg/L), Padaviya (0.19 µg/L), Parakkrama Samudraya (0.15 µg/L) and Unnichchi reservoirs (0.16 µg/L) respectively.

Statistical analysis

The first principal component of the PCA analysis is strongly correlated with average chlorophyll-*a*, MC-LR, COD, BOD,

Table 2 Water quality parameters in selected reservoirs in the present study

Reference no.	District	T (℃)	pH	EC (μS/cm)	DO (mg/L)	Total nitrogen (mg/L)	Total phosphate (mg/L)	COD (mg/L)	BOD (mg/L)	Fluoride (mg/L)	Total hardness (mg/L)	chlorophyll-*a* (μg/L)	Total coliform (CFU/100 mL)	Faecal coliform (CFU/100 mL)
EPA 2007			6.0–8.5		1.0						100.0			
MR	Anuradhapura	28.4 ± 0.3	7.8 ± 0.3	1666.3 ± 0.3	4.5 ± 0.3	0.32 ± 0.003	< 0.05	48.4 ± 0.5	3.4	0.20	77.33	1.59 ± 0.2	> 200	> 200
KR		29.2 ± 0.5	7.7 ± 0.2	770.4 ± 0.2	6.9 ± 0.8	0.15 ± 0.001	< 0.05	26.4 ± 0.8	2.4	0.11	91.33	1.95 ± 0.8	> 200	150
B1R		27.7 ± 0.4	6.8 ± 0.4	631.0 ± 0.2	5.2 ± 0.4	0.20 ± 0.001	< 0.05	20.6 ± 0.4	2.8	< 0.01	92.67	2.24 ± 0.7	120	100
N1R		28.6 ± 0.2	7.2 ± 0.1	862.5 ± 0.4	5.5 ± 0.3	0.30 ± 0.001	0.20 ± 0.01	34.9 ± 0.6	2.9	0.04	86.67	3.47 ± 0.3	88	80
TR		29.8 ± 0.6	7.4 ± 0.2	635.3 ± 0.2	6.5 ± 0.4	0.43 ± 0.001	< 0.05	23.6 ± 0.4	2.7	0.04	65.33	1.14 ± 0.4	120	42
B2R		27.2 ± 0.1	7.7 ± 0.3	777.3 ± 0.4	7.1 ± 0.4	0.55 ± 0.002	< 0.05	26.2 ± 0.3	2.2	0.02	84.00	1.64 ± 0.9	88	50
N2R		28.5 ± 0.3	7.2 ± 0.1	632.3 ± 0.5	7.1 ± 0.3	0.15 ± 0.001	< 0.05	26.4 ± 0.6	2.2	0.04	80.67	1.08 ± 0.4	95	60
PR		28.8 ± 0.7	7.8 ± 0.2	915.4 ± 0.3	6.1 ± 0.4	0.20 ± 0.05	0.10 ± 0.01	38.6 ± 0.3	2.2	0.02	66.67	4.64 ± 0.3	55	45
WR		28.5 ± 0.4	7.1 ± 0.1	954.2 ± 0.1	4.2 ± 0.1	0.34 ± 0.01	< 0.05	24.2 ± 0.4	2.6	< 0.01	98.00	2.43 ± 0.8	> 200	> 200
YR		27.8 ± 0.6	7.3 ± 0.1	393.2 ± 0.2	5.5 ± 0.5	0.15 ± 0.03	0.05 ± 0.01	42.8 ± 0.9	2.6	< 0.01	86.00	1.52 ± 0.8	120	50
R1	Polonnaruwa	30.2 ± 0.1	7.8 ± 0.4	1328.4 ± 0.3	4.8 ± 0.6	0.26 ± 0.03	< 0.05	46.2 ± 0.1	3.2	0.20	122.00	1.93 ± 0.6	> 200	> 200
R2		29.7 ± 0.5	6.6 ± 0.2	1020.4 ± 0.3	5.5 ± 0.6	0.16 ± 0.03	< 0.05	22.4 ± 0.3	3.4	0.01 <	74.67	1.51 ± 0.7	> 200	40
R3		29.4 ± 0.3	6.6 ± 0.3	911.7 ± 0.5	5.6 ± 0.7	0.10 ± 0.03	< 0.05	20.4 ± 0.5	2.2	< 0.01	74.67	1.58 ± 0.5	80	60
R8		28.5 ± 0.2	6.9 ± 0.5	886.8 ± 0.6	4.2 ± 0.3	0.25 ± 0.02	< 0.05	26.4 ± 0.8	2.8	0.02	99.33	2.76 ± 0.6	> 200	50
R5		27.6 ± 0.4	7.2 ± 0.1	737.4 ± 0.3	5.3 ± 0.5	0.18 ± 0.02	< 0.05	20.5 ± 0.4	1.6	< 0.01	86.00	3.52 ± 0.5	80	58
R4	Trincomalee	28.3 ± 0.1	7.7 ± 0.4	413.5 ± 0.2	6.2 ± 0.4	0.15 ± 0.01	< 0.05	44.4 ± 0.5	5.4	< 0.01	91.33	2.81 ± 0.8	> 200	> 200
R11		26.7 ± 0.3	7.9 ± 0.6	674.3 ± 0.3	5.2 ± 0.9	0.15 ± 0.01	< 0.05	20.4 ± 0.3	3.6	0.16	64.67	2.75 ± 0.6	> 200	> 200
R16		28.2 ± 0.1	7.5 ± 0.3	1446.6 ± 0.7	4.0 ± 0.4	0.29 ± 0.02	0.12 ± 0.07	48.2 ± 0.7	3.8	0.1	60.00	2.41 ± 0.1	> 200	42
R17		27.5 ± 0.3	7.6 ± 0.4	847.2 ± 0.3	5.0 ± 0.2	0.30 ± 0.04	0.22 ± 0.09	38.6 ± 0.5	2.6	0.15	27.33	2.19 ± 0.6	> 200	20
R18		26.8 ± 0.5	7.1 ± 0.1	577.5 ± 0.4	6.6 ± 0.5	0.28 ± 0.04	< 0.05	20.2 ± 0.9	2.9	0.02	26.00	2.51 ± 0.6	> 200	> 200
R13		27 ± 1.0	7.4 ± 0.2	1250.1 ± 0.1	5.1 ± 0.4	0.25 ± 0.01	< 0.05	35.1 ± 0.4	4.4	< 0.01	36.00	3.95 ± 0.4	> 200	10
R19		25.5 ± 0.2	6.6 ± 0.3	653.8 ± 0.6	5.1 ± 0.9	0.10 ± 0.01	< 0.05	24.1 ± 0.9	2.6	< 0.01	41.33	2.29 ± 0.3	> 200	5
R12	Batticaloa	28.5 ± 0.4	6.6 ± 0.4	590.2 ± 0.3	5.2 ± 0.7	0.15 ± 0.01	< 0.05	30.2 ± 0.7	2.6	0.18	23.33	3.84 ± 0.8	> 200	> 200
R6	Kurunegala	29.5 ± 0.3	7.2 ± 0.1	594.6 ± 0.7	6.2 ± 0.1	0.18 ± 0.01	< 0.05	22.4 ± 0.3	2.1	< 0.01	93.33	3.46 ± 0.9	> 200	> 200
R7		27.8 ± 0.6	6.5 ± 0.2	451.1 ± 0.3	6.0 ± 0.2	0.15 ± 0.01	0.05 ± 0.01	30.2 ± 0.1	2.4	0.22	109.33	3.31 ± 0.4	> 200	> 200
R14	Matale	25.4 ± 0.2	6.8 ± 0.4	408.2 ± 0.4	4.5 ± 0.7	0.10 ± 0.01	< 0.05	26.2 ± 0.7	2.4	< 0.01	38.00	1.71 ± 0.6	> 200	80
R15		25.7 ± 0.5	6.8 ± 0.7	374.3 ± 0.5	6.2 ± 0.1	0.12 ± 0.01	< 0.05	22.2 ± 0.5	2.2	0.03	54.00	2.79 ± 0.4	70	54
R9	Badulla	26.4 ± 0.2	7.1 ± 0.1	149.8 ± 0.6	7.1 ± 0.8	0.05 >	< 0.05	16.3 ± 0.7	0.6	0.05	48.67	1.49 ± 0.3	9	5
R10		27.6 ± 0.4	7.0 ± 0.2	128.1 ± 0.2	7.9 ± 0.5	0.05 >	< 0.05	11.4 ± 0.3	0.8	0.02	60.67	2.36 ± 0.7	10	8
LR	Hambanthota	27.5 ± 0.3	8.2 ± 0.3	1552.3 ± 0.5	4.0 ± 0.7	0.30 ± 0.03	0.08 ± 0.03	44.2 ± 0.1	2.4	0.02	60.67	2.24 ± 0.6	> 200	> 200
RR		28.4 ± 0.2	7.4 ± 0.2	635.9 ± 0.8	5.8 ± 0.6	0.10 ± 0.01	< 0.05	56.2 ± 0.9	2.6	0.21	73.33	3.74 ± 0.4	> 200	> 200
R20	Kandy	27 ± 3.0	6.6 ± 0.3	604.2 ± 0.1	6.2 ± 0.1	0.20 ± 0.01	< 0.05	28.3 ± 0.2	2.4	0.02	93.33	2.04 ± 0.6	> 200	> 200
R25	Nuwara Eliya	25.2 ± 0.1	7.2 ± 0.1	677.5 ± 0.4	5.0 ± 0.5	0.56 ± 0.02	0.15	40.4 ± 0.4	3.2	0.03	56.67	0.66 ± 0.1	66	54
R26		24.2 ± 0.1	7.1 ± 0.1	650.1 ± 0.3	5.5 ± 0.4	0.70 ± 0.05	0.15	38.0 ± 0.9	3.0	0.05	51.33	0.99 ± 0.3	54	42
R27		23.9 ± 0.7	7.2 ± 0.1	353.8 ± 0.4	6.6 ± 0.9	0.30 ± 0.04	< 0.05	24.4 ± 0.3	2.4	< 0.01	52.00	0.91 ± 0.4	89	58
R28		27 ± 2.0	6.6 ± 0.2	504.2 ± 0.4	4.1 ± 0.5	0.40 ± 0.02	0.09 ± 0.01	36.2 ± 0.1	5.2	0.11	36.67	0.87 ± 0.1	> 200	> 200

Table 2 (continued)

Reference no.	District	T (℃)	pH	EC (µS/cm)	DO (mg/L)	Total nitrogen (mg/L)	Total phosphate (mg/L)	COD (mg/L)	BOD (mg/L)	Fluoride (mg/L)	Total hardness (mg/L)	chlorophyll-*a* (µg/L)	Total coliform (CFU/100 mL)	Faecal coliform (CFU/100 mL)
R21		22.4 ± 0.2	7.0 ± 0.1	590.2 ± 0.3	6.0 ± 0.4	0.30 ± 0.03	< 0.05	23.4 ± 0.7	3.4	0.12	20.67	0.90 ± 0.2	> 200	> 200
R22		21.6 ± 0.3	6.6 ± 0.5	408.2 ± 0.4	6.8 ± 0.9	0.66 ± 0.07	1.25 ± 0.05	44.6 ± 0.5	4.8	< 0.01	18.00	1.04 ± 0.3	> 200	> 200
R23		20.5 ± 0.4	6.8 ± 0.4	674.3 ± 0.5	10.2 ± 0.7	1.80 ± 0.09	10.50 ± 0.04	86.1 ± 0.8	6.2	0.02	62.67	1.15 ± 0.6	> 200	> 200
R29		25.4 ± 0.2	6.8 ± 0.7	224.3 ± 0.6	6.5 ± 0.4	0.20 ± 0.01	0.14 ± 0.01	34.6 ± 0.4	3.7	< 0.01	29.33	0.67 ± 0.1	85	40
R30		24.7 ± 0.6	7.2 ± 0.1	25.6 ± 0.4	6.2 ± 0.7	0.05 >	< 0.05	10.2 ± 0.7	1.2	0.02	13.67	0.98 ± 0.3	36	24
R24		23.7 ± 0.4	7.5 ± 0.3	847.2 ± 0.4	6.2 ± 0.1	0.16 ± 0.001	< 0.05	22.1 ± 0.3	4.2	< 0.01	32.00	0.96 ± 0.1	85	52
R31	Colombo	25.9 ± 0.7	8.8 ± 0.1	1752.0 ± 0.2	2.1 ± 0.1	3.42 ± 0.08	20.55 ± 0.07	1220.6 ± 0.2	10.6	0.23	82.00	48.90 ± 0.3	> 200	> 200

MR Mahakanadara wewa, *KR* Kala wewa, *B1R* Balalu wewa, *N1R* Nachchaduwa, *TR* Tissa wewa, *B2R* Basawakkulama wewa, *N2R* Nuwara wewa, *PR* Padaviya wewa, *WR* Wahalkada wewa, *YR* Yan oya, *R1* Ambagaswewa, *R2* Kaudulla, *R3* Girithale, *R8* Parakrama Samudraya, *R5* Minneriya, *R4* Kanthale, *R11* Maduruoya, *R16* Kondawatuwana, *R17* Jayanthi, *R18* Himidurawa, *R13* Sagama tank, *R19* Senanayaka Samudraya, *R12* Unnichchi, *R6* Kurunegala tank, *R7* Dambulu oya, *R14* Kalu ganga, *R15* Moragahakanda, *R9* Rathkinda, *R10* Ulhitiya, *LR* Lunugamwehera, *RR* Ridiyagama, *R20* Kandy, *R21* Castlereigh lake, *R22* Maussakele, *R23* Gregory, *R24* Upper kothmale, *R25* Rantabe, *R26* Randenigala, *R27* Victoria, *R28* Polgolla, *R29* Kothmale, *R30* Kande ela, *R31* Baire lake, *EPA* Environmental Protection Agency

total phosphate, and total inorganic nitrogen. Furthermore, the second principal component is strongly correlated with water temperature, pH, total hardness, nodularin, and cylindrospermopsin parameters. However, dissolved oxygen negatively correlates with the first and second principal components. EC, anatoxin-a, saxitoxin, and fluoride parameter concentration are correlated with the first and second principal components (Fig. 2).

Padaviya wewa has a very high value for the second principal component and high values for the water temperature, pH, total hardness, nodularin and cylindrospermopsin. Similar results were shown in the Ambagaswewa. However, Castlereagh Lake, Maussakele and Gregory Lake negatively correlated with the water quality parameters. The Beira Lake was well correlated with the first component. It suggested that it has recorded very high values for the average chlorophyll-*a*, MC-LR, COD, BOD, total phosphate and total nitrogen. Tanks in the Anuradhapura district, except Padaviya Wewa, were clustered together, while lakes in the Nuwara Eliya district were clustered together. Furthermore, the lakes in the Nuwara Eliya district have recorded high values for dissolved oxygen. Kandeela, Ulhitiya, Rathkinda, Thissa wewa and Nuwara wewa, which are used for drinking, are well correlated with the parameters of dissolved oxygen while negatively correlated with the concentration of fluoride, electrical conductivity, the concentration of anatoxin and saxitoxin (Fig. 1).

Discussion

The water quality analysis with a combined sanitary inspection can be used to identify the most critical causes of and control measures for contamination of water bodies (Lu et al. 2015). This is important to support effective and national decision-making. Many national and international institutes have published the standard values of water quality, which is a generally applicable approach to ensuring the safety of drinking water in communities and recreational activities (Akhtar et al. 2021). In the present study, water quality, contamination status of cyanotoxins, species composition and abundance of phytoplankton in 43 selected major reservoirs in Sri Lanka to determine the deterioration of reservoir water quality. Reservoirs play a crucial role in supplying water for drinking, agriculture, fishing, industry, recreational activities, and the generation of hydroelectricity. Hence, it is important to determine the contamination levels in reservoir water which precedes taking necessary measures to continue the proper water quality status in reservoirs. It helps to maintain the good health and ecological balance. Furthermore, the degradation of reservoir water quality occurs gradually over an extended period. Once the degradation state reaches beyond the threshold level, returning it to its previous state

Table 3 Species composition and abundance of cyanobacteria in the studied reservoirs

Reservoirs	*Microsystis* sp. (cells/mL)	*Oscillatoria* sp. (cells/mL)	*Cylindrspermopsis* sp. (cells/mL)	*Anabaena* sp. (cells/mL)	*Merismopedia* sp. (cells/mL)
Mahakanadara wewa	7203.25 ± 48.52	8913.62 ± 15.65	811.52 ± 57.42	2453.65 ± 85.64	4158.62 ± 24.39
Kala wewa	4343.50 ± 48.65	1022.64 ± 47.68	4224.64 ± 88.24	245.58 ± 21.36	5643.52 ± 67.29
Balalu wewa	186.26 ± 58.34	1478.46 ± 19.34	544.18 ± 29.36	951.67 ± 85.61	2673.18 ± 74.68
Nachchaduwa	9515.48 ± 65.59	1330.88 ± 75.75	1337.37 ± 84.36	245.62 ± 57.65	632.65 ± 47.39
Tissa wewa	1107.15 ± 57.35	987.17 ± 27.68	655.36 ± 22.14	511.16 ± 82.61	1162.24 ± 21.57
Basawakkulama wewa	2130.97 ± 102.65	689.67 ± 39.24	116.15 ± 26.78	652.67 ± 67.24	1424.63 ± 36.28
Nuwara wewa	2844.15 ± 157.35	719.46 ± 56.24	1422.56 ± 66.24	858.54 ± 52.67	3558.54 ± 57.29
Padaviya wewa	8052.36 ± 65.24	7139.91 ± 16.34	1112.27 ± 21.58	1124.28 ± 85.65	4527.28 ± 59.34
Wahalkada wewa	1138.78 ± 57.15	610.27 ± 55.34	658.67 ± 29.54	2642.64 ± 87.24	915.34 ± 26.24
Yan oya	6728.65 ± 67.24	718.64 ± 78.41	816.82 ± 44.39	346.67 ± 61.25	771.85 ± 18.34
Ambagaswewa	136.12 ± 21.53	249.18 ± 18.34	646.67 ± 27.28	612.28 ± 57.63	1656.34 ± 56.24
Kaudulla	346.54 ± 35.14	854.64 ± 13.64	952.24 ± 15.64	162.45 ± 51.34	1521.55 ± 36.18
Girithale	1153.12 ± 38.70	2015.37 ± 47.58	1012.68 ± 28.64	644.85 ± 24.36	3620.67 ± 92.17
Parakrama Samudraya	2557.69 ± 98.24	3431.19 ± 98.65	623.52 ± 37.65	687.27 ± 24.36	6262.45 ± 56.27
Minneriya	1072.14 ± 230.56	574.82 ± 78.35	854.25 ± 37.64	224.62 ± 46.32	262.62 ± 46.24
Kanthale	9045.36 ± 62.47	847.33 ± 27.24	458.64 ± 37.18	135.56 ± 21.35	1214.28 ± 48.62
Maduruoya	8126.14 ± 53.84	1220.67 ± 79.245	1853.85 ± 27.35	654.74 ± 24.65	2621.67 ± 37.39
Kondawatuwana	7295.39 ± 20.53	916.22 ± 35.15	1514.34 ± 37.69	539.62 ± 39.14	529.84 ± 15.19
Jayanthi	5363.14 ± 23.24	420.84 ± 47.65	2957.62 ± 94.35	124.37 ± 15.31	893.64 ± 20.24
Himidurawa	1239.33 ± 56.67	948.61 ± 31.65	6954.37 ± 27.33	364.64 ± 24.12	411.56 ± 24.36
Sagama tank	3311.54 ± 65.17	109.73 ± 37.68	1852.37 ± 37.64	285.75 ± 24.62	138.77 ± 19.24
Senanayaka Samudraya	4215.36 ± 37.15	3306.45 ± 57.32	8344.66 ± 18.51	1252.92 ± 24.14	1119.61 ± 46.36
Unnichchi	3348.14 ± 58.154	1823.54 ± 88.24	3620.46 ± 57.24	563.65 ± 22.54	4029.47 ± 88.24
Victoria	1186.69 ± 53.47	612.96 ± 27.36	1854.67 ± 38.36	284.84 ± 15.34	463.85 ± 48.29
Dambulu oya	950.45 ± 24.18	917.67 ± 77.24	1616.53 ± 78.52	791.85 ± 48.34	522.64 ± 34.16
Kalu ganga	2094.90 ± 37.26	654.11 ± 25.37	661.65 ± 18.24	651.48 ± 46.37	1220.57 ± 70.58
Moragahakanda	1298.36 ± 56.56	848.95 ± 37.33	1061.17 ± 55.69	202.56 ± 24.14	1249.34 ± 35.61
Rathkinda	935.45 ± 38.24	783.37 ± 21.11	624.37 ± 24.37	52.75 ± 17.62	634.52 ± 12.27
Ulhitiya	1229.19 ± 27.26	888.46 ± 24.68	245.61 ± 28.24	96.62 ± 11.32	512.51 ± 19.14
Lunugamwehera	4033.86 ± 47.66	614.34 ± 44.27	1645.45 ± 59.17	16.65 ± 5.24	633.84 ± 19.17
Ridiyagama	594.46 ± 18.24	845.45 ± 57.69	512.64 ± 28.45	456.48 ± 2.41	823.64 ± 13.48
Kandy	966.78 ± 28.61	516.61 ± 57.62	629.58 ± 28.64	112.65 ± 7.91	1220.29 ± 78.16
Rantabe	722.24 ± 37.64	824.49 ± 52.14	514.61 ± 81.56	625.24 ± 24.34	6233.61 ± 76.56
Randenigala	835.92 ± 43.11	213.67 ± 22.84	554.85 ± 76.54	546.52 ± 16.65	234.82 ± 11.29
Victoria	6844.49 ± 49.57	719.27 ± 57.25	1922.75 ± 65.47	888.75 ± 42.62	5068.14 ± 42.61
Polgolla	1067.64 ± 75.61	620.56 ± 67.69	517.62 ± 85.18	645.65 ± 24.19	314.75 ± 39.17
Castlereigh lake	867.35 ± 25.54	825.17 ± 15.65	753.46 ± 94.57	345.85 ± 51.32	931.64 ± 62.17
Maussakele	15,500.45 ± 105.24	671.34 ± 15.57	968.92 ± 93.47	612.18 ± 24.06	542.67 ± 79.15
Gregory	16,781.61 ± 15.45	2196.55 ± 18.57	1158.58 ± 84.29	45.52 ± 31.24	811.85 ± 64.27
Kothmale	960.67 ± 37.35	514.37 ± 84.65	462.15 ± 85.65	564.56 ± 47.24	328.61 ± 32.18
Kandeela	542.46 ± 18.65	855.27 ± 38.14	924.62 ± 84.65	322.54 ± 29.34	818.72 ± 67.12
Upper kothmale	1221.67 ± 54.29	554.34 ± 15.64	142.78 ± 85.24	232.85 ± 48.45	560.71 ± 12.47
Baire	4,527,660.31 ± 517.27	2,457,690.83 ± 541.36	354,022.31 ± 254.68	165,426.24 ± 142.68	4,548,327.61 ± 611.34

in terms of ecological integrity and quality is impossible. Hence, the continuous monitoring of the water quality and the contamination status in reservoirs is important.

In the present study, 43 selected major reservoirs in Sri Lanka were investigated and the highest deterioration was determined in the Beira lake in Colombo district. According

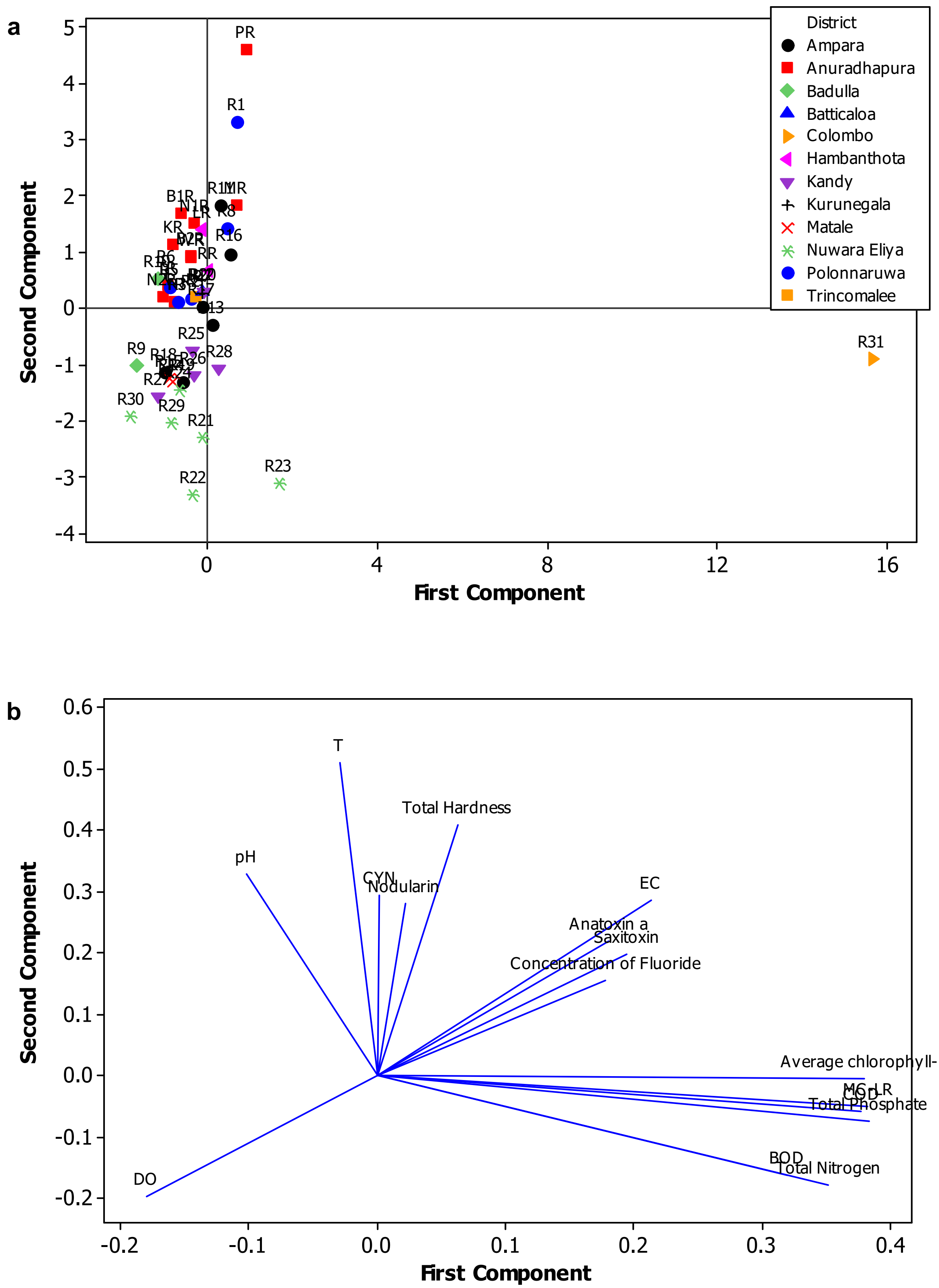

Fig. 2 The Principle Component Analysis (PCA) of water quality parameters in selected reservoirs in Sri Lanka

to Kasthuriarachchi et al. (2016), the MaduruOya reservoir has recorded a high accumulation of nutrients which leads to eutrophication and growth of toxin-producing algal species such as Microcystis and it affected the ecosystem health and human livelihood.

The pH is one of the fundamental water quality parameters. According to Sri Lankan drinking water quality standards, the pH of the drinking water should have remained within the range of 6.5–8.5 (EPA 2007). Notably, the pH level of selected water reservoirs has remained within Environmental Protection Agencies' (EPA's) maximum permissible levels for drinking and recreational activities. EC comprises different inorganic salts and some organic matter that are dissolved in water (Mahagamage et al. 2019). The reservoirs like Beira, Lunugamvehera, Sagama, and Mahakanadara wewa have recorded high EC values which were 1752 μScm^{-1}, 1552 μScm^{-1}, 1250 μScm^{-1} and 1666 μScm^{-1} respectively indicating the presence of the high amount of ions in the water.

Nitrate ($N\text{-}NO_3^-$) is another essential water quality parameter for aquatic life. Recently, the nitrate levels of the surface water reservoirs have increased due to improper anthropogenic activities (Mahagamage et al. 2019). The health impact of high nitrate and nitrite-contaminated water caused the formation of methemoglobinemia, and blue baby syndrome was recorded in different regions of the world (Singh et al. 2022). Therefore, the nitrate levels of the studied reservoirs have remained below the standard levels except for Beira Lake.

The total phosphorous (TP) concentrations in the surface water are relatively low due to the low solubility of the phosphorous (Varol et al. 2020). However, phosphate concentration can increase due to accumulating phosphate detergents in reservoirs (Sirisena and Suriyagoda 2018). Nitrates and phosphates are the significant nutrients contributing to reservoirs' eutrophication phenomenon. In many cases, phosphorous is the limiting factor for the growth of algae and cyanobacteria (Zeng et al. 2016). To control eutrophication, the Environmental Protection Agency has established a recommended limit of 0.05 mg/L for total phosphates in streams that enter lakes (EPA 2007). According to the recorded values of total phosphate of the reservoirs, Polgolla, Lunugamvehera, Maussakele, Gregory, and Beira lakes have recorded the values 0.05 mg/L, 0.08 mg/L, 0.015 mg/L, 0.105 mg/L, 1.22 mg/L respectively. Water hardness is another vital water quality parameter generally expressed as the total concentration of calcium and magnesium ions in water. The Ca^{2+} and Mg^{2+} ions are the most important ions for hardness, and the unique reservoirs located in the northwestern province showed a greater hardness level (Mahagamage et al. 2019). In the present study, the highest total hardness values were recorded in Ambagaswewa (Value) and Dambulu oya (Value).

The coliform count is one of the critical microbiological parameters widely used to determine the contamination potential of drinking water with fecal matter (Mahagamage et al. 2020). *E. coli* is a coliform species always found in warm-blooded animals' guts (Edokpayi et al. 2018). Suppose the water is contaminated with fecal coliform. In that case, it is more likely to present some pathogenic bacterial species, such as *Salmonella* sp., *Shigella* sp., *Campylopytor* spp., etc., which can cause severe waterborne illnesses. According to the Sri Lankan drinking water standards, the maximum permissible level of fecal coliform in 100 mL of water is zero. The results indicated that 58% of studied reservoirs recorded a coliform count greater than 200 CFU/100 mL, indicating the water of those reservoirs was microbiologically unsatisfactory for direct consumption.

The mechanism of water contamination is critically important for the proper legislation and monitoring policies of the reservoirs in the country. Based on the overall water quality analysis it can clearly stated that the Baira Lake is the most polluted water body situated in Colombo (wet zone), Sri Lanka's capital. The water of Baira Lake has been contaminated with toilet effluents from the adjacent toilet pits of the city. Further, the poor sanitary facilities of the city, higher population density and the accumulation of the rainwater run off with may result from the high nitrate concentration, leading to a severe eutrophication problem (Madarasinghe et al. 2020). The Lunugamvehera and Mahakanadara reservoirs which situated in intermediate and dry zones respectively, were recorded high EC values which may be attributed to the geographical variation of the soil beds associated with the water body. Particularly, the abundance of the agricultural lands and frequent usage of nitrogen fertilizers around the Sagama and Lunugamvehera reservoirs may positively impact to concentrate the nitrate and phosphate ions in the reservoirs increasing the EC, TP and in the reservoirs. Additionally, Maussakele (Wet zone) and Gregory Lake (wet zone) have recorded high TP which may be due to the direct discharge of detergents which are used by the surrounding rural community that have associated with tea estates and the tourism-related anthropogenic activities respectively.

Regarding the surveillance for cyanotoxins, previous studies reveal that MC-LR is well distributed while the CYN was circumscribed to limited locations (Abeysiri and Manage 2019). However, there are no reports on the contamination status of reservoirs with anatoxin-a, saxitoxin, and nodularin in Sri Lanka. In the present study, MC-LR was detected as the dominant toxin (> 50%) in collected reservoir samples compared to the CYN (< 10%), SAX (< 10%), NOD (< 10%), and Ana-a (< 10%). MC-LR occurrence is well supported by the presence of *Microcystis* sp. in more than 70% of studied reservoirs in Sri Lanka (Abeysiri and Manage 2019). Freshwater ecosystems carry those toxins and have several impacts on drinking, irrigation, and recreation, and several socio-economic activities have been attributed, such as agriculture, sports, and even tourism. Moreover, dermal, inhalation, or ingestion of contaminated water, directly or indirectly, can occur if populations are misinformed. Very high concentrations were found in surface cyanobacterial scum in Germany (up to 120 ug/L) and Algeria (711.8 ug/L), but these represent a different type of sample and also a different type of analytical method (protein-phosphate assay inhibition) was employed than that used in the present study. Comparatively lower values were reported from Finland (0.21 µg/L), where water blooms are often dominated by different cyanobacterial species than *Microcystis* sp., which is common in Europe.

Although the most usual route of human ingestion of toxins is drinking contaminated water, the accumulation of toxins in vegetables may increase the number of intoxications and the long-term effects, including the risk of cancer (Gupta et al. 2019). Cattle and wildlife, including protected species, may also suffer from the presence of the toxin. Cases of mortality in wild birds due to drinking contaminated water have been recorded in Japan and Denmark (Rattner et al. 2022).

Cyanobacteria breakdown products are significant in providing nutrients for total coliforms existing in the biofilm. When these nutrients are present in small quantities, as is the case for much of the year, the chlorine residual can control any potential growth and cyanobacterial breakdown, providing the nutrition for total coliform regrowth (Kulasooriya 2017). The results of these studies indicate a strong link between the end of the cyanobacteria bloom and the cyanotoxin levels and coliform occurrences in the distribution system. There is likely an increase in available carbon from the cyanobacteria breakdown products, enabling coliforms to regrow (Kollu and Ormeci 2015). Ramanan et al. (2016) detail the role of cyanobacteria-derived toxins and other nutrients in the aquatic environment; cyanobacteria photosynthetic and decomposition processes release hazardous toxins, carbon, and other nutrients are used by bacteria in various mutualistic and competitive relationships.

Moreover, the loading plot of PCA indicated a clear correlation among chlorophyll-*a*, MC-LR, COD, BOD, total phosphate, and total inorganic nitrogen parameters in the reservoirs. Chlorophyll-*a* is regularly used as an estimate of algal biomass, and it is estimated that algal blooms may occur when the chlorophyll-*a* concentration increases by more than 40 μgL^{-1} (Balali et al. 2013). Nitrogen and phosphorous are vital macronutrient for algal growth and plays an important role in the stability of the ecosystem (Yaakob et al. 2021). Accordingly, Beira Lake has recorded very high total nitrogen and phosphate values, and Chlorophyll-*a*, MC-LR, COD, and BOD may increase due to rapid algae growth. Similar results were obtained in the Weerasinghe and Handapangoda (2019) study to analyze surface water quality in Beira Lake from 08 judgmental sampling sites for 06 months period from May to October 2017.

In the present study, the lakes in the Nuwara Eliya district were clustered together, and the dissolved oxygen values were high for the lakes. At the same time, low water temperatures were recorded in these lakes. The dissolved oxygen amount in a given volume of water depends on several reasons, including atmospheric pressure, water temperature, and the amount of other substances dissolved in the water. Accordingly, these lakes may have high dissolved oxygen amounts due to low water temperature. Weerasinghe and Handapangoda (2019) recorded similar results in the study, which analyzed water quality in Gregory Lake, Nuwara Eliya, concerning the dynamic input and output.

The presence of cyanotoxins in water sources poses serious health risks to both humans and animals if ingested or exposed to affected water. These toxins can cause various health issues, ranging from skin irritation to gastrointestinal problems and, in severe cases, potential liver damage or neurotoxic effects. Monitoring cyanotoxin contamination involves routine testing of water bodies, especially those used for drinking water, recreational activities, or agricultural purposes. Therefore, the status of cyanotoxin contamination represents nutrient pollution, poor land use, and inadequate water quality management in these reservoirs. Frequently, water quality monitoring and assessment for cyanotoxin presence is timely important.

The impairment of water quality in reservoirs depends on various factors, including seasonal variations, elevation, geographical distribution, and urban or rural metrics. When considering climate and elevation, only a few selected reservoirs were located in the Nuwara Eliya, Badulla, Kandy, and Matale districts, which have higher elevations in the country. Importantly, there was no noticeable difference in physicochemical parameters, cyanotoxins, and phytoplankton data between reservoirs at high and low elevations (Table 1).

However, urban and rural metrics affected the water quality of certain reservoirs. Particularly, Baire Lake and Gregory Lake, located in the densely populated Colombo and Nuwara Eliya cities, were severely contaminated with high nitrate and phosphate levels, resulting in elevated levels of fecal coliforms and phytoplankton in the water due to extensive population density and effluent discharge into the reservoirs (Table 1).

Nevertheless, some reservoirs in rural areas also recorded lower water quality, especially Basawakkulama Reservoir and Maussakele Reservoir. This may be attributed to poor agricultural practices linked to the excessive use of chemical fertilizers on agricultural lands.

Based on the results of the present study, it is encouraged to adopt sustainable agricultural practices to reduce the runoff of nutrients and pesticides into reservoirs, invest in wastewater treatment facilities to prevent the discharge of untreated water into reservoirs, establish comprehensive water quality monitoring programs, create buffer zones around reservoirs to reduce the impact of human activities and increase public awareness programs.

Conclusion

According to the overall result of the present study, most of the reservoirs are polluted and the water quality has deteriorated. Beira Lake in Colombo district which is situated surrounded by highly urbanized areas is a highly polluted reservoir and each water body was contaminated with at least one algal toxin tested. Furthermore, most of the reservoirs have recorded the presence of fecal coliform indicating high health risks in humans. The water quality measurements in most of the reservoirs indicated negative impacts on the ecological balance of the ecosystem and these results indicate the necessity of proper treatment facilities for the reservoirs in Sri Lanka.

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Data availability The datasets generated and analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest or personal relationships that could have appeared to influence the work reported in this paper.

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