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Integrated Assessment of Kirala Kele Wetland Health: Bridging the Gap between Water Quality Parameters and Biotic Components

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ABSTRACT

The present study was carried out to assess the health of the Kirala Kele Wetland, Sri Lanka, by coupling water quality indices and bioindicators. A total of 12 sampling sites were selected to represent different land-use patterns of the Kirala Kele Wetland using purposive sampling technique, and sampling was conducted from March 2021 to May 2021, on a monthly basis. Triplicated samples ($n = 3$) were obtained for each sampling event at each sampling site. Aquatic macroinvertebrates were collected from each site to determine the biological water quality using the Biological Monitoring Working Party (BMWP) score. Weighted Arithmetic Water Quality Index (WAWQI) was calculated to understand the physicochemical parameters of water, and the mean values of physicochemical water quality parameters were compared with the Sri Lankan water quality standards. According to the WAWQI for the different sampling sites, water is not suitable for drinking without treatment. The resulted BMWP score (BMWP = 61) shows that the water quality is acceptable (clean but slightly impacted) for biotic components of the wetland in accordance with the aquatic macroinvertebrates present. Spatial variation in water quality parameters and the aquatic macroinvertebrates were taken into account, and the temporal variation in water quality parameters within the 3 months from March to May was considered.

Key words: biological indicators, Kirala Kele Wetland, macroinvertebrates, water quality monitoring, wetland health assessment

HIGHLIGHTS

- Results show that the Biological Monitoring Working Score (61) indicates the water quality is acceptable for biotic components of the wetland.
- It showed a spatial and temporal variation in water quality parameters from March to May in the Kirala Kele Wetland.
- To maintain the wetland's health, it is important to focus on reducing and preventing human activities that contribute to its pollution.

1. INTRODUCTION

A region that is either permanently or temporarily saturated with static or flowing fresh, brackish, or salt water in areas of marsh, fen, and peat land is referred to as a wetland (Ramsar Convention 2014). Wetlands are mainly divided into natural wetlands and artificial wetlands. Both these types of wetlands perform a range of functions (physical, chemical, and biological processes-based) of natural water purification by filtering and absorbing a wide variety of pollutants found in surface water (Dias *et al.* 2021), phytoremediation (Jabłońska *et al.* 2021), and bioremediation (Dias *et al.* 2021), providing a habitat for flora and fauna (Rahimi *et al.* 2020), grazing areas for animals, and opportunities for tourism (Fernando & Shariff 2017), flood control (Rojas *et al.* 2022), and carbon sequestration (Byun *et al.* 2019). In terms of ecological perspectives, these wetland systems can also act as naturally occurring defenses against the risks posed by climate change (Eller *et al.* 2021). Conversely, wetlands provide main ecosystem services, including climate regulation (Salimi *et al.* 2021), supporting healthy ecosystems and maintaining biodiversity (Baker *et al.* 2009), and water purification and waste treatment (Xu *et al.* 2020). Considering the human benefits, wetlands cater ecosystem services such as providing food (for fish, shellfish, waterfowl, migratory birds, and human beings also) (de Groot *et al.* 2018), medical resources (Yang *et al.* 2019), recreational opportunities (birdwatching, fishing, and boating) (Saranga *et al.* 2022), and economic benefits (fishing and tourism, increasing property values in adjacent areas) (Aazami & Shanazi 2020). Overall, wetlands play a vital role in supporting a healthy planet and providing benefits to both wildlife including flora and fauna and people. Therefore, these wetland ecosystems are essential for the

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maintenance of aquatic biodiversity, as many plant and animal species are refugees of wetland ecosystems. Unfortunately, ecosystem services and functions provided by wetlands are overweighted by anthropogenic and natural disturbances impacting wetland systems, causing them to degrade their conditions.

With regard to the disturbances in wetlands, anthropogenic activities coupled with natural scenarios have alarmingly negative effects on the water quality, sustainability, and functionality of aquatic ecosystems. For instance, discharge of untreated industrial effluents into water bodies, which can lead to water pollution, is a significant problem in the context of the global environment (Aniyikaiye *et al.* 2019). It has become a significant environmental problem, mainly in developing countries like Pakistan (Aniyikaiye *et al.* 2019), India (Singh *et al.* 2018), Nigeria (Odipe *et al.* 2019), Ethiopia (Dadi *et al.* 2018), and Sri Lanka (Corea 2019), where industrial effluents that have not been treated are discharged into surrounding bodies of water (Aniyikaiye *et al.* 2019). Because of improper practices of industrial and commercial sectors, the majority of industries in the developing nations either directly or indirectly discharge partially treated or raw wastewater into ecosystems (Corea 2019), which include pathogenic organisms, oxygen-demanding organic substances, plant nutrients that stimulate algal blooms, and both inorganic and organic toxic substances including heavy metals (Firdissa *et al.* 2016). It has been discovered that certain heavy metals found in industrial effluents can cause detrimental health risks such as cancers (Karri *et al*. 2021). In addition, wetland systems are challenged in various ways fueled by the negative human activities like siltation, dredging (Oldenborg & Steinman 2019) poaching (Chatterjee & Bhattacharyya 2021), and waste dumping (Gohain & Bordoloi 2021). These adverse effects trigger the loss of habitats and biodiversity, forced extinction of species, spreading of invasive species, among others.

In addition, socioeconomic attributes, namely, poverty, inequality, and a lack of resources, in this sense, accelerate the vulnerability and susceptibility of communities to wetland loss and degradation, while competing land-use priorities and ineffective governance make conservation and protection difficult (Syuhada *et al.* 2020; Joshi *et al.* 2021). Therefore, it should be comprehensively understood that this is typically not brought on by events within the wetlands themselves but rather by activities on areas around or outside of the wetlands (Kotagama & Bambaradeniya 2006). Impact mitigation of human activities and natural phenomena on wetland health decline requires a holistic and interdisciplinary approach that considers the interplay between these factors, the role of wetlands in providing ecosystem services, and the social and economic drivers of wetland degradation (Basu *et al.* 2021). By understanding the complex and interrelated challenges facing wetlands, it is a timely and topical need to develop effective tools and strategies for conserving and restoring these important ecosystems.

Water quality indices based on chemical, biological, and physical attributes, are commonly used tools in water quality monitoring programs to assess the health of aquatic ecosystems and identify changes in water quality over time (Tirkey *et al.* 2013). Chemical water quality indices are based on the measurement of chemical parameters such as pH, dissolved oxygen (DO), and nutrient levels that provide information about the overall water quality (Uddin *et al.* 2021). In addition, physical water quality indices are based on the measurement of physical parameters such as water temperature, flow, and turbidity that provide information about the physical conditions of the water body (Ankcorn 2003). Each of these water quality indices provides a unique perspective on the health of aquatic ecosystems and the impacts of human activities and other stressors. However, the selection of water quality index (WQI) depends on the specific goals and needs of each monitoring program, and thus, a comprehensive and integrated approach is recommended for the most effective assessment of water quality (Tyagi *et al.* 2020). By combining different water quality indices, it is possible to obtain a more complete picture of the health of aquatic ecosystems and to identify the most effective approaches for conserving and managing these systems.

The Weighted Arithmetic Water Quality Index (WAWQI) combines multiple chemical, physical, and biological parameters into a simple and straightforward (Bouslah *et al.* 2017) single score that reflects the overall water quality of a river, lake, or other water body (Tyagi *et al.* 2020). Once the WAWQI score is calculated, it is typically compared with a reference or threshold value that is typically established based on the desired water quality conditions for the specific ecosystem (Central Environmental Authority 2019). However, it is important to consider the limitations and challenges associated with WAWQI. The WAWQI may not provide sufficient detail to identify specific causes of poor water quality or to evaluate the effectiveness of specific conservation and management strategies.

Rapid Bio Assessment protocols assess aquatic ecosystem health on a large scale or over a long term by evaluating a waterbody's aquatic plants, animals, and biological indicators quickly to allow quick and effective management decisions. The Biological Monitoring Working Party (BMWP) promotes biological water quality and aquatic ecosystem health assessments by raising awareness of their value and importance (Rizo-Patrón *et al.* 2013). BMWP sets biological data collection, analysis, and interpretation standards to support water quality monitoring programs to improve biological data accuracy, reliability, and accessibility (Uherek & Pinto 2014).

Among available bioindicator categories, benthic macroinvertebrates make up the majority of the used biota at the moment (Holt & Miller 2011) because of their sessile nature, ease of sampling, and wide diversity based on their position in the aquatic ecosystem food chain (Jain *et al.* 2010). They are often used to monitor changes in wetland ecosystems, detect the impacts of human activities and other stressors, and evaluate the effectiveness of conservation and management efforts (Shimba & Jonah 2016). One of the key advantages of using aquatic macroinvertebrates in these programs is that they provide a wide range of information about the health of wetland ecosystems. For example, the abundance and diversity of macroinvertebrates can provide insight into water quality, habitat conditions, and the presence of pollutants (Holt & Miller 2011). These organisms also play an important role in the food web of wetlands, providing critical resources for other species, such as fish and waterfowl (Jain *et al.* 2010). To generate high-quality data that can be used to assess the impacts of human activities, evaluate the effectiveness of conservation and management efforts, and inform policy decisions related to wetland conservation, it is essential to use established methods for sampling and identifying these organisms.

In the global context, many scientists have extensively employed macroinvertebrates to evaluate the health of wetland ecosystems worldwide, from European countries to the South Asian region (Lenat 1988; Rizo-Patrón *et al.* 2013; Uherek & Pinto 2014; Deborde *et al.* 2016; Shimba & Jonah 2016). Because of the length of their life cycles, macroinvertebrates serve as reliable indicators as they are able to detect changes brought on by any disturbances and respond while they are common and abundant. According to (Paz *et al.* 2014), the degree to which macroinvertebrates are affected by pollution varies. However, there are also significant limitations to consider when using aquatic macroinvertebrates in wetland health and water quality assessment programs. For example, the abundance and diversity of these organisms can be influenced by a range of factors, including water flow, temperature, and the presence of other species (Holt & Miller 2011). Hence, there exists a need to use a rigorous and consistent sampling methodology to ensure that data from different studies or locations can be compared and integrated effectively.

In the Sri Lankan context, Amarathunga & Fernando (2016) investigated the suspended sediment concentration and its impact on aquatic invertebrates in the Gin River, Sri Lanka, to identify the pollution level and water quality of the river. Furthermore, the impacts of agricultural practices on water quality in the Uma Oya Catchment area in Sri Lanka with the incorporation of aquatic macroinvertebrates was determined by Gunawardhana *et al.* (2016). Gunawardhana *et al.* (2018) investigated the spatiotemporal variation of water quality and bioindicators of the Badulu Oya Catchment in Sri Lanka because of the catchment disturbances. A research on land-use impacts on the health of the Uma Oya was done by Jayawardana *et al.* (2017). Wijeyaratne & Liyanage (2021) performed research on Macrobenthos-based Rapid Bioassessment as a tool to assess the sediment and water quality in a treated textile effluent receiving stream ecosystem associated with a wetland marsh. Moreover, research in water quality assessment of the Diyawannawa wetland was based on macrobenthic mollusks diversity (Wijeyaratne & Bellanthudawa 2017).

The Kirala Kele Wetland, is located in Matara, southern province, Sri Lanka, and unfortunately, its water quality has been affected by different causes, which ultimately impact negatively on human, animal, and plant survival (Li & Wu 2019). As the water is consumed by the wetland-dependent communities around the Kirala Kele Wetland for agriculture and drinking purposes, ensuring the wellbeing of this wetland is mandatory to prevent environmental and health risks. To monitor the wetland health, assessment of the water quality in the Kirala Kele Wetland can be conducted along with the awareness programs addressing stakeholder involvement.

In this light, the present study was carried out with the objectives of (1) assessing the water quality of the Kirala Kele Wetland against the physical and chemical water quality parameters, (2) assessing the water quality using WAWQI, (3) assessing the biological water quality parameters with the aid of bioindicators, and (4) assessing the water quality using the BMWP score system, to monitor the health of the wetland. The scientific questions that the present study needs to answer are as follows: (1) Is there any spatial variation of the water quality during the study period? (2) Is there any temporal variation in water quality during the study period? (3) What are the deviated water quality parameters from the water quality standards and possible reasons for deviations? (4) What are the spatial variations of the bioindicators and aquatic macroinvertebrates during the study period? (5) And what is the relationship between the water quality and the bioindicators showing about the environmental changes of the selected sampling sites of the Kirala Kele Wetland? The scientific breakthrough of the present study is that this research aids to understand the suitability of water in the wetland for meeting environmental and drinking water standards using bioindicators. By addressing these questions, the research provides essential insights for effective wetland management and underscores its broader significance in ensuring water quality compliance with regulatory standards and environmental conservation efforts.

2. MATERIALS AND METHODS

2.1. Study area and sampling sites selection

The Kirala Kele Wetland, plays a crucial role in the lives of local communities as an urban freshwater wetland. The Kirala Kele Sanctuary, spanning the coordinates 5 ° 58′ 38″ N – 5 ° 59′ 35″ N and 80 ° 31′ 27″ E – 80 ° 34′ 25″ E, is strategically positioned at the exit of the Southern Expressway in Godagama, approximately 3 km from Matara city (Fernando 2019). This revering partial nature-based wetland is nestled beside the Nilwala River in a small area, evolving from a back swamp on the right bank of the basin, behind the Nilwala River (Fernando & Shariff 2017). The wetland comprises various sub-ecosystems and serves as a coastal freshwater wetland within the Southern province of Sri Lanka. While specific details on the size and hydrology of the Kirala Kele Wetland require further investigation. Its proximity to the Nilwala River and coastal features adds to its ecological significance. The surrounding land use includes diverse activities such as industrial operations, solid waste dumping, intensive fishing, agriculture, livestock raising, land farming, human settlements, and tourism. However, with the increasing urbanization and anthropogenic activities in the region, the wetland faces potential pollution threats, emphasizing the need for comprehensive research to identify and address pollution sources for effective conservation and management.

The water sampling locations (Figure 1) were selected purposively by the sampling technique using educated judgments to reflect the impacts of different land uses of the Kirala Kele Wetland. In the process of selecting sampling sites, site 01 was

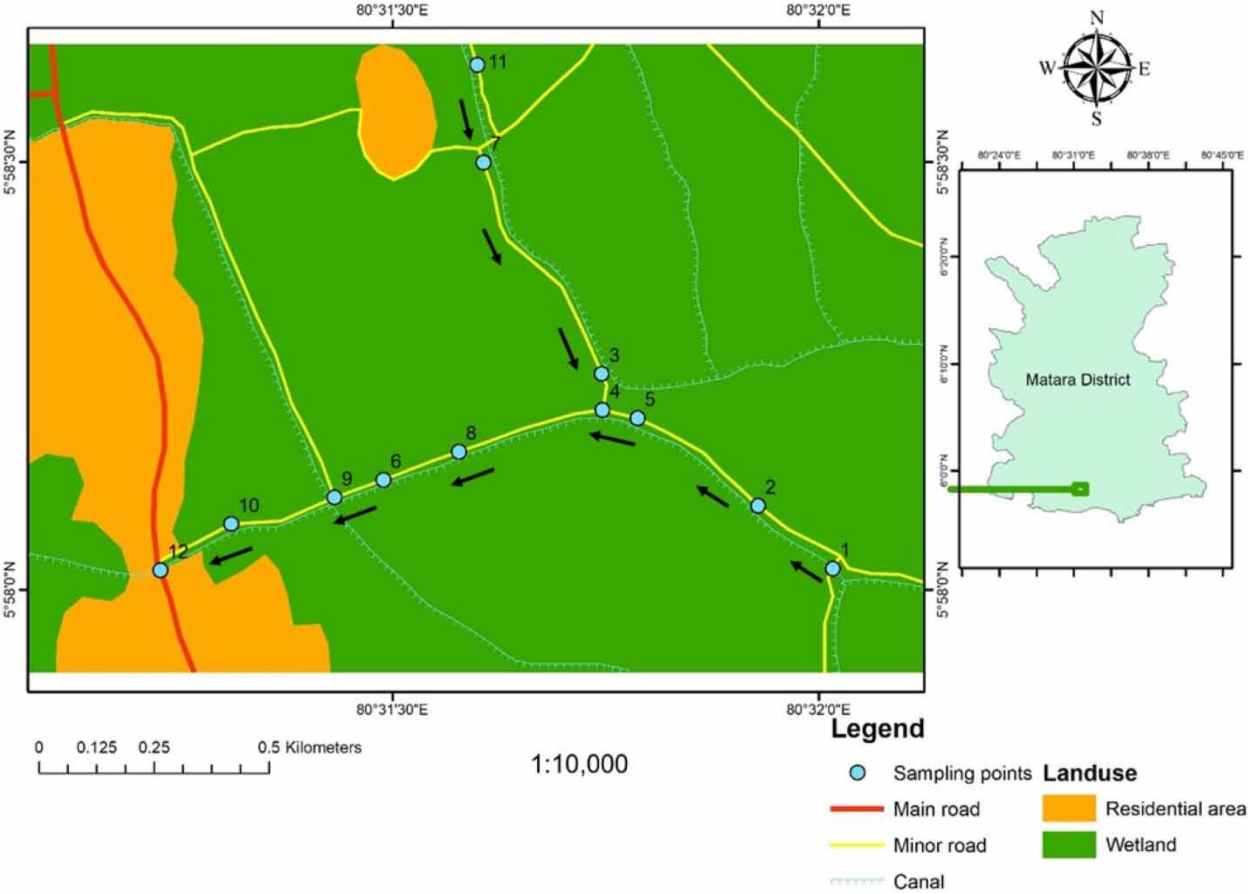


Figure 1 | Selected 12 sampling sites in the western part of the Kirala Kele Wetland. The black color arrows show the water movement of the wetland.

selected from the location with decaying leaves on the water layer. It is characterized by natural vegetation cover (trees and shrubs) and a sheltered environment, and thus site 01 was named as the reference site. Site 02 is mainly characterized as a waste dumping site and as a polluted site. Sampling site 03 was a location where wetland water shows some movement while having no emergent aquatic flora. Furthermore, a high floral density was observed in site 04, and it is characterized by emergent, floating, submerged, and merged aquatic flora and also by high diversity of fauna. The wetland bank is well covered with shrubs and bushes, besides some trees and grass. Site 05 is where the water is stagnant (non-flowing), and this sampling site can be characterized by floating aquatic flora. In site 06, there were some local practices such as agriculture, specifically paddy cultivation, which utilize synthetic fertilizers. In addition, site 07 was a location with a muddy wetland bed. Site 08 is the location where buffaloes take bath, which has a cool environment. In site 09, rigorous numerous human visits can be seen, indicating a lot of human interactions. This sampling site is characterized by different artificial concrete structures. Site 10 is the location where household activities are practiced majorly, which result in dumping household solid waste and wastewater. Site 11 is the inflow water stream of the wetland. Finally, Site 12 is the outflow water stream of the wetland that exposes Godagama city.

2.2. Sampling protocol

The overall comprehensive framework of the present study is illustrated in Figure 2. There are two main sections in the framework, including water quality monitoring and aquatic macroinvertebrate monitoring.

2.3. Water quality sampling

The water samples were collected from 12 sampling sites along 3 km of the wetland bank. Water samples to determine the water quality were collected in 30-day interval (monthly basis) from March to May 2022. Every water sample was taken from the wetland, from a location where the water was well mixed and could be reached safely. Water samples were collected from a depth of 25 cm, at a distance of 30 cm from the channel bank. The simple random sampling technique was adopted in the water quality sampling. Collected water samples were stored in previously cleaned high-density polyethylene bottles of the same size and shape. After storing, sample preservation was conducted using sulfuric acid.

In case of physical and chemical water quality assessment, water temperature, pH, turbidity, biological oxygen demand (BOD_5), DO, total suspended solids (TSS), electric conductivity (EC), Nitrate-Nitrogen (Nitrate-N), and Ammonium-Nitrogen (Ammonium-N) were analyzed (Table 1). Water quality parameters such as water temperature, pH, and DO were measured on the sites itself (on-site parameters) by mercury bulb thermometer, pH meter (Hannah, HI-98127, made in USA), and DO meter (Hannah, HI-9146, Made in USA), respectively. Other parameters: BOD (Titrimetric [APHA, 5210B] testing method), turbidity (turbidity meter – 2100P, made in USA), TSS (conventional gravimetric laboratory procedure), EC (EC meter-Hannah, HI-98129, made in USA), Nitrate-N (ultraviolet spectrophotometer), and Ammonium-N (ultraviolet spectrophotometer), were determined after bringing the water samples into the laboratory in the Department of Agriculture Engineering and Environmental Technology, Faculty of Agriculture, University of Ruhuna.

2.4. Sampling of macroinvertebrates

Samples for analyzing aquatic macroinvertebrates to determine the water quality were collected in 30-day intervals (monthly basis) from March to May 2022. The collection method used to gather the sample macroinvertebrates is the kick sampling, and this method involves using a net to sample organisms from the substrate by kicking the sediment upstream (Eriksen *et al.* 2021). The collected samples were sorted in the laboratory in the Department of Agriculture Engineering and Environmental Technology, Faculty of Agriculture, University of Ruhuna, and the macroinvertebrates are identified to the family level. This was done using a microscope and standard taxonomic keys. The data collected from the sampling was analyzed to assess the health of the ecosystem. Metrics such as the presence/absence of sensitive taxa and the diversity index (BMWP score system) were used to determine the overall health of the ecosystem.

2.5. Data analysis

2.5.1. Spatial and temporal variation of water quality

Spatial and temporal variation of the selected water quality parameters were observed in all the 12 sampling sites of the western part of the Kirala Kele Wetland. They were analyzed with the aid of Minitab 17 statistical software and Microsoft Excel software, by incorporating with one-way ANOVA test for each sampling site and every sampling event (March, April, and May). The spatial variation of water quality (mean and the standard error of mean) was calculated.

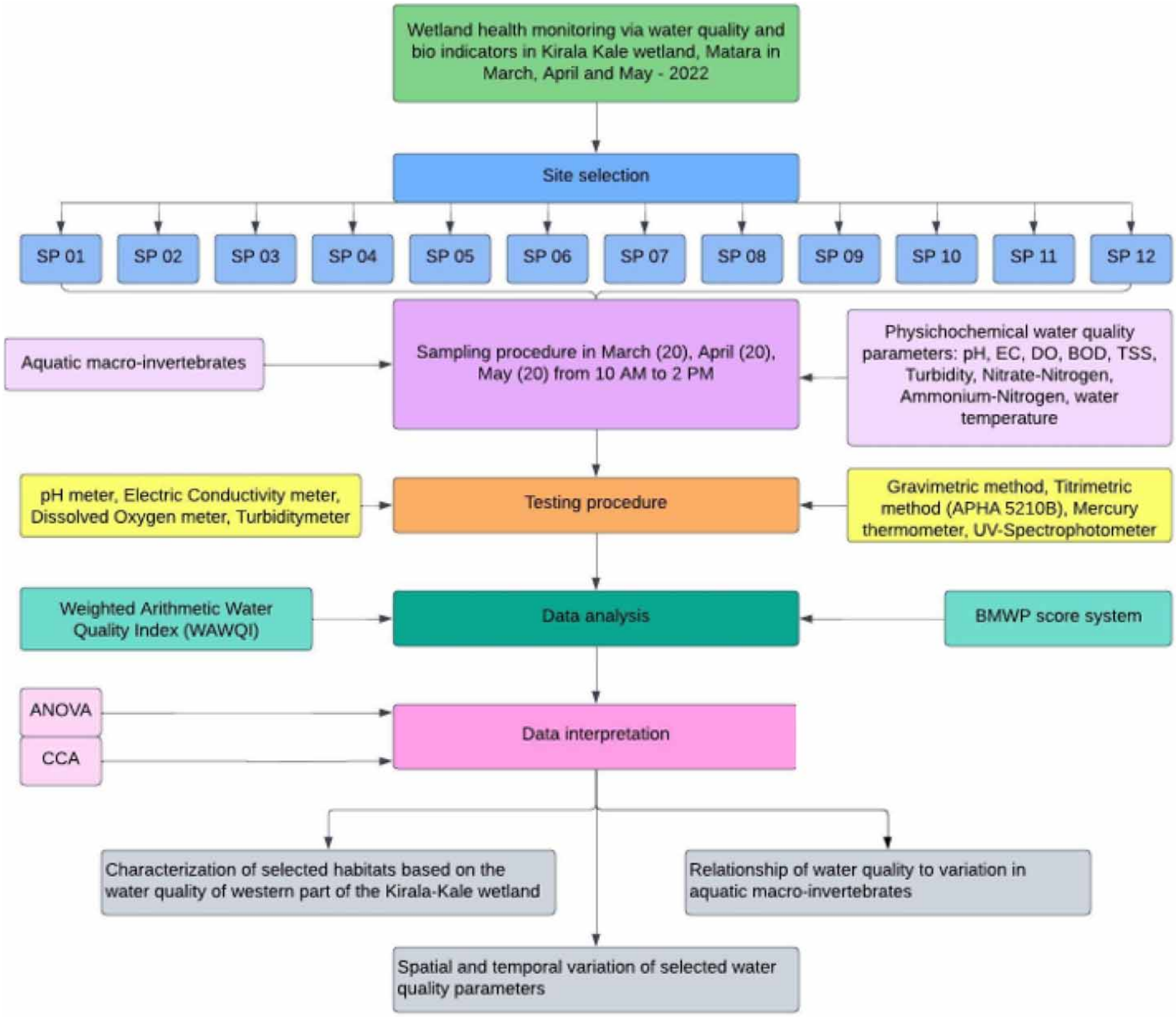


Figure 2 | The overall comprehensive framework of the research study.

Table 1 | Analyzed water quality parameters with standard methodologies

Parameter	**Standard method**	**Reference**
pH	Method 9040C	Brraich & Saini (2015)
EC	2-ac bipolar method	Brraich & Saini (2015)
DO	Titrimetric method	Dissanayake *et al.* (2014)
BOD	Titrimetric (APHA, 5210B) method	Dissanayake *et al.* (2014)
TSS	Gravimetric method	Yahyapour *et al.* (2014)
Turbidity	Nephelometric method	Bouslah *et al.* (2017)
Nitrate-N	Spectrophotometric method	Aluker *et al.* (2019)
Ammonium-N	Spectrophotometric method	Li *et al.* (2020)
Water Temperature	Fixed point method	Brraich & Saini (2015)

The standard values for the quality of water for drinking, irrigation, recreational activities, and bathing were recorded from the National Environmental Act No. 47 of 1980, the gazette of the Democratic Socialist Republic of Sri Lanka – 05/11/2019 (CEA 2019). Then these water quality parameters were compared with the Sri Lanka standards (SLS) guidelines to understand the suitability of water of the Kirala Kele Wetland for the aforementioned purposes.

2.5.2. WQI calculation

The WAWQI method was used to calculate the WQI (Equation (1) to Equation (5)) for the Kirala Kele Wetland (Misaghi *et al.* 2017). The calculated WAWQI values are related to specific water quality ratings and gradings (Table 2).

$$\mathrm{WQI} = \sum Q_i \times W_i, \tag{1}$$

where Q_i is the quality rating scale and W_i is the relative weight

$$\text{Overall WQI} = \frac{\sum Q_i \times W_i}{\sum W_i}, \tag{2}$$

Quality rating scale (Q_i) was calculated as follows:

$$Q_i = \frac{V_i - V_0}{S_i - V_0} \times 100, \tag{3}$$

where V_i is estimated concentration of the ith parameter in the analyzed water, V_0 is the ideal value of this parameter in pure water $V_0 = 0$ (except $\mathrm{pH} = 7.0$ and $\mathrm{DO} = 14.6\ \mathrm{mg/L}$), S_i is recommended standard value of the ith parameter, and relative weight (W_i) was calculated using the following equation:

$$W_i = \frac{K}{S_i} \tag{4}$$

$$K = \frac{1}{\sum \frac{1}{S_i}} \tag{5}$$

where K is the proportionality constant (Brraich & Saini 2015).

2.5.3. Variation of aquatic macroinvertebrates

The BMWP score system was used to assess the biological water quality in the Kirala Kele Wetland with the aid of aquatic macroinvertebrates as an indicator. The cumulative BMWP score for the wetland represents the water quality category according to Table 3. The BMWP score was calculated based on the presence of a taxon from any of the 12 locations in the wetland (Table 4) (Uherek & Pinto 2014).

The presence and absence of aquatic macroinvertebrates in the 12 sampling sites was tabulated. This table can be used to characterize sampling sites according to the presence of any aquatic macroinvertebrate species.

Table 2 | WAWQI and related water quality categories (Misaghi *et al.* 2017)

WAWQI	Rating of water quality	Grading
0–25	Excellent water quality	A
26–50	Good water quality	B
51–70	Poor water quality	C
71–90	Very poor water quality	D
91–100	Unsuitable for drinking purpose	E

Table 3 | BMWP classes, scores, categories, and descriptions (Uherek & Pinto 2014)

Class	BMWP score	Category	Description
I	>150 and 101–150	Good	Very clean water and Clean or not significantly altered
II	61–100	Acceptable	Clean but slightly impacted
III	36–60	Questionable	Moderately impacted
IV	15–35	Critical	Polluted or impacted
V	<15	Very critical	Heavily polluted

2.5.4. Characterization of sites using selected water quality parameters with aquatic macroinvertebrates

Canonical correspondence analysis (CCA) was performed to identify the association among the variation in water quality parameters and the presence or absence of the aquatic macroinvertebrates with the aid of R programming 4.1.3 version.

3. RESULTS

3.1. Spatial variation of water quality parameters

The spatial variation of 9 different water quality parameters in 12 sampling sites during the study period is clearly shown in Figure 3. There was no spatial variation between the pH values of the 12 sampling sites (Figure 3(a)) within the study period ($p > 0.05$). Site 01 (the location with decaying leaves on the water layer) was recorded as the location with the lowest water temperature. The sampling sites 03 (locations where water is flowing) and 04 (locations with high floral density) significantly showed the lowest turbidity (Figure 3(f)) and TDS concentration (Figure 3(e)) in water. Moreover, sampling site 04 shows a significantly higher Ammonium-N level (Figure 3(h)) in water. The lowest average DO concentration (Figure 3(c)) and the highest average turbidity in water were recorded at site 06. The sampling site 07 (a location with a muddy wetland bed) represents the highest average EC (Figure 3(b)) in water during the study period. The location where buffaloes take baths was site 08, which has the highest average DO concentration in water. The site 09 where there is a high human visit presents significantly high TSS in the water and increased water temperature (Figure 3(i)).

3.2. Temporal variation of water quality parameters

The Annexure shows the temporal variations of water quality parameters in March, April, and May, respectively, for all sites. The results were analyzed with the aid of the software Minitab 17. The values of each parameter at the same sampling sites in different the months were compared ($p > 0.05$). When considering the pH value of the Kirala Kele Wetland, there was no significant difference between the months of April and May. There is a significant difference in pH between April and March and May and March. Moreover, there is a significant difference in turbidity values between the months of March and April and March and May. Further, there was a significant difference in Ammonium-N values between the months of March, April, and May, while there was no significant difference in the values of other parameters (EC, DO, BOD, TSS, and Nitrate-N) among the different months during the study period.

3.3. WAWQI

According to Figure 4, the highest WAWQI was recorded in the sampling site 07 (location having muddy wetland bed; WAWQI = 144.87), while the lowest WAWQI was from the sampling site 11 (where the inflow water stream of the wetland is located; WAWQI = 80.60). Site 10 (location where they mainly practice household activities) and site 05 (location where water is static) also showed lower WAWQI values during the study period. Sampling site 06 (location where they practice agriculture), site 08 (location where buffaloes take bath), and site 12 (where the outflow water stream of the wetland is located) depicted higher WAWQI values during the study period.

3.4. Current status of water quality with reference to the accepted SLS guideline values

According to Table 5, the pH of all sampling sites is within the range of the standard pH value for drinking. The EC of water in every sampling site exceeds the standard EC of water for drinking. The DO level of each of the 12 water sampling sites is lower than the standard DO level of water for drinking. Table 5 shows the BOD is higher in each sampling site than the standard value for drinking water. Water in every sampling site shows a better TSS concentration, as it shows values below the standard for drinking water. The turbidity at sampling site 01 is in between the standards, while the other sampling sites

Table 4 | BMWP taxa scores

Taxa	Score
Ephemeroptera – Siphlonuridae, Heptageniidae, Leptophlebiidae, Ephemerellidae, Potamanthidae, Ephemeridae	10
Plecoptera – Taeniopterygidae, Leutricidae, Capnidae, Perlodidae, Perlidae, Chloroperlidae	
Trichoptera – Phryganeidae, Molannidae, Beraeidae, Odontoceridae, Leptoceridae, Goeridae, Lepidostomatidae, Brachycentridae, Sericostomatidae	
Hemiptera – Aphelocheiridae	
Odonata – Lestidae, Agriidae, Gomphidae, Cordulegasteridae, Aeshnidae, Corduliidae, Libellulidae	8
Trichoptera – Psychomyiidae, Philopotamidae	
Plecoptera – Nemouridae	7
Trichoptera – Rhyacophilidae, Polycentropodidae, Limnephillidae	
Ephemeroptera – Caenidae	
Crustacea – Corophiidae, Gammaridae, Paleamonidae	6
Trichoptera – Hydroptilidae	
Mollusca – Neritidae, Viviparidae, Ancylidae, Unionidae	
Polycheata – Nereidae, Nephthyidae	
Odonata – Platyenemididae, Coenagriidae	
Coleoptera – Haliplidae, Hygrobiidae, Dytiscidae, Gyrinidae, Hydrophilidae, Helodidae, Dryopidae, Elminthidae, Chrysomelidae, Curculionidae	5
Diptera – Tipulidae, Simulidae	
Hemiptera – Mesovelidae, Hydrometridae, Gerridae, Nepidae, Naucoridae, Notonectidae, Pleidae, Corixidae	
Platyhelminthes – Planariidae, Dendrocoelidae	
Trichoptera – Hydropsychidae	
Arachnida	4
Coleoptera	
Diptera	
Ephemeroptera – Baetidae	
Megaloptera – Sialidae	
Hemiptera	
Annelida	3
Coleoptera	
Hemiptera	
Mollusca – Valvatidae, Hydrobiidae, Lymnaeidae, Physidae Plnorbidae, Sphaeriidae	
Crustacea – Asellidae	
Hirudinae – Glossiphoniidae, Hirudidae, Erpobdellidae	
Diptera	2
Chironomidae	
Annelida	1
Blattaria	
Diptera	
Lepidoptera	
Oligochaeta	

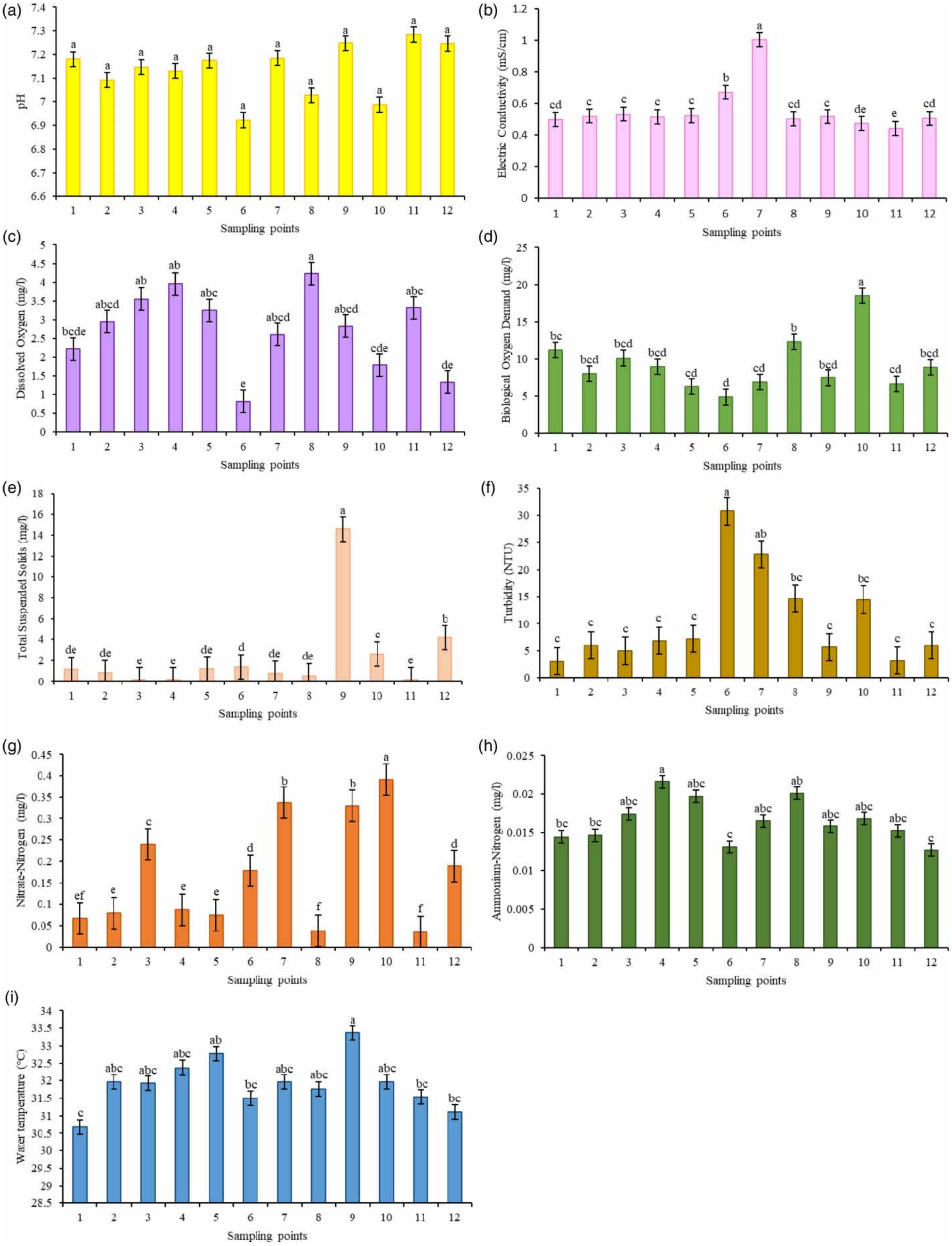


Figure 3 | Spatial variation of water quality parameters in the 12 sampling sites. The label on the bars with 'a, b, c, etc.' refers to the statistical significance of the relevant parameters across sites per the One-Way ANOVA results.

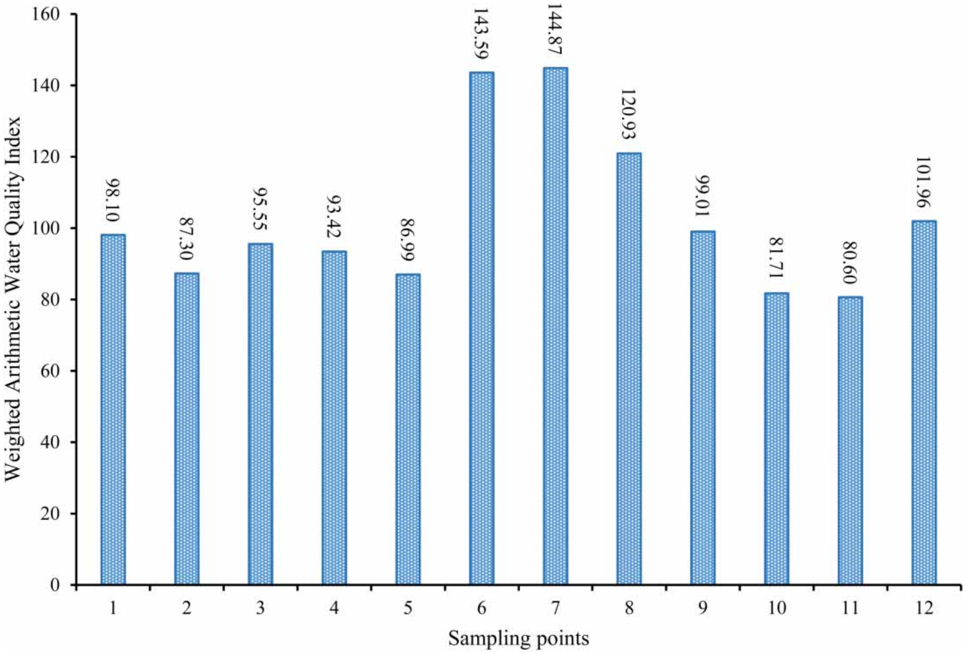


Figure 4 | WAWQI for different sampling sites during the study period.

Table 5 | Standard values of water quality parameters and deviations from the standard values

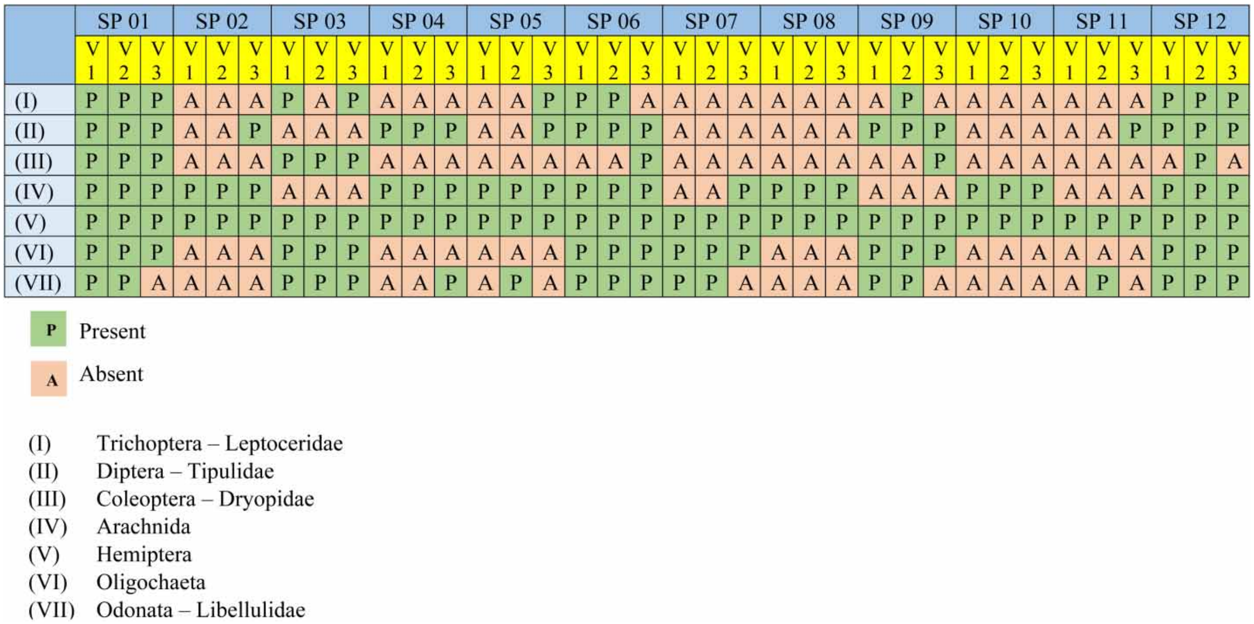
Water quality parameter	SP 01	SP 02	SP 03	SP 04	SP 05	SP 06	SP 07	SP 08	SP 09	SP 10	SP11	SP 12	Standard value
pH	7.18	7.092	7.146	7.13	7.174	6.922	7.184	7.027	7.248	6.987	7.284	7.246	6.0–8.5
EC	0.499	0.521	0.533	0.515	0.523	0.672	1.006	0.503	0.518	0.474	0.441	0.505	0.4 mS/cm (max)
DO	2.2156	2.9476	3.5501	3.9547	3.2512	0.821	2.6079	4.2264	2.8311	1.7864	3.3146	1.3323	6 mg/l (min)
BOD	11.189	8.033	10.122	8.989	6.278	4.889	6.878	12.322	7.466	18.511	6.656	8.878	3 mg/l (max)
TSS	1.156	0.811	0.139	0.128	1.2	1.367	0.778	0.511	14.578	2.578	0.171	4.167	25 mg/l (max)
Turbidity	3.064	6.058	5.022	6.874	7.241	30.77	22.767	14.653	5.643	14.469	3.192	5.985	5 NTU (max)
Nitrate-N	0.0667	0.0794	0.2393	0.0871	0.0746	0.1784	0.3371	0.0372	0.3303	0.3916	0.0345	0.1884	10 mg/l (max)
Ammonium-N	0.0144	0.0146	0.0174	0.0216	0.0197	0.0131	0.0165	0.0201	0.0158	0.0168	0.0152	0.0127	0.5 mg/l (max)

exceed the standard value. The Nitrate-N and Ammonium-N values of every sampling site are within the standard for drinking water.

3.5. Spatial variation of aquatic macro-invertebrates

Table 6 represents the aquatic macroinvertebrates found in the Kirala Kele Wetland during the study period. The majority of the Trichoptera were found in the sampling sites 01 and 12. They were absent from the sampling sites 02, 04, 07, 08, 10, and 11. Diptera were absent in sampling sites 03, 07, 08, and 10, while they were present in high amounts in sampling sites 01, 04, 06, 09, and 12. Sampling sites 01 and 03 indicated having with the majority of the Coleoptera, while they were absent in

Table 6 | Presence/absence of aquatic macroinvertebrates in the 12 sampling sites of the Kirala Kale Wetland



	SP 01			SP 02			SP 03			SP 04			SP 05			SP 06			SP 07			SP 08			SP 09			SP 10			SP 11			SP 12		
	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
(I)	P	P	P	A	A	A	P	A	P	A	A	A	A	A	P	P	P	A	A	A	A	A	A	A	A	P	A	A	A	A	A	A	A	P	P	P
(II)	P	P	P	A	A	P	A	A	A	P	P	P	A	A	P	P	P	P	A	A	A	A	A	A	P	P	P	A	A	A	A	A	P	P	P	P
(III)	P	P	P	A	A	A	P	P	P	A	A	A	A	A	A	A	A	P	A	A	A	A	A	A	A	A	P	A	A	A	A	A	A	A	P	A
(IV)	P	P	P	P	P	P	A	A	A	P	P	P	P	P	P	P	P	P	A	A	P	P	P	P	A	A	A	P	P	P	A	A	A	P	P	P
(V)	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
(VI)	P	P	P	A	A	A	P	P	P	A	A	A	A	A	A	P	P	P	P	P	P	A	A	A	P	P	P	A	A	A	A	A	A	P	P	P
(VII)	P	P	A	A	A	A	P	P	P	A	A	P	A	P	A	P	P	P	P	P	A	A	A	A	P	P	A	A	A	A	A	P	A	P	P	P

P Present

A Absent

(I) Trichoptera – Leptoceridae
(II) Diptera – Tipulidae
(III) Coleoptera – Dryopidae
(IV) Arachnida
(V) Hemiptera
(VI) Oligochaeta
(VII) Odonata – Libellulidae

P represents the "Present" and A represents the "Absent" of macro-invertebrates. V1, V2, V3 refers to the visit 1, visit 2, and visit 3 in the study. (I) Trichoptera – Leptoceridae, (II) Diptera – Tipulidae, (III) Coleoptera – Dryopidae, (iv) Arachnida, (v) Hemiptera, (vi) Oligochaeta, (vii) Odonata – Libellulidae.

sampling sites 02, 04, 05, 07, 08, 10, and 11. High abundance of Arachnida was found in sites 01, 02, 04, 05, 06, 08, 10, and 11. In the sampling sites 03, 09, and 11, Arachnida were absent. Hemipterans were found in all sampling sites of the wetland. The majority of the Oligochaeta were recorded in the sampling sites 01, 03, 06, 07, 09, and 12, while they were absent in sampling sites 02, 04, 05, 08, 10, and 11. Further, Odonata could easily be found in sampling sites 03, 06, and 12, while they were absent in sampling sites 02, 08, and 10. All of the aquatic macroinvertebrates were found in the sampling sites 01, 06, and 12.

3.6. CCA for 12 sampling sites of the Kirala Kele Wetland

Figure 5 shows the outcomes of CCA for the selected sampling sites, water quality parameters, and the aquatic macroinvertebrates in the Kirala Kele Wetland. Based on the CCA, sites 08 and 10 show high Ammonium-N, BOD, and DO content in water, while having less diversity and density of aquatic macroinvertebrates, but including Arachnids. Arachnids are positively correlated with Ammonium-N, BOD, and DO while negatively correlated with pH, Nitrate-N, TSS, and EC. High amounts of TSS, EC, and Nitrate-N are included in water in the sampling sites 09 and 07 of the wetland, with less diversity and density of aquatic macroinvertebrates. Sampling sites 06 and 12 show higher pH, EC, TSS, and Nitrate-N in water, while being densified and diversified with different aquatic macroinvertebrates such as Oligochaetes, Dipterans, Odonatans, and Hemipterans. These aquatic macroinvertebrates are positively correlated with pH, Nitrate-N, EC, and TSS, but negatively correlated with DO, BOD, and Ammonium-N (Figure 5). Sampling sites 11 and 04 present substantially higher water temperature and turbidity. Aquatic macroinvertebrates such as Hemipterans, Odonatans, and Dipterans, which are positively correlated with water temperature and turbidity, were present. The sampling site 07 showed less species richness of aquatic macroinvertebrates. Coleopterans and Plecopterans were present in the sampling sites 01 and 03 of the Kirala Kele Wetland, which are negatively correlated with turbidity and water temperature.

Table 7 indicates the inertia, proportion, and rank values for the water quality parameters and the aquatic macroinvertebrates in the CCA. Table 8 shows eigenvalues for constrained and unconstrained axes, respectively.

4. DISCUSSION

4.1. Spatial variation of water quality parameters

Variations and dynamics in the water quality of selected sampling sites reflect the status of their habitat quality due to both natural and anthropogenic disturbances; therefore, this section of the discussion answers research question 1 of the present

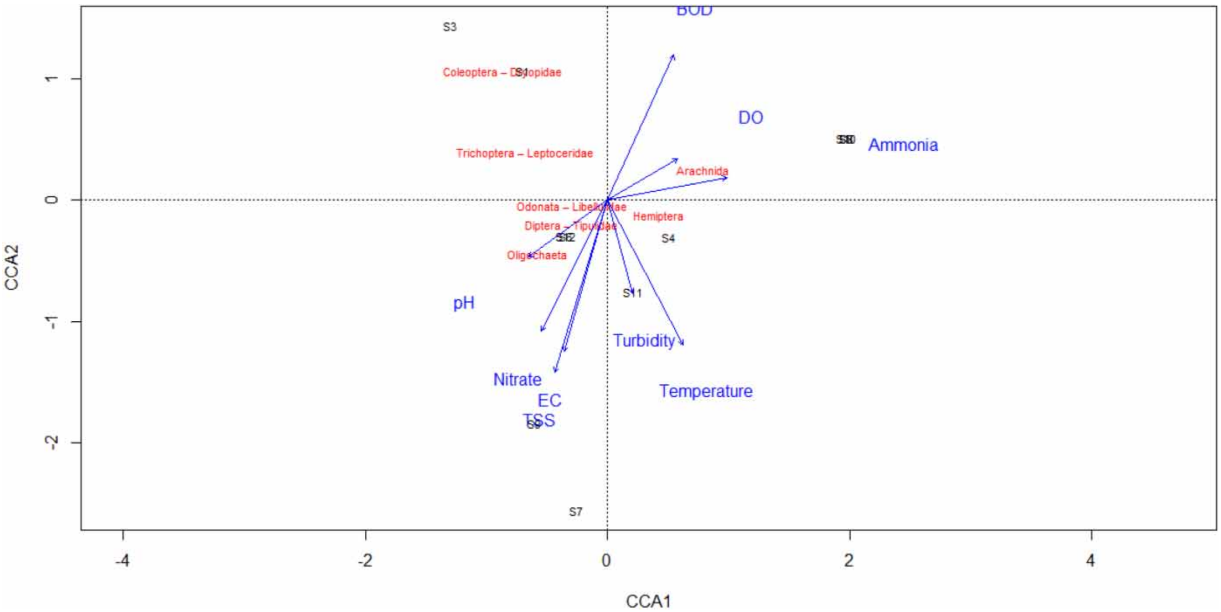


Figure 5 | Canonical correspondence analysis for water quality parameters and the aquatic macroinvertebrates in the selected habitats of the Kirala Kele Wetland.

Table 7 | Inertia, proportion, and rank for the water quality parameters in CCA (inertia is scaled Chi-square)

Factor	Inertia	Proportion	Rank
Total	0.70166	1.00000	
Constrained	0.60930	0.86837	5
Unconstrained	0.09236	0.13163	2

Table 8 | Eigenvalues for constrained and unconstrained axes of the CCA plot

Factor	CCA 01	CCA 02	CCA 03	CCA 04	CCA 05
Eigenvalues for constrained axes	0.30653	0.11439	0.10089	0.06145	0.02604
Eigenvalues for unconstrained axes	0.05527	0.03708	–	–	–

study by pinpointing the factors affecting water quality in selected sites of the Kirala Kele Wetland. According to Liu *et al.* 2020, human interactions with wetlands have an impact on a parameter: the temperature of the water. Sampling sites with high human interactions, for different anthropogenic activities, show an increased average temperature of water. To expand and promote the recreational activities associated with wetlands, it is necessary to implement sustainable and environmentally friendly measures, as some development activities can accelerate the deforestation of riverine wetland plants. Moreover, the use of cement for construction activities will increase the heat transfer from the atmosphere, which occurs through conduction. Structures can introduce more heat energy to wetlands. Li *et al.* (2020) highlighted that there have been significant CO_2 emissions into the atmosphere as a result of building construction, operation, and use; hence, a crowded population and activities around the sampling site cause a high accumulation of CO_2 in the area. Consequently, intense buildings and construction increase both ambient air temperature and water temperature. Apart from that, the availability of decaying leaves on the water layer also affects the changes in water temperature. When there is a layer of decaying leaves, heat is not transferring directly through the water because of the barrier between the atmosphere and water (Mackintosh *et al.* 2016). The study findings asserted that the significantly lowest water temperature was recorded among the sampling sites ($p < 0.05$; Tukey's pairwise test) where there was decaying matter. Hence, our findings are supported by the fact that decaying matter availability plays a major role in regulating the water temperature in water bodies.

Comparing all 12 sampling sites, sampling site 11 showed the highest average pH value, while the lowest average pH value was found where there are agricultural practices. Akhtar *et al.* (2021) reported that the use of many fertilizers and chemicals in agriculture can negatively affect the surface and groundwater, such as by lowering the pH. Pesticide substances such as herbicides, insecticides, rodenticides, and fungicides have the potential to flow off the surface and infiltrate groundwater systems for a significant duration, along with their byproducts formed during degradation. Apart from that, evidence suggests that lowering pH has been observed due to the usage of agro-chemicals in Sri Lanka (Jayasiri *et al.* 2022). Excessive levels of nutrients like nitrates and phosphates, surpassing the capacity of plants to absorb them, can result in surface runoff and seepage into groundwater. As a result, the pH of water can be altered. Therefore, the variation in pH among sampling sites is attributed to the impacts of agricultural activities on surrounding landscapes.

Ions are attached to soil particles, and when soil particles are washed away, the runoff carries ions and impurities of different sizes. The highest average EC was found in the area distinguished by a muddy wetland bed and agricultural activities. Ye *et al.* (2018) claim that mud encourages electrons to reduce or oxidize more quickly, lowering the resistance to electron transfer. The anaerobic digestion system's conductivity is significantly improved by adding mud, which also makes it easier to transfer electric charge. Conversely, the area where water enters the stream had the lowest average EC value. The water contains fewer ions because there is less contamination at the inflow, which lowers the EC.

Site 06, where agricultural practices are conducted, indicated the lowest average DO concentration in comparison with other sites. In agricultural farming practices, because of the removal of excess water from paddy fields and its direct transfer to a wetland, agricultural synthetic fertilizers are mixed with the wetland water. This phenomenon accelerates the addition of phosphorus and nitrogen fertilizers, causing eutrophication, which reduces the concentration of DO in water. Divya & Belagali (2012) highlighted similar findings to the present study using research conducted in Karnataka and Kerala, where increased fertilizer loads in water samples led to decreased DO levels. By contrast, the location where buffaloes bathe and rapid water flows occur had the highest average DO value. This is because the movement of buffaloes in the water generates turbulence, which facilitates the absorption of additional oxygen into the water, thereby increasing the DO concentration (Salmasi *et al.* 2021).

The highest average BOD value was recorded in the location where buffaloes take bath, where decaying leaves are in the water, and where the residents are located. Potential reasons are the discharging of kitchen wastewater and sewage by nearby residents, which contain higher organic matter, the discharge of buffalo dung into wetland water, and the degradation of decaying leaves. Widyarani *et al.* (2022) found that domestic wastewater carries a higher BOD. Therefore, the DO level is reduced, increasing the BOD. The lowest average BOD value was recorded in the location with agriculture practices, resulting from the mix of wetland water and agricultural fertilizers. Retnaningdyah *et al.* (2017) identified that hydrophilic macrophytes are able to improve water quality by lowering BOD in water. The highest average turbidity value was recorded in the location with agricultural practices and a muddy wetland bed. The removal of buffalo dung increases the amount of solid particles in water. Skarbøvik & Roseth (2015) have observed similar results in their studies, describing that turbidity exhibited strong correlations with suspended solids, total phosphorus, and dissolved phosphate in a small agricultural stream with primarily diffuse sources of sediments and phosphorus. The lowest average turbidity value was recorded in the location where the inflow water stream is located, owing to the lack of pollution sources in the area. The highest average TSS value was recorded in the location where more visitors reached, due to the throwing away of residual food parts and other things into wetland water that contain organic compounds that degrade and increase the solid particles in water, supporting the increase of suspended solids. Reopanichkul *et al.* (2009) found that waste disposal and altered land use due to tourism-related activities were connected to considerable differences in water quality. These changes affected the environmental conditions of the ecosystem. The lowest average TSS value was recorded in the location with the highest floral density because plants can remove TSS through filtration and changing the velocity of flowing water. Yahyapour *et al.* (2014) explained this well in the context of naturally occurring streams, as the vegetation is crucial to the movement and suspended solid settling. The reduction of turbidity and removal of TSS by vegetation in an open channel are empirically explored. It clearly shows the removal efficiency of TSS when changing the floral density, length of the vegetation, and flow velocity. The highest average Nitrate-N value was recorded in the location with the human residences and where there was a high level of human presence. There is a possibility of mixing septic effluents with wetland water in this location and discharge of solid waste into the wetland, leading to an increase in the Nitrate-N level of the water. McQuillan (2004) states that dissolved particles, Nitrate, anoxic components, organic compounds, and bacteria can contaminate groundwater as a result of septic systems. Kumar & Prakash (2020) show that increased copper, manganese, lead, cadmium, phosphate, nitrate, and other chemical substances in discharged water are among the dangerous substances that affect health. Groundwater should be safe from physical and chemical risks as it pertains to public health. No environmental pollution by humans near the inflow water stream was observed, and no specific sources to improve the nitrogen level in the water were found. Therefore, the lowest value was recorded in the location where the inflow water stream is located. The decaying leaves contribute to the Ammonium-N in water (Mackintosh *et al.* 2016). Agricultural lands remove excess water from this area. Therefore, the nitrogenous wastes of buffaloes also mix with water. According to Hill *et al.* (2005), nitrogen (ammonium and nitrate), phosphorus, and other nutrients drain into surface and ground water when dung is released onto crop land in quantities greater than can be utilized or held by the soil. There are many aquatic animals near the bunch of flowers. They excrete nitrogenous waste into the water body. Hence, a high value of Ammonium-N was recorded in the location with a high floral density. The lowest average Ammonium-N value was recorded where the outflow water stream is located. Water is flowing as a waterfall; therefore, an air stripping process is incorporated to lower the Ammonium-N level in the water. This is justified by the study of Wang *et al.* (2017), which presented a nitrogen removal solution indicating this waterfall method.

4.2. Temporal variation of water quality parameters

Understanding the changes in water quality over time is important to explore the seasonal and time-based natural and human-induced variations associated with wetlands. This section of the discussion attempts to investigate the answers to research question 2 of the study. According to the analysis, a significant difference exists in turbidity values between the months of March and April and March and May. In the month of April, a high amount of rainfall caused an increase in runoff generation, and the runoff carried a large number of ions, organic matter, etc. This triggered the turbidity of the water (Solano-Rivera *et al.* 2019).

The increase in ambient and water temperatures during the month of April can be attributed to the decrease in pH compared with the other months. Higher temperatures frequently influence the chemical reactions that occur in bodies of water. In this instance, the increased temperature accelerated the rate of reactions that result in the production of acids or the consumption of alkaline compounds, leading to a decrease in pH (Li *et al*. 2013). Warmer temperatures can stimulate the metabolic processes of aquatic organisms, such as bacteria and algae. These organisms may undergo acid-producing processes, such as the production of carbon dioxide during respiration (Rubalcaba *et al.* 2020). In addition, higher temperatures can increase the solubility of gases, such as carbon dioxide, in water, resulting in higher concentrations of dissolved carbon dioxide and subsequent acidification.

The significant difference in Ammonium-N values between the months of March, April, and May clearly explains the effects of precipitation and the introduction of impurities and nitrogenous fertilizers into the wetland water. In April, precipitation was higher compared with the other months, and consequently, this higher precipitation caused leaching, which is the process of dissolved substances being carried away from the soil or other materials by water. Hence, the higher Ammonium-N level observed during April supports the argument that more Ammonium-N compounds were washed out from the soil or other sources and entered the wetland water. Impurities and nitrogenous fertilizers, which are commonly used in agricultural practices, can mix with the wetland water during precipitation events or through runoff. Nitrogenous fertilizers contain compounds that are rich in nitrogen, including ammonium and nitrate. When these fertilizers are present in the wetland water, they can contribute to the overall level of Ammonium-N.

4.3. WAWQI

A combination of water and accumulated waste in the wetland due to the increased rainfall in April and May resulted in high BOD and low DO levels. Scientific study by Widyarani *et al.* (2022) support this observation. Heavy precipitation increases the accumulation of trash, including solid waste, in the wetland. Consequently, it increases the BOD level due to the presence of organic matter in the water, such as food scraps, plant matter, and other debris. Furthermore, the accumulated waste serves as a source of organic material, giving bacteria and other microorganisms the nutrients they need to grow and complete the decomposition process. As a result, there is a greater need for oxygen, which raises BOD levels. Lower DO concentrations in the water are a result of the simultaneous oxygen consumption that the decomposition process causes.

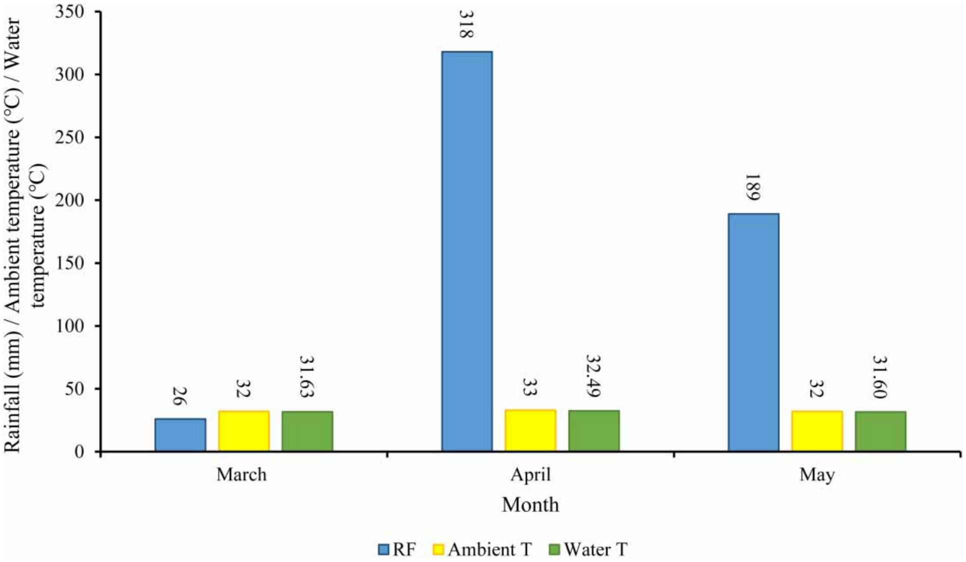


Figure 6 | Monthly rainfall (mm), monthly ambient temperature (°C), and monthly water temperature (°C) during the study period.

The location with a muddy wetland bed exhibits the highest WAWQI value of 144.87, primarily because of increased turbidity and EC in the water, rendering it unsuitable for drinking. As shown in Figure 6, the runoff brought on by increased rainfall in April and May is most likely the cause of this. The elevated solid content in the water contributes to higher turbidity and EC levels. Several factors contribute to the higher WAWQI values observed in agricultural lands, areas where buffaloes bathe, and the outflow stream of the wetland.

Agricultural lands, particularly paddy fields, contain water with higher turbidity, lower DO levels, and higher concentrations of Nitrate-N and Ammonium-N. Li *et al.* (2023) also indicate that cultivated lands contribute to a decline in water quality. Runoffs resulting from increased rainfall, improper waste disposal, and the use of synthetic fertilizers are major factors contributing to the unhealthy WAWQI for agricultural lands.

The discharge of buffalo waste into the water is another reason for the unsuitability of wetland water for drinking. Akhtar *et al.* (2021) support this finding in their study conducted in Malaysia. In addition, Widyarani *et al.* (2022) mention that the removal of solid waste by wetland visitors and the effluent discharge from human residences both significantly disturb the water quality and raise the WAWQI.

Increased rainfall, runoff, effluent discharge, and solid waste disposal are potential reasons for the elevated WAWQI in the wetland. By contrast, the location of the inflow water stream exhibits the lowest WAWQI value (80.60) due to the absence of disturbances and pollution sources. Similarly, areas with motionless water experience lower WAWQI values owing to reduced pollution sources in the vicinity. The primary drivers of change in water quality are likely to be rainfall and runoff.

4.4. Comparison of water quality with the standards

While accomplishing the third objective of the present study, this discussion section provides answers to research question 3 of the study. All sampling sites contain waters with elevated EC concentrations, exceeding the standard limit for drinking water. All sampling sites were exposed to runoff during the rainy season, proving this. Therefore, the Kirala Kele Wetland has turbidity and suspended solids levels that exceed the standard value for EC in potable water. In addition, the DO concentration at each sampling location is below the standard value. This is attributable to numerous factors. First, aquatic fauna and flora contribute to the depletion of oxygen by consuming it. In addition, the removal of biodegradable solid waste and effluents from human residences causes eutrophication, which further affects the DO concentration (Divya & Belagali 2012). Higher ambient and water temperatures in the Kirala Kele Wetland region also contribute to the decrease in DO concentrations. In addition, excessive algal growth resulting from agricultural fertilizer runoff contributes to the reduction of oxygen in the water. The observed deviations from the standard values for EC and DO in the wetland water are caused by these factors, which are influenced by increased rainfall and runoff in the area. Mackintosh *et al.* (2016)

also demonstrates that, as a result of pollutants from watershed surfaces being washed into waterways, anthropogenic activity generates trash and pollutants, and water quality in urban settings frequently deteriorates. Due to this decrease in DO in water, the BOD in water is greater than the standard value. The turbidity of wetland water is higher than the standard value for potable water due to runoff and heavy precipitation. During the rainy season, human residents and visitors to the wetland transport their solid waste and increase the turbidity of the water. If wetland water is supplied without DO improvement, it is difficult for plant roots to survive due to a lack of oxygen. Therefore, plant health as a whole is declining. The yield of agricultural land is decreasing over time. The pH, EC, and Nitrate-N levels of the water in the Kirala Kele Wetland are appropriate for bathing and recreational activities. DO and BOD levels in the water are undesirable for recreational activities. In this instance, it is necessary to increase the DO concentration of water and decrease the BOD of wetland water. In terms of bathing and recreational activities, TSS, turbidity, and Ammonium-N are not given much weight. The primary recreational activity in the Kirala Kele Wetland is fishing. Due to the decline in DO concentration, fish and aquatic life have insufficient oxygen. Fish and other aquatic life will likely perish, and recreational activities will cease to function. Wind and wave action, the addition of more aquatic plants to purify the water, and the operation of a portable splash or spray-type aerator will be useful for increasing the DO concentration in wetland water.

4.5. Relationship between aquatic macroinvertebrates and water quality parameters

As insights on the macroinvertebrate variations impacts on water quality monitoring, this section of the study assesses the research questions 4 and 5 and finds answers for understanding the changes of macroinvertebrate populations with changing water quality parameters. The distribution of aquatic macroinvertebrates among the sampling sites in the CCA plot (Figure 3.5) is critically explained by the special characteristics of habitats with the aquatic macroinvertebrates. Based on the CCA, Trichoptera–Leptoceridae are dominant in the location having decaying leaves on the water layer, which has a cool environment with clean and flowing water (De Moor & Ivanov 2008). It is clearly shown by the CCA because the Trichopterans are negatively correlated with water temperature and turbidity. Dipetera–Tipulidae are dominant in moist vegetative and decomposing sites (De Jong *et al.* 2008), in case of the wetland, the location where agriculture is practiced and the location with the outflow water stream of the wetland that disposes degradable waste from households. The location with the decaying leaves on the water layer and the location where water is flowing are the sites where Coleoptera–Dryopidae are dominant. The locations have fresh clean water while the water is flowing, which is favorable to the Coleoptera, which are negatively correlated with turbidity. Odonata–Libellulidae are densified in the locations where agriculture is practiced, having floral density, or decaying leaves on the water layer that densified with more flora and fresh clean water (Sandamini *et al.* 2019). It is justified by the CCA due to the negative correlation with BOD and Ammonium-N. Arachnida is mostly dominant in the locations with the garbage dumping sites and decomposing sites such as human residences and where buffaloes take bath (Frantisek *et al.* 2019). Residents dispose more garbage that is degradable and non-degradable into the wetland, hence there are more Arachnids, which are positively correlated with BOD and Ammonium-N. Hemiptera can be seen in each and every sampling site due to the high diversification of the taxon. In the locations where agriculture is practiced, where the outflow water stream is located, and where there is a high level of human activity, the muddy areas and decomposing sites are dominated by Oligochaeta (Lone *et al.* 2022), which are positively correlated with Ammonium-N and TSS.

4.6. Implications for conservation; future directions

Wetland health monitoring programs associated with physicochemical and biological components of wetlands are conducted worldwide; however, it is crucial to note that the comprehensive monitoring system we selected should be able to gather key information that can be utilized to explain the mechanism, process, and assessment of wetland ecosystem dynamics and linkages (Rashid *et al.* 2023). Thus, we suggest effective strategies should be formulated to close the knowledge gaps to comprehend the behavior and trade-offs of the Kirala Kele Wetland. To estimate and evaluate the temporal and geographic changes in the Kirala Kele Wetland on a completely systemic basis under various management and regulation scenarios, it is urgently necessary to develop integrated ecosystem assessment models (Topaldemir *et al.* 2023; Xu *et al.* 2018). According to the outcomes of the present study, we suggest following the subsequent approaches to ensure the health of the Kirala Kele Wetland.

1. Development of a keymap to illustrate and identify the existing point and non-point sources (Bai *et al.* 2021) associated with the Kirala Kele Wetland.

2. Establishment of continuous water quality monitoring stations/points to monitor the physical, chemical, and biological parameters of the water and sediments of the Kirala Kele wetland in risk pollution sources identified from mapping (Ebrahimi-Khusfi *et al.* 2023).
3. Strengthening the awareness among the general public and communities associated with the Kirala Kele Wetland on the risk linked with the wetland systems and the importance of their active participation in wetland conservation (Berkowitz *et al.* 2020).
4. Alarming the other stakeholders such as Central Environmental Authority, Matara and Urban Council, Matara, Pradeshiya Sabhas, and non-governmental organizations to collaborate for conservation and management of this wetland system. This can be practiced through an institutional structure known as ecological compensation that utilizes ecosystem service values of ecosystems to modify the relative costs and benefits of environmental protection for various stakeholders.
5. Encouraging scientific contribution from higher education institutions on how wetland management options affect the mismatch between supply and demand for ecosystem services and trade-offs is necessary for successful ecological compensation schemes.
6. Strengthening the policy framework associated with wetlands management.

4.7. Limitations of the study

The study's limitations should be thoroughly evaluated in relation to its findings and recommendations. Implementing a year-round sampling framework would enhance the research's temporal scope, allowing for a more profound and comprehensive assessment of the wetland's health, surpassing the current limited duration of 3 months. To address this constraint, it would be beneficial to extend the research duration to cover a longer time span, ideally the entire 12-month cycle and potentially multiple years. This would yield a more precise depiction of the temporal fluctuations occurring within the wetland.

Furthermore, the absence of historical data regarding the wetland's condition poses a notable constraint. Historical data are essential for comprehending the pattern of changes occurring in an ecosystem over time. Additional historical literature would have been beneficial.

In addition, year-round monitoring of macroinvertebrates would have given more insights on the impacts of the changes of water quality on the composition of the macroinvertebrates as they are extensively used as bioindicators.

5. CONCLUSION

In conclusion, the study's findings show that anthropogenic activities such as agriculture, household activities, and human visits, as well as natural factors such as the floral density of the Kiara Kele Wetland, have a significant impact on water quality parameters. Understanding the spatial variation of water quality parameters can aid in the identification of problem areas and the development of targeted management strategies to improve water quality and wetland health. Overall, water quality parameters varied over time, with some showing significant differences between months. This emphasizes the significance of regular monitoring and analysis of water quality parameters for effective wetlands management and conservation.

Furthermore, the findings indicate that various local activities, such as agriculture, household activities, and animal husbandry, have an impact on the quality of water in the wetland. The location of the wetland bed, inflow and outflow water streams, and other factors all contribute to the WAWQI values. As a result, appropriate management practices should be put in place to reduce the negative impact of human activities and ensure the long-term use of wetland resources.

Overall, the results indicate that, while the pH, TSS, and nitrogen levels in the water are within the standard range, the high levels of EC, low DO, high BOD, and phosphate-phosphorus are cause for concern. As a result, appropriate measures should be taken to ensure that the water is safe to drink and that any negative impacts on aquatic ecosystems are avoided.

It is important to note that the presence or absence of specific macroinvertebrates in these sampling sites can be influenced by a number of factors, such as water quality, flow, and vegetation. Further investigation may be required to determine the specific factors that contribute to the observed patterns.

Finally, the CCA indicates that the selected water quality parameters have a significant impact on the density, diversity, and composition of aquatic macroinvertebrates in the Kirala Kele Wetland. The presence or absence of specific macroinvertebrate taxa is highly correlated with specific water quality parameters, indicating that these organisms are sensitive to changes in water quality. The CCA can aid in decision-making about wetland management and conservation strategies by identifying priority areas for protection or restoration based on the composition of macroinvertebrate communities and associated water quality parameters.

DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Aazami, M. & Shanazi, K. 2020 Tourism wetlands and rural sustainable livelihood: The case from Iran. *J. Outdoor Recreat. Tour.* **30**, 100284. https://doi.org/10.1016/j.jort.2020.100284.

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A. & Umar, K. 2021 Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water* **13** (19), 2660.

Aluker, N. L., Herrmann, M. E. & Suzdaltseva, Y. M. 2019 A spectrophotometric study of nitrate and nitrite salts and their aqueous solutions. *Opt. Spectrosc.* **127**, 991–996. https://doi.org/10.1134/S0030400X19120026.

Amarathunga, A. D. & Fernando, R. W. 2016 Suspended sediment concentration and its impact on aquatic invertebrates in the Gin River, Sri Lanka. *J. Food Agric.* **9**, 24. https://doi.org/10.4038/jfa.v9i1-2.5204.

Aniyikaiye, T. E., Oluseyi, T., Odiyo, J. O. & Edokpayi, J. N. 2019 Physico-chemical analysis of wastewater discharge from selected paint industries in Lagos, Nigeria. *Int. J. Environ. Res. Public Health* **16**. https://doi.org/10.3390/ijerph16071235.

Ankcorn, P. D. 2003 Clarifying turbidity – The potential and limitations of turbidity as a surrogate for water-quality monitoring. In: *Proceedings of the 2003 Georgia Water Resources Institute Conference*, pp. 1–4.

Baker, C., Thompson, J. R. & Simpson, M. 2009 Hydrological dynamics I: Surface waters, flood and sediment dynamics. In *The Wetlands Handbook*. https://doi.org/10.1002/9781444315813.ch6.

Bai, H., Chen, Y., Wang, Y., Song, Z., Tong, H., Wei, Y., Yu, Q., Xu, Z. & Yang, S. 2021 Contribution rates analysis for sources apportionment to special river sections in Yangtze River Basin. *Journal of Hydrology* **600**, 126519.

Basu, T., Das, A., Pham, Q. B., Al-Ansari, N., Linh, N. T. T. & Lagerwall, G. 2021 Development of an integrated peri-urban wetland degradation assessment approach for the Chatra Wetland in eastern India. *Sci. Rep.* **11**, 1–22. https://doi.org/10.1038/s41598-021-83512-6.

Berkowitz, J. F., Schlea, D. A., VanZomeren, C. M. & Boles, C. M. 2020 Coupling watershed modeling, public engagement, and soil analysis improves decision making for targeting P retention wetland locations. *Journal of Great Lakes Research* **46** (5), 1331–1339.

Bouslah, S., Djemili, L. & Houichi, L. 2017 Water quality index assessment of Koudiat Medouar Reservoir, northeast Algeria using weighted arithmetic index method. *J. Water L. Dev.* **35**, 221–228. https://doi.org/10.1515/jwld-2017-0087.

Brraich, O. S. & Saini, S. K. 2015 Water quality index of Ranjit Sagar wetland situated on the Ravi river of Indus river system. *Int. J. Adv. Res.* **3**, 1498–1509.

Byun, C., Lee, S. H. & Kang, H. 2019 Estimation of carbon storage in coastal wetlands and comparison of different management schemes in South Korea. *J. Ecol. Environ.* **43**, 1–12. https://doi.org/10.1186/s41610-019-0106-7.

Central Environmental Authority, S.L. 2019 Ambient water quality standards. *Gaz. Democr. Social. Repub. Sri Lanka* **2017**, 4.

Chatterjee, A. & Bhattacharyya, S. 2021 Assessing the threats facing wetland mammals in India using an evidence-based conservation approach. *Mamm. Rev.* **51**, 385–401. https://doi.org/10.1111/mam.12242.

Corea, A. S. L. E. 2019 Reviewing effluent and estuarine water quality in view of introducing effluent standards for coastal aquaculture in Sri Lanka. *J. Environ. Prof. Sri Lanka* **8**, 1. https://doi.org/10.4038/jepsl.v8i1.7873.

Dadi, D., Mengistie, E., Terefe, G., Getahun, T., Haddis, A., Birke, W., Beyene, A., Luis, P. & Van der Bruggen, B. 2018 Assessment of the effluent quality of wet coffee processing wastewater and its influence on downstream water quality. *Ecohydrol. Hydrobiol.* **18**, 201–211. https://doi.org/10.1016/j.ecohyd.2017.10.007.

Deborde, D. D. D., Hernandez, M. B. M. & Magbanua, F. S. 2016 Benthic macroinvertebrate community as an indicator of stream health: The effects of land use on stream benthic macroinvertebrates. *Sci. Diliman A Philipp. J. Pure Appl. Sci.* **28**, 5–26.

de Groot, D., Brander, L. & Max Finlayson, C. 2018 Wetland ecosystem services. In: *The Wetland Book*, pp. 323–333. https://doi.org/10.1007/978-90-481-9659-3_66.

De Jong, H., Oosterbroek, P., Gelhaus, J., Reusch, H. & Young, C. 2008 Global diversity of craneflies (Insecta, Diptera: Tipulidea or Tipulidae sensu lato) in freshwater. *Hydrobiologia* **595**, 457–467. https://doi.org/10.1007/s10750-007-9131-0.

De Moor, F. C. & Ivanov, V. D. 2008 Global diversity of caddisflies (Trichoptera: Insecta) in freshwater. *Hydrobiologia* **595**, 393–407. https://doi.org/10.1007/s10750-007-9113-2.

Dias, S., Correia, B., Fraga-Santiago, P., Silva, C., Baptista, P. C., Gomes, C. R. & Almeida, C. M. R. 2021 Potential of an estuarine salt marsh plant (*Phragmites australis* (Cav.) *Trin. Ex steud10751*) for phytoremediation of bezafibrate and paroxetine. *Hydrobiologia* **848**, 3291–3304. https://doi.org/10.1007/s10750-020-04245-7.

Dissanayake, P., Bank, W. & Jayakody, P. 2014 *Report on Water Quality Survey and Pollution in Kurunegala, Sri Lanka, Priyanka Dissanayake, Alexandra Clemett, Priyantha 1999–2003*.

Divya, J. & Belagali, S. L. 2012 Effect of extensive use of chemical fertilizers on nitrate and phosphate enrichment in water resources of selected agricultural areas of T. Narasipura Taluk, Mysore District, Karnataka, India. *In Proceeding of international conference SWRDM-2012. Department of Environmental Science*. Shivaji University, Kolhapur (pp. 43–47).

Ebrahimi-Khusfi, Z., Zandifar, S., Ebrahimi-Khusfi, M. & Tavakoli, V. 2023 Heavy metal mapping, source identification, and ecological risk assessment in the International Hamoun wetland, Sistan region, Iran. *Environmental Science and Pollution Research* **30** (11), 29321–29335.

Eller, F., Arias, C. A., Sorrell, B. K. & Brix, H. 2021 Preface: Wetland ecosystems – Functions and use in a changing climate. *Hydrobiologia* **848**, 3255–3258. https://doi.org/10.1007/s10750-021-04630-w.

Eriksen, T. E., Brittain, J. E., Søli, G., Jacobsen, D., Goethals, P. & Friberg, N. 2021 A global perspective on the application of riverine macroinvertebrates as biological indicators in Africa, South-Central America, Mexico and Southern Asia. *Ecol. Indic.* **126**. https://doi.org/10.1016/j.ecolind.2021.107609.

Fernando, S. L. J. & Shariff, N. M. 2017 Site suitability analysis for ecotourism development at the Kirala Kele partial-nature-based wetland of southern Sri Lanka. *International Journal of Sciences* **32** (3), 89–104.

Fernando, S. L. J. 2019 Potentiality of water resources in the Kirala Kele partial-nature-based wetland of southern Sri Lanka. *Advances in Social Sciences Research Journal* **6** (7), 606–614.

Firdissa, B., Solomon, Y. & Soromessa, T. 2016 Assessment of the status of industrial waste water effluent for selected industries in Addis Ababa, Ethiopia. *Assessment* **6** (17), 1–15.

Frantisek, K., Kithsiri, B., Ranawana, V. A., Sanjeewa, J. & David Hoferek, F. S. 2019 *Scorpions of Sri Lanka Euscorpius*.

Gohain, S. B. & Bordoloi, S. 2021 Impact of municipal solid waste disposal on the surface water and sediment of adjoining wetland Deepor Beel in Guwahati, Assam, India. *Environ. Monit. Assess.* **193**, 1–19. https://doi.org/10.1007/s10661-021-09040-y.

Gunawardhana, W. D. T. M., Jayawardhana, J. M. C. K. & Udayakumara, E. P. N. 2016 Impacts of agricultural practices on water quality in Uma Oya catchment area in Sri Lanka. *Procedia Food Sci.* **6**, 339–343. https://doi.org/10.1016/j.profoo.2016.02.068.

Gunawardhana, W. D. T. M., Jayawardhana, J. M. C. K., Udayakumara, E. P. N. & Malavipathirana, S. 2018 Spatio-temporal variation of water quality and bio indicators of the Badulu Oya in Sri Lanka due to catchment disturbances. *J. Natl. Sci. Found. Sri Lanka* **46**, 51–67. https://doi.org/10.4038/jnsfsr.v46i1.8265.

Hill, D. D., Owens, W. E. & Tchounwou, P. B. 2005 Impact of animal waste application on runoff water quality in field experimental plots. *International journal of environmental research and public health* **2** (2), 314–321.

Holt, E. A. & Miller, S. W. 2011 Bioindicators: Using organisms to measure environmental impacts | learn science at Scitable. *Nat. Educ. Knowl.* **3**, 8.

Jabłońska, E., Winkowska, M., Wiśniewska, M., Geurts, J., Zak, D. & Kotowski, W. 2021 Impact of vegetation harvesting on nutrient removal and plant biomass quality in wetland buffer zones. *Hydrobiologia* **848**, 3273–3289. https://doi.org/10.1007/s10750-020-04256-4.

Jain, A., Singh, B. N., Singh, S. P., Singh, H. B. & Singh, S. 2010 Exploring biodiversity as bioindicators for water pollution. In *National Conference on Biodiversity, Development and Poverty Alleviation*, pp. 50–56.

Jayawardana, J. M. C. K., Gunawardana, W. D. T. M., Udayakumara, E. P. N. & Westbrooke, M. 2017 Land use impacts on river health of Uma Oya, Sri Lanka: Implications of spatial scales. *Environ. Monit. Assess.* **189**. https://doi.org/10.1007/s10661-017-5863-0.

Jayasiri, M. M. J. G. C. N., Yadav, S., Dayawansa, N. D. K., Propper, C. R., Kumar, V. & Singleton, G. R. 2022 Spatio-temporal analysis of water quality for pesticides and other agricultural pollutants in Deduru Oya river basin of Sri Lanka. *Journal of Cleaner Production* **330**, 129897.

Joshi, D., Gallant, B., Hakhu, A., DeSilva, S., McDougall, C., Dubois, M. & Arulingam, I. 2021 Ramsar convention and the wise use of wetlands: Rethinking inclusion. *Ecol. Restor.* **39**, 36–44. https://doi.org/10.3368/er.39.1-2.27.

Kumar, M. & Prakash, V. 2020 A review on solid waste: its impact on air and water quality. *Journal of Pollution Effects & Control* **8** (4), 1–3.

Karri, R. R., Ravindran, G. & Dehghani, M. H. 2021 Wastewater-sources, toxicity, and their consequences to human health. *In Soft computing techniques in solid waste and wastewater management (2021)*. 3–33.

Kotagama, S. W. & Bambaradeniya, C. N. B. 2006 An overview of the wetlands of Sri Lanka and their conservation significance. *Natl. Wetl. Dir. Sri Lanka* 56–57.

Kovařík, F., Ranawana, K. B., Jayarathne, V. A., Hoferek, D. & Šťáhlavský, F. 2019 Scorpions of Sri Lanka (Arachnida: Scorpiones). Part III. Heterometrus yaleensis sp. n.(Scorpionidae). *Euscorpius* **2019** (283), 1–13.

Lenat, D. R. 1988 Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. *Journal of the North American Benthological Society* **7** (3), 222–233.

Lenat, D. R. & Lenat, D. R. 2012 Macroinvertebrates water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates, p. 7.

Li, P. & Wu, J. 2019 Drinking water quality and public health. *Expo. Heal.* **11**, 73–79. https://doi.org/10.1007/s12403-019-00299-8.

Li, D., Xu, X., Li, Z., Wang, T. & Wang, C. 2020 Detection methods of ammonia nitrogen in water: A review. *TrAC – Trends Anal. Chem.* **127**, 115890. https://doi.org/10.1016/j.trac.2020.115890.

Li, Q., Ma, Y., Chen, J., Cai, Y., Lu, Q., Yu, Q., Duan, X., Zhao, D. & An, S. 2023 The negative effect of the high pH of waste concrete in constructed wetlands on COD and N removal. *Journal of Water Process Engineering* **51**, 103356.

Liu, S., Xie, Z., Liu, B., Wang, Y., Gao, J., Zeng, Y., Xie, J., Xie, Z., Jia, B., Qin, P., Li, R., Wang, L. & Chen, S. 2020 Global river water warming due to climate change and anthropogenic heat emission. *Glob. Planet. Change* **193**, 103289. https://doi.org/10.1016/j.gloplacha.2020.103289.

Lone, A. R., Thakur, S. S., Tiwari, P., James, S. W. & Yadav, S. 2022 Phylogenetic relationships in earthworm Megascolex species (Oligochaeta: Megascolecidae) with addition of two new species. *Diversity* **14** (11), 1006.

Mackintosh, T. J., Davis, J. A. & Thompson, R. M. 2016 Impacts of multiple stressors on ecosystem function: leaf decomposition in constructed urban wetlands. *Environmental Pollution* **208**, 221–232.

McQuillan, D. 2004 Ground-water quality impacts from on-site septic systems. In Proceedings, National Onsite Wastewater Recycling Association, 13th Annual Conference, Albuquerque, NM (pp. 6–18).

Misaghi, F., Delgosha, F., Razzaghmanesh, M. & Myers, B. 2017 Introducing a water quality index for assessing water for irrigation purposes: A case study of the Ghezel Ozan River. *Sci. Total Environ.* **589**, 107–116. https://doi.org/10.1016/j.scitotenv.2017.02.226.

Odipe, O. E., Olalekan, R. M. & Suleiman, F. 2019 Assessment of heavy metals in effluent water discharges from textile industry and river water at close proximity: A comparison of two textile industries from Funtua and Zaria, North Western Nigeria. *Madridge J. Agric. Environ. Sci.* **1**, 1–6. https://doi.org/10.18689/mjaes-1000101.

Oldenborg, K. A. & Steinman, A. D. 2019 Impact of sediment dredging on sediment phosphorus flux in a restored riparian wetland. *Science of the Total Environment* **650**, 1969–1979.

Paz, L. E., Rodriguez, M., Gullo, B. & Capítulo, A. R. 2022 Impacts of urban and industrial pollution on functional traits of benthic macroinvertebrates: Are some traits advantageous for survival?. *Science of The Total Environment* **807**, 150650.

Rahimi, L., Malekmohammadi, B. & Yavari, A. R. 2020 Assessing and modeling the impacts of wetland land cover changes on water provision and habitat quality ecosystem services. *Nat. Resour. Res.* **29**, 3701–3718. https://doi.org/10.1007/s11053-020-09667-7.

Ramsar Convention 2014 The Convention on Wetlands, https://www.ramsar.org/publications. Accessed on 23.08.2023.

Rubalcaba, J. G., Verberk, W. C., Hendriks, A. J., Saris, B. & Woods, H. A. 2020 Oxygen limitation may affect the temperature and size dependence of metabolism in aquatic ectotherms. *Proceedings of the National Academy of Sciences* **117** (50), 31963–31968.

Rashid, I., Aneaus, S., Dar, S. A., Javed, O., Khanday, S. A. & Bhat, S. U. 2023 A novel GIS-based multicriteria analysis approach for ascertaining the catchment-scale degradation of a Himalayan wetland. *Environmental Research* **229**, 115967.

Retnaningdyah, C., Arisoesilaningsih, E. E. & Samino, S. 2017 Use of local Hydromacrophytes as phytoremediation agent in pond to improve irrigation water quality evaluated by Diatom Biotic Indices. *Biodiversitas Journal of Biological Diversity* **18** (4), 1611–1617.

Reopanichkul, P., Schlacher, T. A., Carter, R. W. & Worachananant, S. 2009 Sewage impacts coral reefs at multiple levels of ecological organization. *Marine Pollution Bulletin* **58** (9), 1356–1362.

Rizo-Patrón, V. F., Kumar, A., McCoy Colton, M. B., Springer, M. & Trama, F. A. 2013 Macroinvertebrate communities as bioindicators of water quality in conventional and organic irrigated rice fields in Guanacaste, Costa Rica. *Ecol. Indic.* **29**, 68–78. https://doi.org/10.1016/j.ecolind.2012.12.013.

Rojas, O., Soto, E., Rojas, C. & López, J. J. 2022 Assessment of the flood mitigation ecosystem service in a coastal wetland and potential impact of future urban development in Chile. *Habitat Int.* **123**. https://doi.org/10.1016/j.habitatint.2022.102554.

Salimi, S., Almuktar, S. A. A. A. N. & Scholz, M. 2021 Impact of climate change on wetland ecosystems: A critical review of experimental wetlands. *J. Environ. Manage.* **286**, 112160. https://doi.org/10.1016/j.jenvman.2021.112160.

Salmasi, F., Abraham, J. & Salmasi, A. 2021 Effect of stepped spillways on increasing dissolved oxygen in water, an experimental study. *Journal of Environmental Management* **299**, 113600.

Saranga, B. G. P. T., Wijeweera, W. P. S. N., Kannan, R. 2022 An update on the status and distribution of the Knob-billed Duck Sarkidiornis melanotos in Sri Lanka, with notes on its behaviour. *Indian Birds MonoMonograph* **5**, 48–52.

Sandamini, P. M. M. A., Gunarathna, S. D. & Chandana, E. P. S. 2019 Habitat quality and climate variability determine odonate species diversity and distribution patterns in selected habitats of southern Sri Lanka. *Asian J. Conserv. Biol* **8**, 47–57.

Shimba, M. J. & Jonah, F. E. 2016 Macroinvertebrates as bioindicators of water quality in the Mkondoa River, Tanzania, in an agricultural area. *African J. Aquat. Sci.* **41**, 453–461. https://doi.org/10.2989/16085914.2016.1230536.

Singh, S., Tiwari, R. K. & Pandey, R. S. 2018 Water pollution due to discharge of industrial effluents. *Int. Arch. App. Sci. Technol.* **9**, 111–121.

Skarbøvik, E. & Roseth, R. 2015 Use of sensor data for turbidity, pH and conductivity as an alternative to conventional water quality monitoring in four Norwegian case studies. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science* **65** (1), 63–73.

Solano-Rivera, V., Geris, J., Granados-Bolaños, S., Brenes-Cambronero, L., Artavia-Rodríguez, G., Sánchez-Murillo, R. & Birkel, C. 2019 Exploring extreme rainfall impacts on flow and turbidity dynamics in a steep, pristine and tropical volcanic catchment. *Catena* **182**, 104118.

Syuhada, A., Armanto, M. E., Siswanto, A., Yazid, M. & Wildayana, E. 2020 Food security and environmental sustainability on the south Sumatra Wetlands. *Indonesia. Syst. Rev. Pharm.* **11**, 457–464. https://doi.org/10.5530/srp.2020.3.58.

Tirkey, P., Bhattacharya, T. & Chakraborty, S. 2013 Water quality indices – Important tools for water quality assessment. *Int. J. Adv. Chem.* **1**, 15–28.

Topaldemir, H., Taş, B., Yüksel, B. & Ustaoğlu, F. 2023 Potentially hazardous elements in sediments and Ceratophyllum demersum: An ecotoxicological risk assessment in Miliç Wetland, Samsun, Türkiye. *Environmental Science and Pollution Research* **30** (10), 26397–26416.

Tyagi, S., Sharma, B., Singh, P. & Dobhal, R. 2020 Water quality assessment in terms of water quality index. *Am. J. Water Resour.* **1**, 34–38. https://doi.org/10.12691/ajwr-1-3-3.

Uddin, M. G., Nash, S. & Olbert, A. I. 2021 A review of water quality index models and their use for assessing surface water quality. *Ecol. Indic.* **122**, 107218. https://doi.org/10.1016/j.ecolind.2020.107218.

Uherek, C. B. & Pinto Gouveia, F. B. 2014 Biological monitoring using macroinvertebrates as bioindicators of water quality of Maroaga stream in the Maroaga cave system, Presidente Figueiredo, Amazon, Brazil. *Int. J. Ecol.* **2014**. https://doi.org/10.1155/2014/308149.

Wang, S., Wang, L., Deng, L., Zheng, D., Zhang, Y., Jiang, Y., Yang, H. & Lei, Y. 2017 Performance of autotrophic nitrogen removal from digested piggery wastewater. *Bioresource Technology* **241**, 465–472.

Widyarani, Wulan, D. R., Hamidah, U., Komarulzaman, A., Rosmalina, R. T. & Sintawardani, N. 2022 Domestic wastewater in Indonesia: Generation, characteristics and treatment. *Environmental Science and Pollution Research* **29** (22), 32397–32414.

Wijeyaratne, W. D. N. & Bellanthudawa, B. K. A. 2017 Assessment of suitability of macrobenthic mollusc diversity to monitor water quality and shallow sediment quality in a tropical rehabilitated and non-rehabilitated wetland system. *Int. J. Aquatic Biol.* **5** (2), 95–107.

Wijeyaratne, W. M. D. N. & Liyanage, U. P. 2021 Macrobenthos-based RBP I l (Rapid Bioassessment Protocol Il) as a tool to assess the sediment and water quality in a treated textile effluent receiving stream ecosystem associated with a wetland marsh: A case study from Sri Lanka. *Lakes Reservoirs Res. Manage.* **26** (4), 1–25.

Xu, X., Jiang, B., Tan, Y., Costanza, R. & Yang, G. 2018 Lake-wetland ecosystem services modeling and valuation: Progress, gaps and future directions. *Ecosyst. Serv.* **33**, 19–28. https://doi.org/10.1016/j.ecoser.2018.08.001.

Xu, X., Chen, M., Yang, G., Jiang, B. & Zhang, J. 2020 Wetland ecosystem services research: A critical review. *Glob. Ecol. Conserv.* **22**, e01027. https://doi.org/10.1016/j.gecco.2020.e01027.

Yahyapour, S., Golshan, A. & Ghazali, A. H. b. 2014 Removal of total suspended solids and turbidity within experimental vegetated channel: Optimization through response surface methodology. *J. Hydro-Environ. Res.* **8**, 260–269. https://doi.org/10.1016/j.jher.2013.03.004.

Yang, T. X., Sheng, L. X., Zhuang, J., Lv, X. G. & Cai, Y. P. 2019 Function, restoration, and ecosystem services of riverine wetlands in the temperate zone. *Ecol. Eng.* **137**, 46–52. https://doi.org/10.1016/j.ecoleng.2017.01.004.

Ye, J., Hu, A., Cheng, X., Lin, W., Liu, X., Zhou, S. & He, Z. 2018 Response of enhanced sludge methanogenesis by red mud to temperature: Spectroscopic and electrochemical elucidation of endogenous redox mediators. *Water research* **143**, 240–249.

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