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Integrating water quality monitoring and ecological assessment for wetland classification and risk evaluation in the Kirala Kele wetland, Sri Lanka

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ABSTRACT

We conducted the present study to assess the spatial and temporal variations of selected physicochemical water quality parameters, to quantify the level of ecological risks of disturbances occurring, and to understand the relationship between the selected disturbances observed and physicochemical parameters of surface water of sampling sites of the Kirala Kele wetland. We selected sampling sites to reflect different land uses in the Kirala Kele wetland using purposive sampling and collected triplicated surface water samples to assess quality of water. The sampling sites of wetland characterization and risk assessment were followed using the protocol by Escom. We found that there was a significant temporal variation of pH, electrical conductivity, water temperature, and dissolved oxygen content among sampling sites ($p > 0.05$, One-Way ANOVA), however, spatial variation of electrical conductivity and dissolved oxygen was significantly higher in site 9, site 10, and site 11, respectively ($p > 0.05$, One-Way ANOVA). Site 2, site 5, site 10, and site 11 showed a category B level in wetland characterization and risk assessment highlighting the few levels of modifications and largely natural status of sites. The study demonstrates the applicability of this model for rapid assessment of wetland characteristics and risks to sustainably conserve and manage wetlands.

Key words: ecological disturbances, Kirala Kele wetland-Sri Lanka, monitoring and evaluation, surface water quality, wetland classification and risk assessment

HIGHLIGHTS

- Study showed a relationship with variation of water quality parameters and ecological risks in the Kirala Kele wetland.
- Wetland characterization revealed 'category B' levels in Sites 2, 5, 10, and 11.
- Other sampling sites showed 'category C' with moderate disturbances in the Kirala Kele wetland.
- This study suggests the need for an integrated wetland management approach and continuous monitoring to conserve the wetland.

1. INTRODUCTION

In the past few decades, naturally sensitive ecosystems such as wetlands have undergone irreversible negative impacts due to both anthropogenic and natural disturbances namely deforestation, solid waste dumping, discharging of industrial effluents, and other extreme events such as floods and droughts triggered by climate change scenarios (Kaleel 2017; Gupta *et al.* 2020). Despite the wetlands' uniqueness and their ecosystem services, many scientists have recognized that these ecosystems are vulnerable due to the complexity and interdependence of water–land–biotic interactions (Clarkson *et al.* 2013; Desta *et al.* 2012; Fernando 2019). Consequently, these sensitive wetlands are more susceptible to degradation as it exerts pressure and risk on these natural and manmade wetlands for their longevity and sustainability to continue their services. Nowadays, wetland ecologists and scientists have proposed numerous concepts of wetland risk assessment and wetland health assessment, however, the ever-growing human population and their demands, industrial development coupled with changing climate have directed the focus of wetland management studies to understand the quantification and characterization of risks associated with wetlands in wetland management action planning (Gupta *et al.* 2020; Eller *et al.* 2021).

Despite numerous scientific endeavors to study wetland health and conduct wetland risk assessments, the precise definitions of these terms remain a work in progress. This is primarily due to the complicated nature of wetland systems and their complex responses to external environmental factors (Sun *et al.* 2016; Ren *et al.* 2022). Nonetheless, in past couple of decades, many studies presented the ideology of the wetland health risk assessment in multiple ways (Das *et al.* 2020;

Wu & Chen 2020). Most of them have highlighted that in the concept of wetland risk assessment, the approach must be an integrative, responsive, multi-scale and dynamic system of matrices (Sun *et al.* 2017). Additionally, to design a comprehensive and cohesive assessment of wetland risks, estimations involved should be multifaceted levels of estimations (very low to very high) of potential hazards or threats posed by the stresses to both biotic and abiotic components of the wetlands (Sutula *et al.* 2006; Papas 2014). Furthermore, according to the United States Environmental Protection Agency (U.S. EPA), a successful risk assessment framework also should be viably capable of demonstrating to either qualitatively or quantitatively evaluate the actual and potential adverse impacts caused by ecological stresses or disturbances (Lomnicky *et al.* 2019).

Wetland risk assessment can consider both chemical (nutrients, contaminants, etc.) and nonchemical factors. In reality, wetlands face simultaneous attacks from chemical and physical stressors (Herlihy *et al.* 2019), thus numerous problems arise during the problem formulation and risk characterization phases of risk assessment when assessing the effects of chemical, physical, and biological stressors (Faber-langendoen *et al.* 2019). Therefore, a clear positioning of management and policy input is necessary for adequate technical support prior to the risk analysis activities associated with exposure and ecological effects assessment. This includes the resolution of questions revolving around two interrelated issues centered on data interpretation (performance-based versus criterion-based practices) and the distinction between risk analysis (characterization), risk assessment, and risk management (Oberholster *et al.* 2014; Ghosh & Das 2020). Recent published literature has identified the suitability of the Bayesian network as a graphical tool to determine possible risk levels of wetlands (Malekmohammadi *et al.* 2023; Banan-Dallalian *et al.* 2023). On top of that many research groups have focused on the employability of Geographic Information Systems and Remote Sensing (GIS and RS) to design fuzzy-based risk assessment models to screen out the risk associated with conversions of wetland systems in the world (Jia *et al.* 2015; Wu & Chen 2020). Besides, the use of heavy metals and toxic substances of waters and sediments have been concerned in the context of assessment of wetland risks to assess the accumulation of pollutants in abiotic components (Ramachandra *et al.* 2020). To quantify the impacts on biotic components and correlate the bioavailability of heavy metals and toxic substances, fish, micro-invertebrates, macro-invertebrates, and planktons are used as bioindicators in wetland risk assessment (Pham *et al.* 2019; Yang *et al.* 2019; Zhu *et al.* 2019). In these studies, the research substantially prioritized distinguishing the point and non-point sources and the distribution of these pollutants in wetlands to manage their effects. Fang *et al.* (2021) asserted the impacts of land use changes on the degradation and risk escalation of wetlands systems. Also, flood and drought risk assessments in wetlands have been discussed in depth whereas the ecological modeling, forecasting, and prediction approaches play a major role in the analysis (Sun *et al.* 2016, 2017; Das *et al.* 2020). However, to ease the applications of risk assessment, Escom's Wetland Classification and Risk Assessment Index Field Guide has been introduced as one of the most dependable rapid appraisal indices for the classification, assessment, and management of wetlands (Fennessy *et al.* 2007; Wanda *et al.* 2016; Beuel *et al.* 2016). To determine the health of wetlands, the index utilizes data on site information, field measurements (for instance, EC, pH, temperature, and DO), and physical characteristics of wetlands.

In the Sri Lanka context, several published literature has focused on the exploration of the impacts of land use change, the decline of wetland vegetation cover, variation, and deterioration of water quality on the wetland resilience and recovery capacities using the GIS and RS as a tool (Darshana 2017; Zahir & Nijamir 2018). In addition, Samarasinghe & Dayawansa (2013) conducted an analysis of the degradation of risk of Kolonnawa marshy land and thereby they calculated the overall risk on the marshy wetlands caused by attributes such as land use change, solid waste dumping, industrial developments, population expansion, etc. Besides freshwater ecosystems, the ecological risk to climate change has been assessed in the coastal wetlands as well using sea level rising and economic valuation methods (Mehvar *et al.* 2019). Apart from that flood risk assessment was explored because of land use change. The pharmaceutical and personal care products discharged into surface inland water wetland has also been studied (Styszko *et al.* 2021). Moreover, rapid assessment of wetland ecosystem services (RAWES) was also studied to portray the valuation of ecosystem services and their potential risks (Walters *et al.* 2021). Besides, the Artificial Neuro Network also has been utilized as a method to detect the water level changes in the flood detention areas of Colombo, Sri Lanka (Jayathilake *et al.* 2022). Together the incorporation of bioindicators such as birds, amphibians, and macrophytes in wetland systems has become one of the commonly followed practices in wetland health risk assessment due to excess pollutants incoming to wetland networks (Wijeyaratne & Bellanthudawa 2020; Jayawardena *et al.* 2021; Samaraweera *et al.* 2022).

The significance of the present study is that this study provides a framework to assess the risk of wetlands caused by multi scale disturbances agents synergized with physicochemical parameters of surface water quality through the Wetland Classification and Risk Assessment Index introduced by Escom (Wanda *et al.* 2016). Further, this study serves as a preliminary level of approach to understanding the level of risks posed by multiple disturbances to a wetland with numerous environmental pressures. With the aid of outcomes of this present study, it opens up space for wetland ecologists and scientists to develop and design the conservation and management framework of ecologically significant wetland ecosystems. Therefore, the present study was conducted with the objective of (1) to assess the spatial and temporal variation of selected physicochemical water quality parameters in sampling sites of Kirala Kele wetland, (2) to quantify the level of ecological risks of disturbances occurring at sampling sites of Kirala Kele wetland using the Wetland Classification and Risk Assessment protocol by Escom, and (3) to assess the relationship between the selected disturbances observed and physicochemical parameters of surface water of the Kirala Kele wetland. The science questions that are answered in the present study are (1) Is there a significant variation in selected physicochemical parameters of surface water of the Kirala Kele wetland over time and space? (2) What is the level of characterization of ecological risks observed among the selected sampling sites of Kirala Kele wetland, and (3) Is there a relationship between surface water quality and ecological risks observed on the sampling sites of Kirala Kele wetland?

2. MATERIALS AND METHODS

2.1. Study area

This study was conducted in the Kirala Kele wetland, Sri Lanka. The Kirala Kele wetland is made up of different types of wetlands, marshland, mangrove areas, paddy lands, and irrigation canals as well as numerous home gardens as it populated villages. Kirala Kele covers an area of 1,800 hectares with 310 hectares of it being designated a wetland located at the exit of the southern expressway in Godagama about three kilometers from Matara town (Fernando 2019). The Kirala Kele wetland is located in southern area from the center of Matara district. It is located between the Matara – Akuressa main road and Matara – Hakmana main road in the west and east of the wetland (5.979°N, 80.513°E) (Saranga *et al.* 2022). Figure 1 shows the location of the Kirala Kele wetland and the selected 12 sampling points of the Kirala Kele wetland. Site 1 is a site with industrial activities. Site 2 is a solid waste dumping site. Site 3 is a location where fishing is intensively conducted. Site 4 is a location where buffaloes take bath and site 5 is a location with high floral density. Site 6 is a location where agriculture practices are conducted and site 7 is a livestock raising site. Site 8 is a location where land farming is practiced and site 9 is where there exist human settlements. Site 10 is a site with tourism activities. Site 11 and site 12 are respectively the locations where water inflow and location water outflow are presented.

2.2. Sampling framework

The step-wise comprehensive framework of the research study is depicted in Figure 2. The study framework is composed of main two components with exploration of water quality of selected sampling sites and disturbances levels of the Kirala Kele wetland.

2.2.1. Water quality sampling

The present study was carried out from March to May 2022 on a monthly basis (sampling events; March, April, and May; $n = 3$). Pre-cleaned sample bottles were used to collect water samples and sampling bottles were rinsed twice with surface water from the sampling sites before taking the final sample. Three replicates ($n = 3$) from each sampling site at the same water depth (25 cm) were obtained from all 12 sampling sites in three sampling events. Later, these water samples were preserved using sulfuric acid (1 mL, 95% conc. sulfuric acid) as per the international surface water quality standards (APHA 2014). Then the collected sampling bottles were immediately transported to the laboratory of Department of Agricultural Engineering and Environmental Technology, Faculty of Agriculture, University of Ruhuna, Matara, Sri Lanka for the water sample analysis.

Then the collected samples were analyzed for electric conductivity (mS/cm), pH, temperature (°C) and dissolved oxygen (mg/L) (Wanda *et al.* 2016). Temperature and dissolved oxygen were measured onsite. pH and electrical conductivity were measured at the laboratory. pH was measured by using the pH meter (HANNA – HI 98127). Temperature was measured by using the thermometer. Electric conductivity was measured by using the electrical conductivity meter (HANNA – HI 98130). Dissolved oxygen was measured by using the Dissolved oxygen meter (HANNA – HI 9146). These parameters were measured according to the APHA standards (APHA 2014).

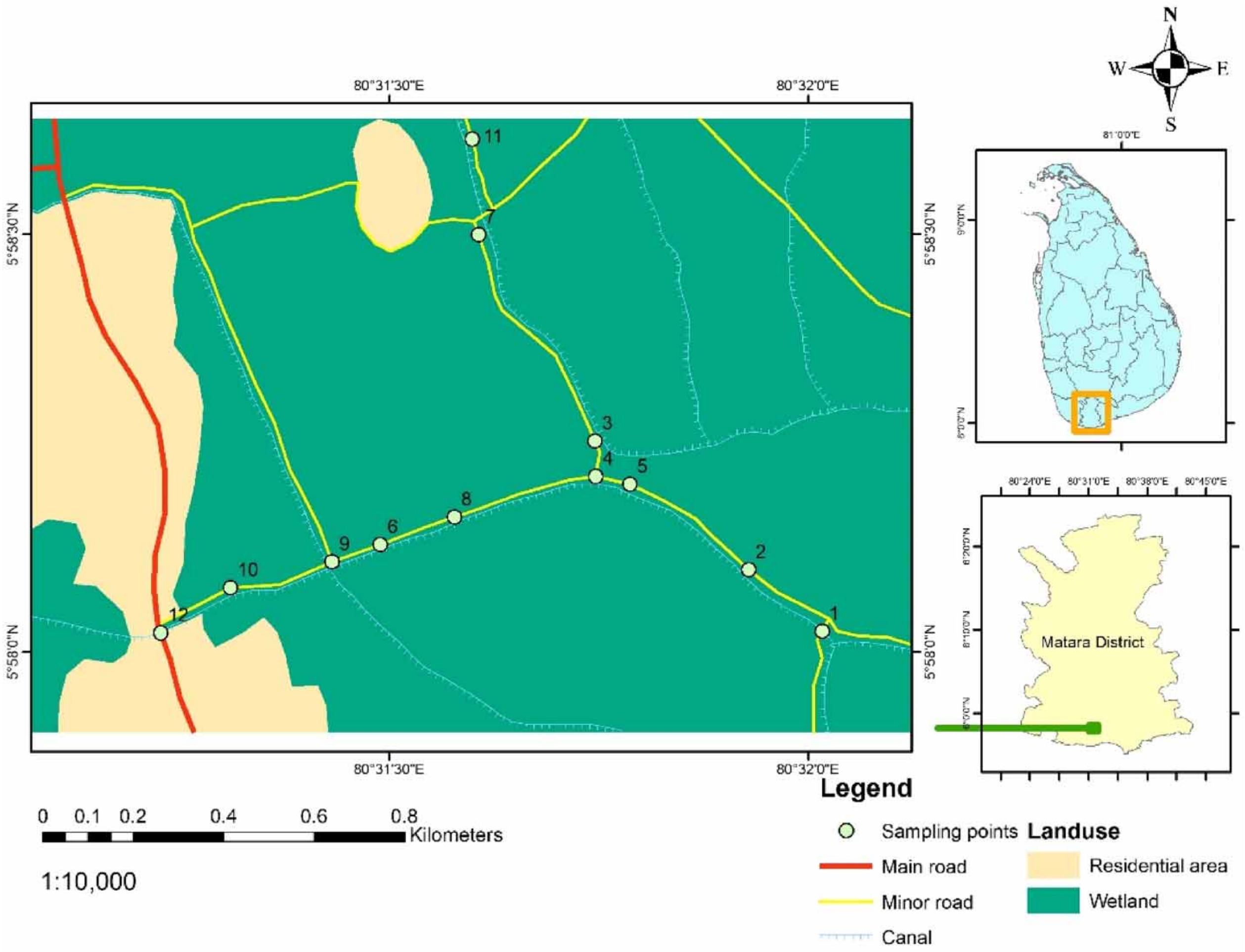


Figure 1 | Map showing the location of the Kirala Kele wetland and the selected 12 sampling points in the wetland.

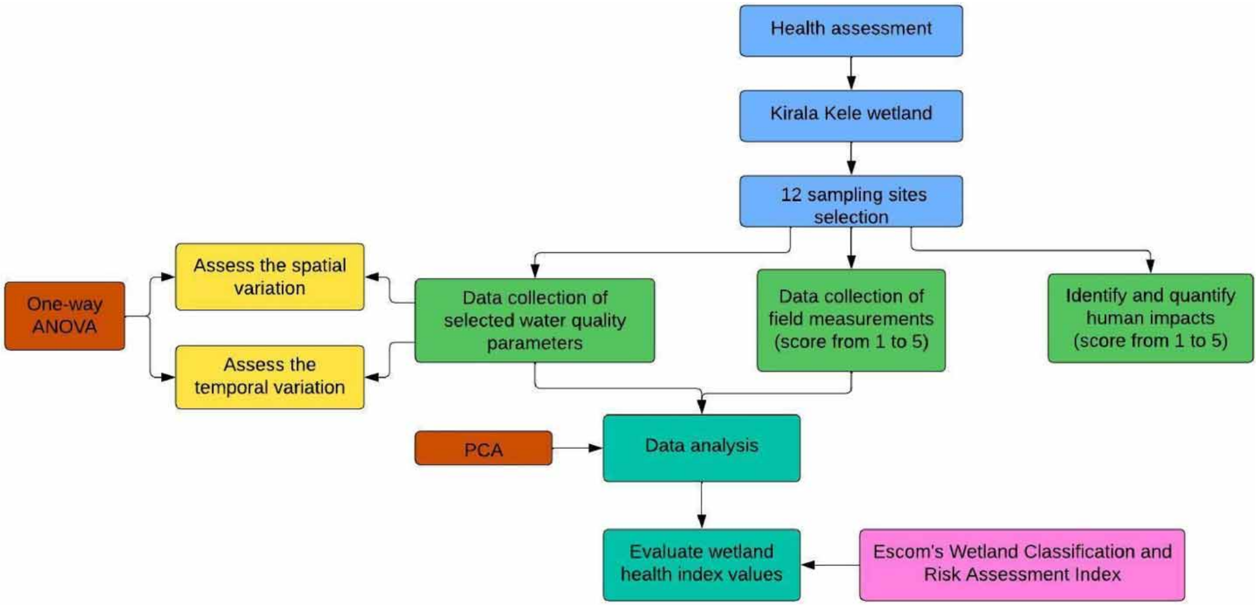


Figure 2 | Flowchart of the research study.

2.2.2. Characterization of the Kirala Kele wetland by considering chemical and physical characteristics

Field measurements were carried out to get data on pugging (No./m^2), stability of bank, percentage of aquatic cover (%), presence of algae (m^2), fringing vegetation cover (m) and number of layers of macrophyte plants in or near water in the western part of the wetland (Wanda *et al.* 2016).

The process of pugging happens by livestock such as cattle and buffaloes. In this study, only consider the animal impact under the pugging. It may cause soil compaction, increase erosion, decrease water infiltration rates and cause a reduction in water storage capacity. Pugging was measured using the mean number of cattle hoof marks in quadrants (1 m^2) placed randomly on the sediment surface at the water's edge of a wetland (Wanda *et al.* 2016). Five replicates ($n = 5$) in each sampling point were collected. Data were collected from 12 sampling sites and the average value of all the 12 sampling sites was recorded at the end. Then a score system was introduced based on 1–5 giving the higher score 5 to higher mean number of pugging.

The bank stability condition of each sampling site was determined by getting the visual observation through walking in the Kirala Kele wetland and the condition was recorded under 5-score categories as stable (score 5), good (score 4), moderate (score 3), poor (score 2), or unstable (score 1) wetland banks (Wanda *et al.* 2016). The wetland bank was classified as stable if it is fully covered by sufficient vegetation cover. It was decided by visual observation subjected to educational judgment considering the number and type of the plants (large trees, small trees, shrubs, etc.). '*stable*' bank condition means that a large number of plants are available and cannot be counted. The wetland bank was categorized as of '*good*' stability if it has some minor spot erosion occurring in a few small sized places. The wetland bank was considered as '*moderate*' stability, if it is with some erosion occurring having interlinked spot erosion points with minor structural and vegetation damage occurring to small areas of erosion. The wetland bank was considered '*poor*' stability, with a significant area of erosion occurring and number of plants such as trees and shrubs availability is very low. The wetland banks were categorized as '*unstable*' if they showed occurrence of extensive erosion with bare banks; steep banks contribute to the erosion. At the end, the combined average condition of stability of sampling sites was recorded.

The aquatic cover percentage (%) was estimated by visual counts computing the percentage of water surface that was covered with aquatic vegetation. Aquatic plants included the emergent, submerged and floating plants in the open water zones of the wetland (Wanda *et al.* 2016). The fraction of area covered by the algae in a sample area (m^2) was assessed as a physical measurement. The number of macrophyte layers was another parameter to classify wetland risk assessment. Data were collected to calculate the number of macrophyte layers in or near water that are emergent, submerging, or floating on water. In addition, fringing vegetation cover (m^2) was measured based on visual measurements of the riparian strip taken at the 12 sampling points of the wetland and at the end mean width of the natural vegetation fringing was determined (Wanda *et al.* 2016).

The physicochemical parameters of water including the pH, electrical conductivity, and dissolved oxygen were characterized under 5 classes and scores were assigned ranging from (higher values; score 5 and lower values; score 1 in pH and dissolved oxygen and electrical conductivity in the vice-versa condition).

2.2.3. Evaluate the wetland index score considering physical and chemical characteristics

The wetland index score was determined based on field measurements of various physical and chemical characteristics. All scores were added to calculate the total score to each as shown in Table 1 (Wanda *et al.* 2016).

The average values were evaluated according to the score range for each parameter and the appropriate score was entered into this modified Field Guide for Wetland Classification and Risk Assessment Index of Escom (Wanda *et al.* 2016). Then we assessed the health of all selected 12 sampling points separately in Kirala Kele wetland based on the field guide for wetland classification and risk assessment index of Escom. For that the output score obtained from the index field guide (Table 2) was transformed to a percentage. The percentages were calculated by dividing the observed score value from the total score value and multiplying by 100 (Equation (1); Wanda *et al.* 2016). Forty-five (45) was the maximum possible total score.

$$\text{Percentage} = \frac{\text{Output score obtained the score sheet}}{\text{Total score}} \times 100 \tag{1}$$

After that the calculation of the percentage values that was used to determine the A-F ecological categories as shown in Table 2.

Table 1 | Different physical and chemical parameters and their score value range introduced by Escom (Wanda *et al.* 2016)

	Score value range				
Physical and chemical parameters	**5**	**4**	**3**	**2**	**1**
Electrical conductivity (mS/cm)	0–0.292	0.293–0.833	0.834–2.500	2.501–5.833	>5.833
pH	7.01–7.5	6.61–7.0	6.21–6.6 or 7.51–8.0	6.01–6.2	<6 or >8
Dissolved oxygen (mg/L)	>7	5.01–7.0	2.01–5.0	1.5–2.0	<1.5
Fringing vegetation cover (m^2)	>30	8–29.9	3–7.9	0.5–2.9	<0.5
Pugging (mean no. of pugs/m^2)	0	1–6	7–12	13–19	>19
Stability of bank	Stable	Good	Moderate	Poor	Unstable
Percentage of aquatic cover (%)	51–85	26–50	5–25	>85	<5
Algae present surface area (m^2)	0	0.01–0.1	0.11–0.5	051–1.0	>1.0
Number of macrophyte layers	>3	3	2	1	0

Table 2 | Ecological categories (Wanda *et al.* 2016)

Category	Value of score (%)	Description of each ecological category
A	90–100	Natural, not modified.
B	80–90	Few modifications and largely natural. Few small-scale changes in biota and natural habitats may have taken place but the essential ecosystem functions are unchanged.
C	60–80	Modified moderately. Natural habitats and biota loss and changes have occurred, but predominantly the basic ecosystem functions are still not changed.
D	40–60	Modified largely. Largely loss of natural habitats, biota and basic ecosystem functions have occurred.
E	20–40	Modified seriously. Extensively loss of natural habitats, biota and basic ecosystem functions.
F	0–20	Modified critically. Modifications have reached to a critical level and the system has been completely modified with completely loss of natural habitat and biota.

2.2.4. Determination of major human impacts on the Kirala Kele wetland

Both primary and secondary data were used to determine the major human impacts on Kirala Kele wetland. Direct observations of human activities being carried out in and around the wetland, evidence of degradation on land and settlement, discussions conducted with neighboring community were used for the collection of primary data (Kimani 2016; Sunny *et al.* 2020). Journals, online websites, and published academic books about the wetlands were used for collection of secondary data. Then identified human impacts were rated on the scale from very low to very high and assigned values from 1 to 5 for each site separately based on the frequency of occurrence, intensity and the magnitude of occurrence of those selected human disturbances supported by the educational judgment.

2.3. Statistical analysis

First, the data of water quality parameters (pH, electrical conductivity, dissolved oxygen and temperature) at each sampling site in each sampling event were analyzed using One-way ANOVA to assess the spatial and temporal variation of these parameters using MINITAB 17. Second, the ecological disturbances were identified, and their risks were characterized by giving an overall index value based on the Wetland Classification and Risk Assessment Index of Escom (Wanda *et al.* 2016). In addition, the types of human disturbances were identified, and those attributes were weighed and grouped ranging from very low-1 to very high-5 assigning weightage from 1 to 5 scale. Third, Principal Component Analysis (PCA) was conducted using MINITAB 17 to determine characteristic water quality parameters and identified disturbances that caused risk to characterize each sampling site in the Kirala Kele wetland.

3. RESULTS

3.1. Spatial and temporal variation of water quality parameters and meteorological parameters among sampling sites in the Kirala Kele wetland

Total rainfall (mm) of the Kirala Kele study area was obtained from Agro Meteorological Station, Mapalana, Matara. The highest total rainfall was recorded in year 2021 (2,740 mm). The second highest total rainfall was recorded in 2022 (2,491 mm) and the lowest rainfall recorded in year 2020 (1,997 mm) (Supplementary material, Annexure A). The highest total rainfall recorded throughout the study in May (353 mm). The second highest total rainfall was recorded in April (224 mm). Comparatively a lower total rainfall value was recorded in March (117 mm). Same average ambient temperature was recorded in all 3 years (29°) (Supplementary material, Annexure A). Throughout the study highest ambient temperature was recorded in April (30 °C). All other 2 months recorded the same ambient temperature (29 °C).

The spatial variation of mean ± Standard Error of Mean (SEM) of water quality parameters in each sampling site is given in Figure 3. The mean pH of water of sampling sites ranged from 6.15 to 7.80. The lowest mean pH was recorded in site 6 (6.95 ± 0.34) while the highest mean pH was recorded in site 1 (7.3 ± 0.07). However, there was no significant spatial variation of pH among sampling sites at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Figure 3). The mean electrical conductivity of the water of sampling sites was ranged from 0.41 to 1.11 mS/cm. Mean electrical conductivity of site 9 was (1.01 ± 0.02) significantly higher compared to other sites and mean electrical conductivity of site 10 was significantly lower compared to all other sites (0.46 ± 0.01) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Figure 3).

The mean dissolved oxygen concentration of sampling sites ranged from 0.67 to 5.50 mg/L. Mean dissolved oxygen concentration of site 10 (4.26 ± 0.37 mg/L) and site 11 (4.27 ± 0.98 mg/L) were significantly higher compared to other sites at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Figure 3). Further, the mean water temperature of sampling sites ranged from 29 to 34.1 °C. Mean water temperature of site 7 was significantly higher compared to other sites (33.7 ± 0.35 °C) and mean water temperature of site 1 was significantly lower compared to all other sites (31.6 ± 1.42 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Figure 3).

The temporal variation of mean ± SEM of water quality parameters in each sampling site is given in Supplementary material, Annexure B. In site 1, the mean pH was significantly lower in March (7.16 ± 0.006) than other months. The mean dissolved oxygen in March (1.60 ± 0.003 mg/L) was significantly higher and the mean dissolved oxygen in April (0.90 ± 0.012 mg/L) was significantly lower. The mean water temperature in April (33.9 ± 0) was significantly higher and the mean water temperature was significantly lower in March (29.0 ± 0) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Supplementary material, Annexure B).

In site 2, the mean pH in April (7.46 ± 0.033) was significantly higher and the mean pH in March (6.46 ± 0.008) was significantly lower. The mean electrical conductivity in May (0.55 ± 0.003) was significantly higher than in the other 2 months. The mean dissolved oxygen in March (3.11 ± 0.003 mg/L) was significantly higher and the mean dissolved oxygen was significantly lower in May (2.40 ± 0.003 mg/L). Also, the mean water temperature was significantly higher in April (33.5 ± 0 °C) and significantly lower in March (31.0 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Supplementary material, Annexure B).

In site 3, the mean pH in March (6.31 ± 0.003) was significantly lower than other months. The mean dissolved oxygen in March (4.31 ± 0.014) was significantly higher and significantly lower in May (3.15 ± 0.014) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison). In site 4, the mean pH in April (7.53 ± 0.033) was significantly higher and significantly lower in March (6.44 ± 0.005). The mean dissolved oxygen was significantly higher in March (4.73 ± 0.005 mg/L) when compared to other months. The mean water temperature was significantly higher in April (32.4 ± 0 °C) and significantly lower in March (32.0 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Supplementary material, Annexure B).

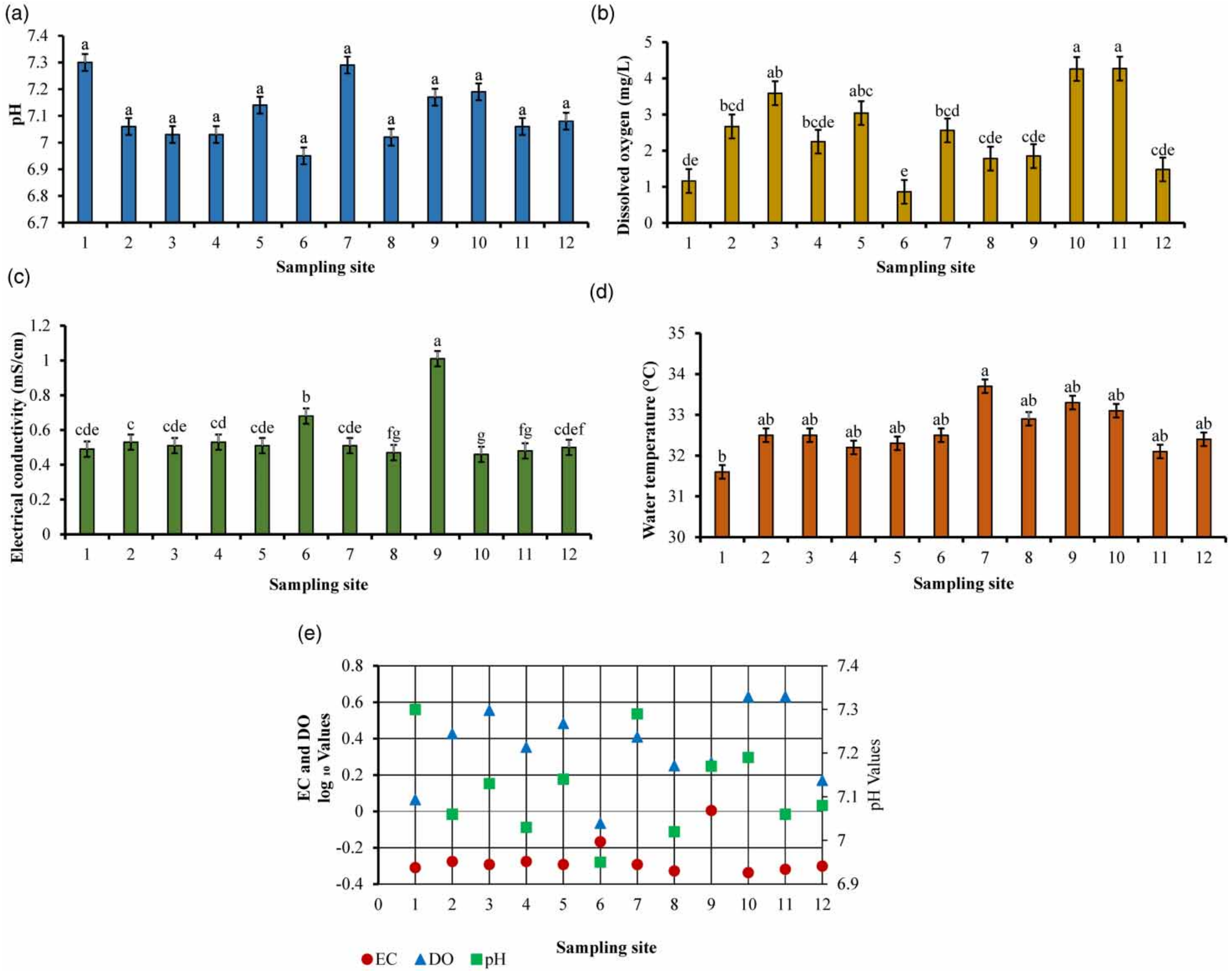


Figure 3 | Spatial variation of water quality parameters of 12 sampling sites; (a) pH, (b) dissolved oxygen (mg/L), (c) electrical conductivity (μS/cm), (d) water temperature (C^0), and (e) variation of pH values, EC and DO log $_{10}$ values.

In site 5, the mean pH was significantly lower in March (6.31 ± 0.003) than in other months. The mean dissolved oxygen was significantly higher in March (4.89 ± 0.02 mg/L) than other months. The mean water temperature was significantly higher in April (33.0 ± 0 °C) and significantly lower in March (32.0 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison). In site 6, the mean pH was significantly lower in March (6.26 ± 0.01) than other months. The mean dissolved oxygen in March (0.77 ± 0.008 mg/L) was significantly higher than in the other 2 months. The mean water temperature was significantly higher in May (33.0 ± 0 °C) and significantly lower in March (32.5 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Supplementary material, Annexure B).

In site 7, the mean pH in March (6.47 ± 0.003) was significantly lower than April and May. The mean dissolved oxygen was significantly higher in March (3.04 ± 0.011 mg/L) when compared to other months. The mean water temperature was significantly higher in May (34.1 ± 0 °C) and significantly lower in March (33.0 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison). In site 8, the mean pH in May (7.26 ± 0.03) was significantly higher and the mean pH in March (6.40 ± 0.01) was significantly lower. The mean dissolved oxygen was significantly higher in April (1.88 ± 0 mg/L) and significantly lower in March (1.65 ± 0.003 mg/L). The mean water temperature in April (33.7 ± 0 °C) was significantly higher and significantly lower in March (31.0 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Supplementary material, Annexure B).

In site 9, the mean pH was significantly higher in April (7.76 ± 0.033) and significantly lower in March (6.18 ± 0.006). The mean electrical conductivity was significantly higher in April (1.05 ± 0.026 mS/cm) and significantly lower in March (0.98 ± 0.003 mS/cm). The mean dissolved oxygen in March (4.17 ± 0.003 mg/L) was significantly higher and significantly lower in April (0.68 ± 0.005 mg/L). The mean water temperature in April (33.3 ± 0 °C) was significantly higher and significantly lower in March (32.8 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Supplementary material, Annexure B). In site 10, the mean pH in March (6.16 ± 0.008) was significantly lower than April and May. The mean dissolved oxygen in April (4.66 ± 0.006 mg/L) was significantly higher and the mean dissolved oxygen was significantly lower in March (3.51 ± 0.008 mg/L). The mean water temperature in April (33.6 ± 0 °C) was significantly higher and significantly lower in March (32.5 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Supplementary material, Annexure B).

In site 11, the mean pH was significantly lower in March (6.22 ± 0.005) than other months and the mean dissolved oxygen in March (2.30 ± 0.003) was significantly lower than other months. The mean water temperature in April (33.3 ± 0 °C) was significantly higher and significantly lower in March (30.0 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison). In site 12, the mean pH in March (6.24 ± 0.01) was significantly lower than April and May. The mean dissolved oxygen in April (1.82 ± 0.003 mg/L) was significantly higher and the mean dissolved oxygen was significantly lower in March (0.82 ± 0.033 mg/L). The mean water temperature in April (33.1 ± 0 °C) was significantly higher and significantly lower in March (31.3 ± 0 °C) at 95% level of significance ($p < 0.05$; One-way ANOVA followed by Tukey's pairwise comparison) (Supplementary material, Annexure B).

3.2. The calculation of the wetland index score

3.2.1. Field measurements

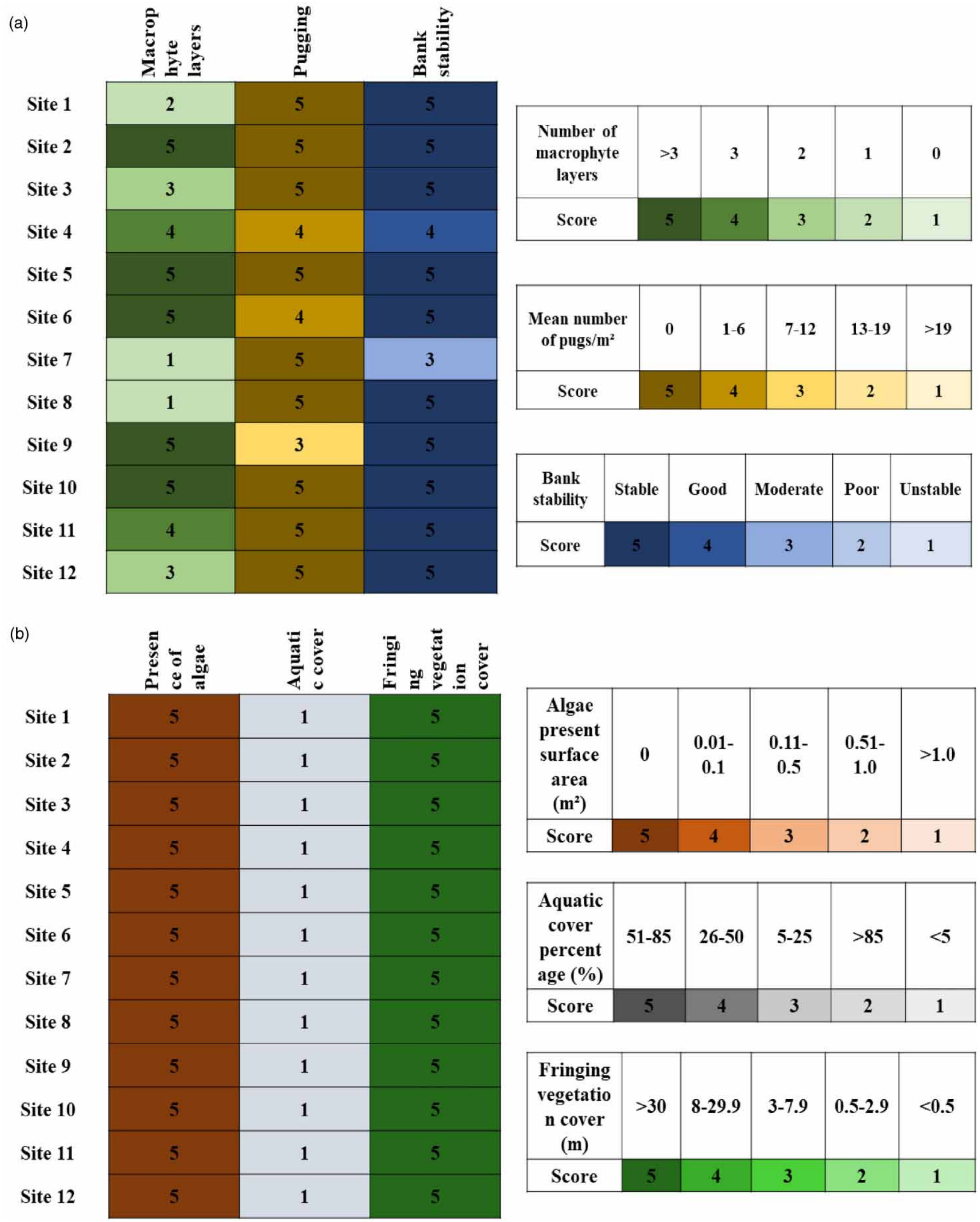
3.2.1.1. Macrophyte layers. Recorded data of macrophyte layers, pugging and bank stability among the selected sampling sites are illustrated in Figure 4(a). Diverse macrophyte layers were observed in Kirala Kele wetland and those macrophytes include emergent plants such as cattail (*Typha latifolia*), rooted floating plants such as lotus (*Nelumbo nucifera*), water snowflake (*Nymphoides indica*), pond weed (*Potamogeton distinctus*), free floating plants such as duck weed (*Lemnoideae*), water hyacinth (*Eichhornia*), and submerged plants such as *Elodea Canadensis, Potamogeton crispus*. Notably, site 2, site 4, site 5, site 9, site 10 presented macrophyte layers above 3 whereas site 7 and site 8 presented no macrophyte coverage in those sites (Figure 4(a)).

3.2.1.2. Pugging. According to the field score sheet for the physical characteristics, the combined mean number of pugs/m^2 is in between 1 and 6 (Figure 4(a)). Interestingly, site 9 showed the highest number of pugging per m^2 recorded among sampling sites while the majority of sites showed no signs of pugging in their locations.

3.2.1.3. Bank stability. In most of the sampling sites, bank stability was recorded as '*stable*' and there was sufficient vegetation cover available. On the contrary, site 3 showed a '*moderate*' and site 4 showed a '*good*' bank stability condition respectively. Sufficient vegetation cover means that many plants are available there and cannot be counted and no extensive erosion was observed on the bare banks (Figure 4(a)).

3.2.1.4. Presence of algae. Figure 4(b) shows data and their scores for the recorded presence of algae, aquatic cover percentage and fringing vegetation cover. There was no presence of the algae mats on the water surface in the wetland (Figure 4(b)). If algae present, it can be seen as a scum on the surface of water. Sometimes there was an odor there. During sampling, no scum or odor was observed, and clear water was present. Therefore, in all the sampling sites registered a score is five.

3.2.1.5. Aquatic cover percentage. Average aquatic plants available surface area of 12 sampling points is 37.756 m^2. Total area of samples collected from water channels in the western area of the Kirala Kele wetland is 97,560 m^2. Based on the results, aquatic cover percentage is <5% in all the sampling sites (Figure 4(b)) thus, the registered score is one for all the sampling sites.



(a)

	Macrophyte layers	Pugging	Bank stability
Site 1	2	5	5
Site 2	5	5	5
Site 3	3	5	5
Site 4	4	4	4
Site 5	5	5	5
Site 6	5	4	5
Site 7	1	5	3
Site 8	1	5	5
Site 9	5	3	5
Site 10	5	5	5
Site 11	4	5	5
Site 12	3	5	5

Number of macrophyte layers	>3	3	2	1	0
Score	5	4	3	2	1

Mean number of pugs/m²	0	1-6	7-12	13-19	>19
Score	5	4	3	2	1

Bank stability	Stable	Good	Moderate	Poor	Unstable
Score	5	4	3	2	1

(b)

	Presence of algae	Aquatic cover	Fringing vegetation cover
Site 1	5	1	5
Site 2	5	1	5
Site 3	5	1	5
Site 4	5	1	5
Site 5	5	1	5
Site 6	5	1	5
Site 7	5	1	5
Site 8	5	1	5
Site 9	5	1	5
Site 10	5	1	5
Site 11	5	1	5
Site 12	5	1	5

Algae present surface area (m²)	0	0.01-0.1	0.11-0.5	0.51-1.0	>1.0
Score	5	4	3	2	1

Aquatic cover percentage (%)	51-85	26-50	5-25	>85	<5
Score	5	4	3	2	1

Fringing vegetation cover (m)	>30	8-29.9	3-7.9	0.5-2.9	<0.5
Score	5	4	3	2	1

Figure 4 | Recorded quantities for (a) macrophyte layers, pugging and bank stability and their score values, (b) presence of algae, aquatic cover percentage and fringing vegetation cover and their score values for each sampling site of the Kirala Kele wetland.

3.2.1.6. Fringing vegetation cover. In this Kirala Kele wetland, there is a continuous natural vegetation cover available in the wetland banks. Therefore, all 12 sampling points have more than 30 m width of fringing vegetation cover. The mean fringing vegetation cover of all 12 sampling points was higher than 30 m. Based on that registered a score is five in the score field guide (Figure 4(b)).

3.2.2. The calculation of wetland index score for all sampling points

Figure 5 depicts the calculated total wetland index scores percentages of each sampling site of Kirala Kele wetland. Sampling sites namely 2, 5, 10, and 11 presented a % wetland index score value above 80%-90% indicating that these sampling sites belong under the category B of wetland characterization and risk assessment introduced by Escom. On the contrary, all other sampling sites belonged to category C wetland characterization and risk assessment.

The observed total score value was divided by total score (45), and it was multiplied by 100 to get the percentages of all the sampling points. Note that category: B (light brown color bars; 80–90%) indicates that there are few modifications and largely natural and few small-scale changes in biota and natural habitats may have taken place, but the essential ecosystem functions are unchanged (Table 2). Also, category C: (light green color bars; 60–80%) indicates that the site is modified moderately, and natural habitats and biota loss and changes have occurred, but predominantly the basic ecosystem functions are still not changed (Table 2).

3.3. Human impacts quantification

Following human activities that were carried out in and around the Kirala Kele wetland were identified as major impacts that may cause the degradation of the wetland. Figure 6 shows quantification of identified human impacts in each sampling site in the Kirala Kele wetland. Those human impacts were namely solid waste disposal, land reclamation, agricultural activities, land use changes, spreading of invasive species, and animal pouching.

3.4. PCA based on water quality parameters and field measurements

The variation of physicochemical parameters among sampling sites in Kirala Kele wetland is given by the PCA. The resulting PCA plot of the physicochemical parameters is given in Figure 7. The Eigen values of sampling sites based on physicochemical parameters is given in Table 3. The eigenvectors of sampling sites based on physicochemical parameters are given in Table 4. Site scores of sampling sites obtained by PCA based on physicochemical parameters are given in Table 5.

In Figure 7, a PCA biplot was constructed to visualize the relationships between water quality parameters and disturbances with respect to the sampling sites. PC1 and PC2 explain 30.7 and 55% of the variation in the data, respectively. Regarding the biplot matrix, the presence of algae and bank stability are primarily explained by PC2, while macrophyte coverage, pH and pugging are positively correlated and primarily explained by PC1. In contrast to the matrix, macrophyte coverage and pugging were negatively correlated with all other disturbances to the sites, whereas pH and DO were negatively correlated with temperature and EC water quality parameters according to the biplot results.

When considering the PCA results, it is evident that sites 5 and site 12 were characterized by macrophyte coverage and fringing vegetation disturbances, as they appear in the same quadrant. Site 2 was primarily distinct with bank stability.

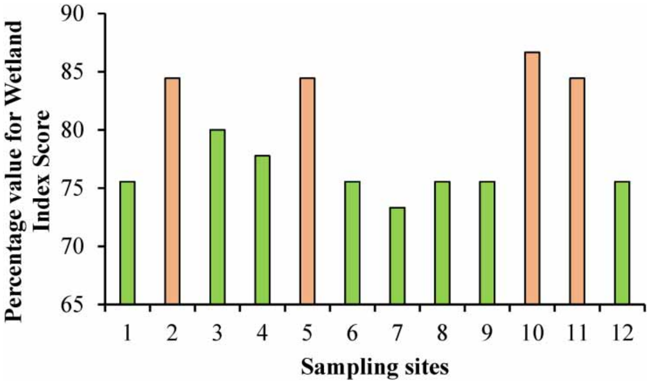
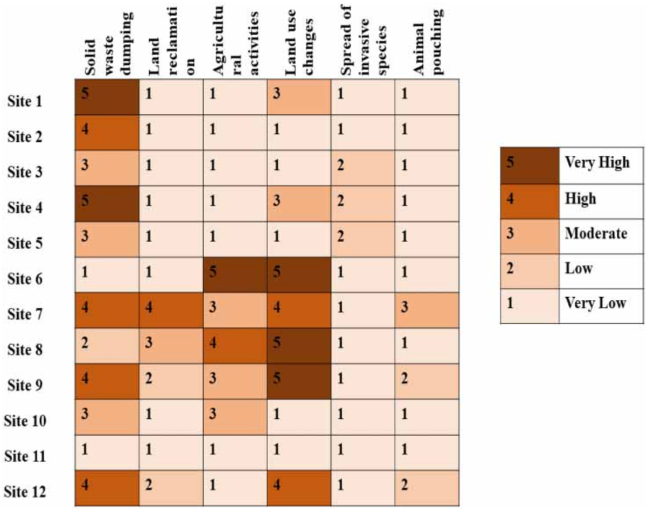


Figure 5 | The calculated Kirala Kele wetland index score range for each physical and chemical parameter of disturbances.



	Solid waste dumping	Land reclamation	Agricultural activities	Land use changes	Spread of invasive species	Animal pouching
Site 1	5	1	1	3	1	1
Site 2	4	1	1	1	1	1
Site 3	3	1	1	1	2	1
Site 4	5	1	1	3	2	1
Site 5	3	1	1	1	2	1
Site 6	1	1	5	5	1	1
Site 7	4	4	3	4	1	3
Site 8	2	3	4	5	1	1
Site 9	4	2	3	5	1	2
Site 10	3	1	3	1	1	1
Site 11	1	1	1	1	1	1
Site 12	4	2	1	4	1	2

5	Very High
4	High
3	Moderate
2	Low
1	Very Low

Figure 6 | Quantified human driven impacts (solid waste dumping, land reclamation, agricultural activities, land use change, spreading of alien/invasive species, and animal poaching) in each sampling site with their weightage scores. Score 1 was assigned to the 'very low' impacts while Score 5 was assigned to 'very high' impact.

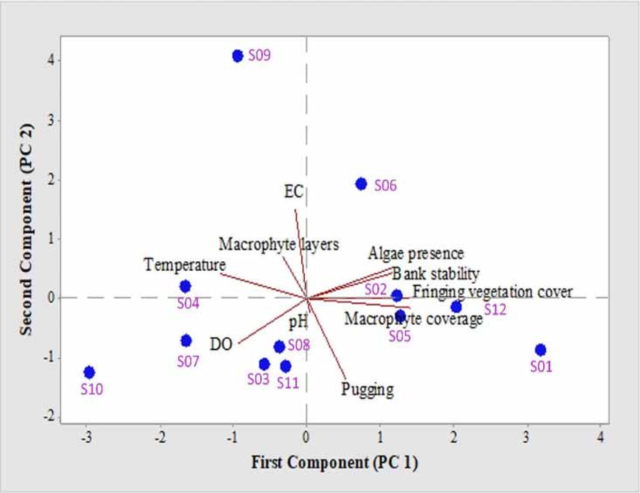


Figure 7 | The ordination of the sampling sites in the Kirala Kele wetland of the PC 1 and PC 2 scores of PCA created using physicochemical parameters.

Additionally, site 4 and site 7 were characterized by the temperature and DO parameters, respectively, as indicated by the biplot results. Furthermore, site 9 was primarily represented by the EC parameter.

4. DISCUSSION

The present study was conducted with the objective of determining variation of water quality and assessment of associated physical disturbances in one of the ecologically important wetland; Kirala Kele in Sri Lanka. We found that there exists a significant variation of water quality parameters; DO, EC, temperature of water, pH among 3 sampling events conducted and site 2, site 5, site 10, and site 10 are at higher risk (Category B) compared to all other sampling sites. These outcomes illustrate the need of essential integrative planning in the wetland health conservation and management of wetland degradation.

Table 3 | The eigenvalues of the 12 sampling sites based on physicochemical parameters in the Kirala Kele wetland

Eigenvalues	Proportion	Cumulative
3.0705	0.307	0.307
2.4304	0.243	0.550
1.7839	0.178	0.728
1.4280	0.143	0.871
0.4705	0.047	0.918
0.3395	0.034	0.952
0.3103	0.031	0.983
0.1315	0.013	0.996
0.0353	0.004	1.000
0.0001	0.000	1.000

Table 4 | The eigenvectors of the 12 sampling sites based on physicochemical parameters in the Kirala Kele wetland (coefficients in the linear combinations of variables making up PCs)

Variable	PC1	PC2	PC3	PC4	PC5
pH	0.011	−0.089	−0.661	−0.160	−0.186
EC	−0.052	0.618	−0.078	−0.090	−0.100
DO	−0.308	−0.316	0.100	−0.529	−0.052
Temperature	−0.381	0.170	−0.307	0.045	0.787
Pugging	0.175	−0.559	0.057	−0.200	0.338
Macrophyte coverage	0.458	−0.064	−0.263	−0.275	0.080
Algae presence	0.390	0.218	−0.344	−0.322	0.039
Macrophyte layers	−0.107	0.291	0.314	−0.545	0.236
Fringing vegetation cover	0.456	0.010	0.102	0.352	0.393
Bank stability	0.381	0.180	0.391	−0.211	0.043

Table 5 | The score calculation based on PCA for the 12 sampling sites in the Kirala Kele wetland based on physicochemical parameters

Site	Score 1	Score 2	Score 3	Score 4	Score 5
1	3.193834	−0.86791	−1.57283	0.394125	−1.11078
2	1.219795	0.048106	0.363248	−1.47367	0.617839
3	−0.58409	−1.11305	0.508736	−0.55053	−0.44723
4	−1.66187	0.204698	0.889132	1.315913	−1.21342
5	1.27547	−0.29171	0.364556	−1.08555	0.490882
6	0.735805	1.941489	1.399198	1.153828	0.292646
7	−1.64368	−0.70708	−3.2807	0.832807	0.553094
8	−0.36989	−0.81023	1.093192	2.205198	0.815557
9	−0.94311	4.103388	−0.892	−0.8056	−0.21454
10	−2.97523	−1.24233	0.168107	−1.17618	0.177019
11	−0.28535	−1.13523	1.043232	−1.08311	−0.48655
12	2.03831	−0.13014	−0.08388	0.272783	0.525475

4.1. Spatial and temporal variation trends of water quality

The distribution of aquatic freshwater organisms is largely controlled by water quality characteristics hence, the ecological categories obtained from the risk assessment for a given wetland could be validated by using these water quality parameters as indicators of ecosystem integrity. With this foundation, this section of the discussion explores the answers for the first research question of the study. The water quality analysis illustrates the water collected from sampling sites of the Kirala Kele wetland persisted in the range of pH in between 6.5 and 7.5 which is the permissible levels of standards for surface water quality in Sri Lanka. Even though there was no discernible shift in the pH levels that were recorded across the selected sampling locations, most of the sampling sites depicted a lower pH value in March compared to other months in which a lower rainfall was recorded. The pH ranges from 6.5 to 8.5 is optimal for the majority of aquatic species and changes in this pH beyond the optimal level will significantly impact on the physiology, metabolism, and decreased reproduction, slowed growth and low survival of aquatic fishes, crustaceans, and planktons, etc. (Balbinot-alfaro *et al.* 2019). Besides, variations in pH also impact the solubility, transport and bioavailability of several contaminants including copper to aquatic species (Bhatti *et al.* 2018).

These pH changes in wetland systems may cause by several factors such as organic matter loss, removal of soil minerals during harvest, surface erosion and the effects of sulfur and nitrogen fertilizers (Mgbenu & Egbueri 2019; Ewaid *et al.* 2020). Adding nitrogen and sulfur fertilizers can lower soil pH over time (Ding *et al.* 2019). However, the reasons for pH variation between sampling periods may be due to biotic factors such as changes in vegetation types, interactions with the minerals of the soil below, coupled with dynamics or rainfall and temperature of the waters of wetlands. For instance, pH in wetlands is influenced by temperature as the CO_2 production and biological activity in wetland ecosystems are augmented by an increase in temperature and resultantly, carbonic acid production can reduce the pH of wetlands (Neina 2019). Also, wetland evaporation increases fueled by temperature increase causes wetland waters more alkaline water. On the other hand, rainfall also affects the pH of wetlands in a way that heavy rainfall can input sulfuric and nitric acids dissolved in waters (Hu *et al.* 2020a). Further, the pH decreased and increased over the growing season due to the absorption of CO_2 by submerged vegetation from the water. Sometimes pH decreases may occur due to external factors such as runoff, vegetation type and soil type surrounding the wetlands (Gehant 2011; Kang *et al.* 2021).

In the context of temporal changes of EC, the study did not depict a significant difference among the three sampling events. However, elevated level of EC showed in site 9 compared to category E level (for irrigation and agricultural activities) surface water quality (EC permittable level which was 0.7 mS/cm (Sri Lanka Water Quality Standard, 2019) warrants the reason for this variation as there are human settlements in the surrounding. EC measures the concentration of dissolved substances, minerals and chemicals present in the water and shows a positive correlation of dissolved concentration of substances with higher conductivity (Yang *et al.* 2021). As explained by Oberholster *et al.* (2014), disturbed wetland systems called pans are prone to more contamination because chemicals entering a pan become trapped and can accumulate over time due to the lack of outlets. More organic inputs from human settlements including waste causing wetlands to become more saline. On top of that some of the studies reported precipitation and groundwater influx also affect to the make changes in EC of the wetland waters (Gehant 2011), while many studies have studied that temperature has a substantial impact on variation of EC in a wetland system (Hu *et al.* 2020b; Wang *et al.* 2021). Higher temperatures and drought induced conditions prevailing associated with wetland systems accelerate the evapotranspiration causing more concentrated ion content in wetlands which ultimately increase EC (Liu *et al.* 2019a). Apart from that, effects of anthropogenic stresses on surface water quality are not always obvious because of the complicated interactions among several social, environmental, climatic and political elements. Intensive agricultural practices, irrigation and fertilizers applications, and improper solid waste dumping urge more pollutant inputs to sensitive wetlands and results in enhanced nutrients such as nitrogen and phosphorus, salt compounds. These typical manifestations effects increase EC in wetlands (Mainali & Chang 2021).

Findings of the present study demonstrated that highest dissolved oxygen values in April and May. Some studies showed that temperature, precipitation and water table level have an impact on dissolved oxygen concentration in water (Herrera 2021). In water, oxygen concentration would decline as air temperature rose and the dissolved oxygen concentration decreased with the increase of the surface water temperature (Shalby *et al*. 2020; Shrestha & Wang 2020). Site 1 and site 9 were recorded lower dissolved oxygen values in April. Some of the sampling sites recorded higher dissolved oxygen values in both April and May. Because rain saturates with oxygen as it falls, oxygen concentrations tend to rise in most surface water during rainy seasons (Liu *et al.* 2019b). The critical level of dissolved oxygen is above 4.5 mg/L. This is an indicator of good water quality and the health of an aquatic ecosystem (Banerjee *et al.* 2018). According to the results of present study, some of the sampling sites depicted a lower dissolved oxygen values when compared to this critical level. Due to agriculture activities, it may cause the release of different nutrients and organic compounds in to the water and ultimately, the nutrient accumulation cause to increase biological oxygen demand and reduced dissolved oxygen concentration. Due to the reduced solubility of oxygen at higher temperatures and the quick uptake of residual dissolved oxygen by aquatic organisms, a high concentration of nutrients and elevated water temperature typically lead to eutrophication and worsened water quality (Mainali & Chang 2021).

We noted that most of the sampling sites recorded higher water temperature values in April and lower water temperature values in March. Temperature is an important physical property, and it can negatively influence the biological, physical, and chemical properties of water such as dissolved oxygen, electrical conductivity, salinity, pH, water density, metabolic rates, etc. (Xue *et al.* 2019). The temperature of the water will rise along with the air temperature however, regional physical-geographical elements and climate related parameters reflected by air temperature determine the temporal distribution of the water temperature. Not only that but temperature can also be affected by anthropogenic factors such current agricultural land uses, industrial thermal emissions or hydraulic systems that change flow (Jurgelėnaitė *et al.* 2012). Moreover, these temperature changes in the water mainly related to the morphological and hydrological characteristics of the wetlands (Yang & Yu 2019). These justifications given by the published literature correspond with our results as the sampling sites of Kirala Kele wetland contain diverse land uses, and thus, fluctuation of rainfall, temperature, inputs of nutrients and organic loads integrated with disturbances motive the changes of physicochemical parameters of wetland waters.

4.2. Wetland characterization and risk assessment

According to the results of the wetland index score values for sampling sites, site 1, site 4, site 6, site 7, site 8, site 9, and site 12 were classified as ecological category 'C' (score in between 60 and 80%), which stands for modified moderately status, natural habitats and biota losses and changes have occurred but predominantly the basic ecosystem functions are still not changed. On the contrary, site 2, site 3, site 5, site 10, and site 11 were categorized as ecological category 'B' (score in between 80–90%), which reflects that few modifications but largely a natural status, few small-scale changes in biota and natural habitats may have taken place but the essential functions are unchanged.

As per the visual observations, we found that these modifications have occurred due to the effect of the anthropogenic activities carried out in and around the wetland to meet the demand of human population and lands. Most of the study sites weighed in the scale of 1–2 presenting very low to low level of animal poaching, spreading of invasive species, and land reclamation scenarios in the surrounding whereas solid waste dumping, land use change, and agricultural practices were rated in moderate to very high scale (3–5) in the scoring system in some sampling sites of the Kirala Kele wetland. Evidence from previous studies assert that there exist several factors that contribute to the degradation and loss of wetlands, including eutrophication, pollution, overharvesting, overexploitation, population increase, and economic development (Chen *et al.* 2018; Host *et al.* 2019; Leandro *et al.* 2020).

To characterize the sampling sites, we assessed the weightage of macrophytes cover and fringing cover, and presence of macroalgae, and bank stability on wetland risk assessment. Out of identified components, the increased coverage of fringing vegetation and '*stable*' bank stability among sampling sites exhibited a positive correlation in our study. Apart from that, our findings support this correlation as less or no macroalgae covers were observed in sampling sites. Baird *et al.* (2019) clarified macrophytes and fringing vegetation are main vegetative components of wetland ecosystems to support the balance and the banks stability. Macrophytes play a role in wetland ecosystem productivity as primary producers as well as remove excess nutrients and pollutants from the water column helps control water quality by lowering the probability of algal blooms (Gopal & Goel 1993). By slowing water flow and trapping sediment particles, macrophytes control sedimentation, which in turn reduces the risk of erosion and increases bank stability (Baird *et al.* 2019). Fringing vegetation in a wetland composed of trees, shrubs, and herbaceous plants that form their periphery and it is essential for preventing erosion and keeping the banks from crumbling (Rivaes *et al.* 2017). In addition, the presence of fringing vegetation promotes the biodiversity of wetland ecosystems by providing food, shelter, and breeding grounds for a range of species, and strengthening the carbon sequestration role to mitigate the effects of climate change (Dosskey *et al.* 2010).

Even if our visual records did not spot pugging effects on sampling sites, many literatures has proven that wetland systems are often affected by pugging (Bilotta *et al.* 2007; Negus *et al.* 2019). Negative impacts caused by heavy machinery trigger pugging, and it alters soil structure, vegetation, and hydrology in wetland ecosystems as it can compact soil, making it hard for water to penetrate. This decreases water holding capacity, increases runoff, and erodes wetland health (Tengia *et al.* 2016). Pugging can reduce plant biodiversity by causing some species to die out and others to take over (Bengtsson 2018). Similarly, water logging conditions that arose due to pugging lead to degrade water quality, nutrient cycling, wetland flora and fauna (McCarthy *et al.* 2016). With this said, it is important that wetland managers must limit heavy machinery and livestock access and restore and rehabilitate pugging-damaged areas.

It is worth noting that the introduction of non-native species, such as *Acacia* spp, *Salvinia molesta*, *Eichhornia crassipies* (also known as water hyacinth), *Lantana camera*, red-eared turtles (*Trachemys scripta*), and tank cleaners (*Hypostomus plecostomus*), could potentially pose a significant threat to the local biodiversity of the wetland system in the future. In addition, small-scale agriculture activities that involve clearing lands may lead to the loss of wildlife habitats, including streaked weaver and rails, as farmers often burn reed beds for land clearance (Saranga *et al.* 2022). Moreover, the development of highways that pass through Kirala Kele has been identified as a potential risk for bird deaths (Saranga *et al.* 2022). Species such as gray-headed swamphen and Eurasian moorhen may also be at risk of ingesting pelletized fertilizers, which can lead to their deaths as well as those of their predators that feed on their carcasses. Furthermore, local wildlife is hunted for human consumption, such as ducks, wild hares, and wild boars, which could also result in future biodiversity loss in the wetland.

4.3. Relationship of water quality and physical disturbances in characterization of sampling sites of the Kirala Kele wetland

Macrophytes are commonly employed as bioindicators in wetland health monitoring assessments. However, it is important to note that certain plant species can also have an impact on flow patterns and cause modifications in the composition of physicochemical and biological elements within wetland ecosystems. PCA results indicate a correlation between site 5 and the presence of macrophytes, which is consistent with the observed high availability of floral and macrophyte density in site 5. Furthermore, site 12, which is the location of the wetland outlet, exhibited a comparable characteristic in the form of macrophyte coverage. The justification for this assertion is supported by the research conducted by Cellot *et al.* (1998), which found that the occurrence of macrophyte drifts was significantly higher in the outlets and canals compared to the inlets of the canal. Due to the flow patterns and elevated velocities observed at the outlet, certain macrophytes exhibit a predominant occupancy within such environments.

Furthermore, DO is an additional important water quality parameter in wetland environments, as it is essential for the survival of aquatic organisms. DO concentrations in the Kirala Kele wetland ranged from 3.6 to 8.2 mg/L, with higher concentrations occurring in areas with minimal physical disturbance. The study by Saranga *et al.* (2022) detected that the construction of highways and the use of fertilizers on nearby agricultural lands were significant factors influencing the DO levels in the wetland.

Site 9 of the study was characterized by the EC variation. The linkages of EC and physical disturbances were apparent in the wetland and according to a study conducted by Jayawardana *et al.* (2017), EC levels in the Kirala Kele wetland ranged from 19.5 to 174.2 S/cm, with higher values found in sites with greater physical disturbance, such as areas near agricultural lands. The use of fertilizers and other agricultural chemicals can substantially increase EC concentrations in wetland systems. In terms of temperature factor, the water temperature in the Kirala Kele wetland ranged from 24.2 to 28.4 °C, with higher values found near human settlements and agricultural lands. It was discovered that physical disturbances such as land clearing and the construction of highways have a significant effect on the water temperature in wetlands (Saranga *et al.* 2022).

4.4. Implications for conservation

Man-induced activities such as urbanization, agriculture, and infrastructure development pose a growing risk to ecosystems hence, to ensure the continued provision of ecosystem services by wetlands, it is essential to manage them sustainably of the wetland. Therefore, the wetland characterization and risk assessment tool used by the present study can be applied as a strategy for achieving sustainable wetland management from small to large scale wetland systems. Applications such as Sun *et al.* (2017); Duan *et al.* (2020); and Zhou *et al.* (2020) emphasized the suitability of this instrument as it provides a comprehensive framework for assessing wetland ecosystems, enabling the development of targeted and efficient management strategies. Because this methodology accounts for multiple parameters, such as hydrology, vegetation, and water quality of wetland ecosystems, it permits the identification of conservation and restoration priority areas. From the perspectives of sustainability and resources allocation, this method aids in designing targeted and efficient management strategies, maximizing the benefits of conservation and restoration efforts.

In the Sri Lankan context, emerging development activities have exerted intolerable pressure on natural wetlands, semi-urban and urban wetlands. Given the significance of wetland conservation, prior management options can be planned as this method opens up space to detect early risks. To help this approach, the stakeholder groups including Central Environmental Authorities, Marine Environment Protection Agency, Sri Lanka Land Reclamation And Development Corporation, Urban Development Authorities in Sri Lanka as governmental organizations can collaborate with private institutions, and universities to enhance the inclusiveness of stakeholders in wetland risk assessment and management. Nevertheless, in several cases, wetland management programs have been unsuccessful as there was no representation of associated community who are dependent on the wetland in planning, decision making and implementation stages (Obiero *et al.* 2012; Hettiarachchi *et al.* 2015). As a result, it is timely and relevant to adhere to co-management approaches where nexus of government-other partners-community-resources-technology come together to synergize the sustainability of wetland conservation and management.

5. LIMITATIONS OF THE STUDY

The limitations of the study must be carefully considered in light of its findings and recommendations. First, the incorporation of a framework for year-round sampling would facilitate a deeper, more comprehensive understanding of the wetland's health than the research's limited temporal scope of only 3 months (March, April, and May 2022). To overcome this limitation, extending the research period to encompass a longer time frame, preferably the entire 12-month cycle and possibly multiple years, would provide a more accurate representation of the temporal dynamics within the wetland.

Second, the study focuses primarily on the northwestern portion of the Kirala Kele wetland. The classification and evaluation results would be impacted, however, by a representative sampling of the entire wetland. This limitation necessitates a more robust and systematic approach to site selection, taking into account, among other factors, ecological diversity, geographic distribution, and wetland zones.

In addition, the lack of historical data on the wetland's health represents a significant limitation. Data from the past can provide crucial context for understanding the trajectory of changes over time within an ecosystem. Although it is acknowledged that human activities are highly influential, the study does not quantify the precise contributions of these activities to ecosystem degradation. More historical literature would have helped. Measuring the extent of pollution from practises such as the use of agricultural pesticides and fertilizers, solid waste disposal, and land reclamation would provide a deeper understanding of the ecosystem's challenges and guide the development of more targeted intervention strategies. In addition, the socioecological context of the Kirala Kele wetland could be investigated in greater depth. It is essential to comprehend the socioeconomic and cultural factors that influence the health of an ecosystem in order to develop comprehensive conservation and restoration strategies.

6. CONCLUSION

The main purpose of this study was to assess the health of the selected sites of the Kirala Kele wetland using the Field Guide for Wetland Classification and the Escom Risk Assessment Index as this method serves as an evaluation method with a methodical approach to understanding the wetland's state. The Wetland Classification results placed sampling sites of the Kirala Kele Wetland in the category B (80–90%) and category C (60–80%) ranges. This classification suggests that the wetland belongs to ecological groups B and C, suggesting that it has undergone little changes and is mostly in its natural state. However, slight modifications in the biota and natural habitats have occurred, but the core functions of the ecosystem have generally remained intact.

On the other hand, we conclude that several human activities that have had a negative impact on the health of the wetland were uncovered through this study. Agricultural practices such as the use of pesticides and fertilizers, for example, can pollute the wetland and disrupt its delicate equilibrium. Improper solid waste disposal, such as dumping garbage or dangerous materials, leads to the degraded environment of the wetland. In addition, the ongoing land rehabilitation and reclamation activities in some sampling sites transform marsh regions into dry land for a variety of uses (residential) and thus, these actions decline wetland habitat and have a negative influence on the biodiversity of the Kirala Kele wetland.

In terms of other disturbances, the spread of invasive species poses a serious threat to the health of the wetland. These non-native species can outcompete and displace native species, disturbing the ecosystem's natural equilibrium. Furthermore, removing plants from a wetland for agricultural or other reasons alters the natural environment and limits the availability of food and shelter for the native flora and wildlife.

Based on the findings, the negative impact on wetland health is exacerbated by a lack of awareness and adequate management techniques, therefore, it is obvious that immediate attention and action are required to preserve the Kirala Kele wetland's existing condition for future generations. The study emphasizes the importance of active participation by government policymakers in enforcing legislation and implementing conservation measures. Furthermore, participation from local communities and visitors is critical for raising awareness, encouraging responsible conduct, and supporting programs aimed at conserving the wetland's natural health.

DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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