ORIGINAL RESEARCH ARTICLE

A plant-based system for evaluating the health of wetlands in Mathioya watershed, Murang'a County, Kenya.

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Abstract
Wetlands in Mathioya watershed have been undergoing degradation over the past decades. This can be attributed to human activities such as farming within the wetlands, washing of cars in wetlands, and harvesting/clearing of wetland vegetation. Such activities are likely to impact on the health of the wetlands, which could lead to an overall loss of wetland function and ecosystem services. The aim of this study was to assess the health status of wetlands in Mathioya watershed, Murang'a County. Plant metrics and water quality parameters were used to develop the Plant Index of Biotic Integrity (PIBI). The PIBI was then used to evaluate the health of the wetlands in response to anthropogenic disturbance. The plant metrics selected to be included in the final PIBI include: number of tolerant species, sensitive species, exotic species and shrub species. A trisect interquartile method was then used to assign values to the core metrics. Scores from the selected four metrics were summed to come up with the final PIBI. The metric scores ranged between 4 and 20, with 4 being very poor health and 20 very good health. From the results, only two wetlands were of moderate health, six were of poor health, and one wetland was of very poor health. The average score shows that wetlands in Mathioya watershed are generally of poor health. This study concludes that the majority of the wetlands (6 out of 9) were of poor health, wetlands in areas with relatively low human activities were of better health. Therefore, a restoration project should be initiated to restore the ecological integrity of the wetlands.

Keywords: Wetlands, metrics, plant index of biotic integrity, Mathioya watershed

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1.0 Introduction

Wetlands are virtually found in every continent (Ramsar Convention, 2016). Globally, wetlands cover an estimated 6% of the total land area. With the largest wetlands being the Amazon River basin, the West Siberian plain and the Pantanal wetland which span Brazil, Bolivia and Paraguay in South America (Keddy et al., 2009). The United Nations Millennium Ecosystem Assessment established that environmental degradation is more common in wetland ecosystems than any other ecosystem. This prompted the development of rapid assessment tools and biotic indices to help in the assessment and monitoring of wetlands.

In China, wetlands occupied an estimated 6% of the total territorial area (Peng et al., 2010). However, for the period between 1978 and 2008, China lost approximately 33% of wetlands (Fengqin & Shuwen, 2019). South Africa has lost more than a third of its wetlands (Oberholster et al., 2014). This has been attributed to the increase in human population and the resultant increase in demand for water resources. In East Africa (Kenya, Uganda, Tanzania and Rwanda), wetlands cover an estimated area of 0.15 million km^2 (Amler et al., 2015). They have been reported to provide essential ecosystem goods and services such as biodiversity conservation, sink for pollutants, source of water for consumption and irrigation, hunting sites, grazing fields, source of medicinal plants and agricultural site (Alvarez et al., 2012). However, these wetlands are under threat due to their conversion to other land forms such as agricultural fields.

In Kenya, wetlands cover about 3% to 4% of the total land surface and can reach up to 6% during the rainy seasons. However, the wetlands in Kenya are faced with numerous threats ranging from reclamation and encroachment for agriculture, settlement and industrial development to attack by invasive species and pollution thus compromising the ecological services provided by wetlands. For instance, the King'wal wetland at the upper catchment of Lake Victoria is under threat mainly from activities such as agriculture, animal grazing, human settlement and urbanization (Achieng et al., 2014).

Scientists have used different methods to assess the health of wetlands. With the increasing loss and degradation of wetlands, there was a need to come up with proper methods that could be used to assess the health of wetlands. This prompted the development of biological assessment methods to evaluate the condition of wetlands and determine whether these wetlands are still healthy (US EPA, 2002). The assessment of biological communities emphasizes on measuring their traits that are considered reliable indicators of wetland condition. Many biological assessment projects also include measures of physical and chemical attributes that are used to help diagnose potential sources of degradation.

Various biological indicators have been used to assess the condition of wetlands. Biological indicators have been found to be effective in evaluating changes in aquatic ecosystems and the associated effects (Alemu et al., 2018). Some of the biological indicators used include

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macrophytes, birds, fish, and macroinvertebrates. For assessment of wetland health, plants are currently being used as a major indicator of the wetland health (Gallaway et al., 2019). This is supported by their traits such as, immobility, relative ease to sample and identify and response to anthropogenic disturbance (Yang et al., 2018). The aim of this study was to assess the health status of wetlands in Mathioya watershed, Murang'a County.

2.0 Materials and Methods

2.1 Study Area

The study was conducted in Mathioya watershed, Murang'a County, Kenya. The watershed covers three Sub-counties namely Kiharu, Mathioya and Kangema. The area is located between longitudes 36°50'0"E and 37°10'0"E and latitudes 0º45'0"S and 0º34'30"S with an area of 541 km^2 (Figure 1).

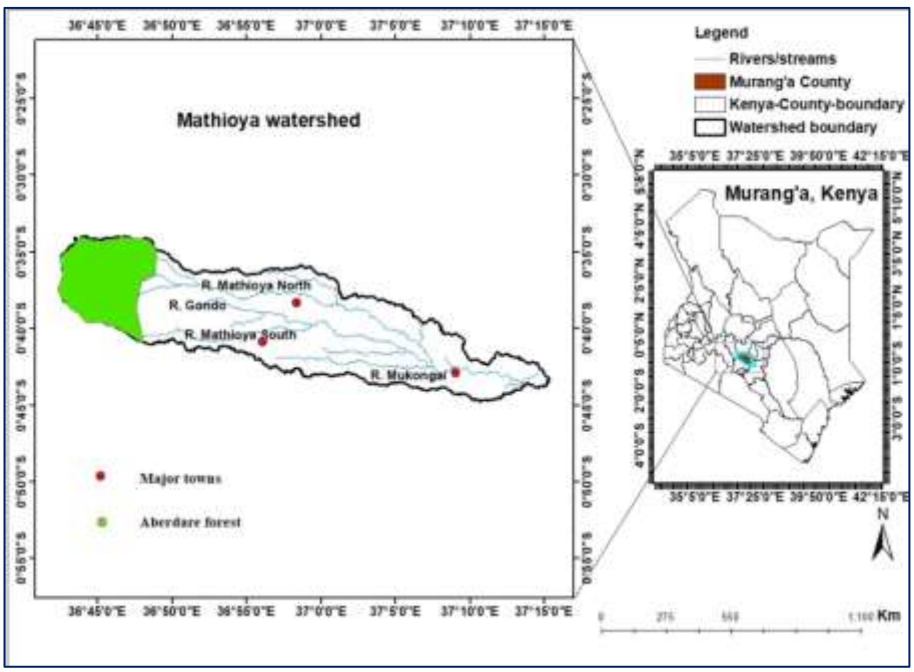

Figure 1: Map of the study area

The main tributaries of River Mathioya are Mathioya South and Mathioya North, which are in turn fed by many low order streams. The land use is predominantly small-scale tea, and mixed farming of coffee, maize, potatoes and agroforestry systems including cultivation of macadamia trees. The soils in the areas are mainly nitisols and andisols with pyroxenes, olivine, amphiboles and feldspars (Willets, 2013). The rainfall pattern is bimodal in nature with the long rains falling between the months of March and May, and the short rains between October and December. The annual average rainfall reaches a maximum of 2700 mm at 2500 m ASL and the maximum

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daily temperature ranges between 26ºC and 30ºC, while the daily minimum temperature ranges between 14ºC and 18ºC (Yatich et al., 2009).

2.2 Description of Selected Wetlands

Nine wetlands were selected for the study on the lower (n=3), middle (n=3) and upper (n=3) parts of the watershed (Figure 2). The selected wetlands were primarily riverine wetlands, based on Brinson (1993) hydrogeomorphic wetland classification. Focusing on similar wetland types was important as it helped in minimizing variation present in characteristics that could affect the plant community, such as hydrological isolation. Riverine wetlands were selected because they are the most common types of wetlands in Mathioya watershed. Additionally, wetlands were selected depending on their level of human disturbance to ensure a full gradient of condition.

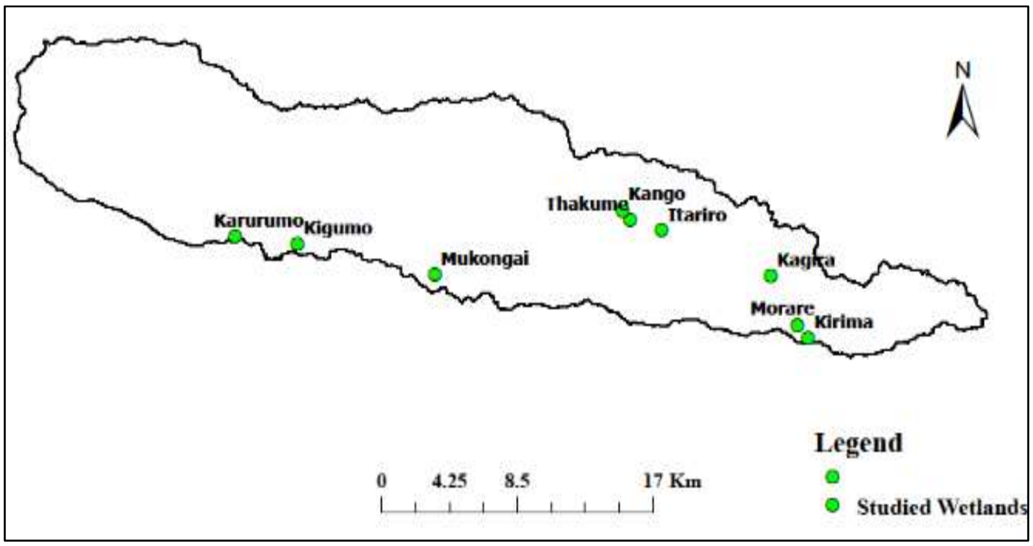

Figure 2: Map Showing Location of the Selected Wetlands

2.3 Vegetation Sampling

Wetland vegetation data was collected in October, 2020. Vegetation data was collected using 1m x 1m quadrats placed in 10m x 10m plots within a wetland (Figure 3).

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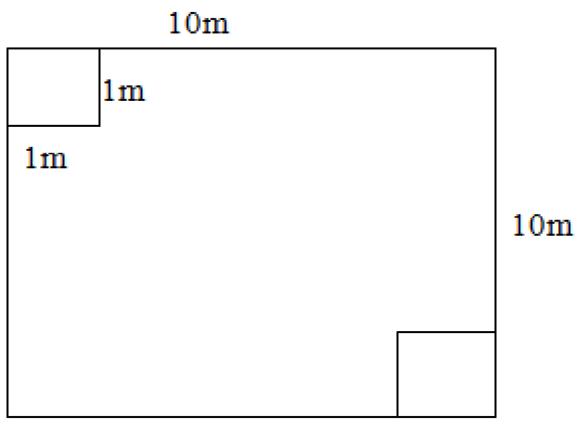

Figure 3: 1m x 1m Quadrats Placed in 10m x 10m Plot

Plots were placed at the intake, middle, and outlet of the wetland. All vascular plants located in the quadrats were identified to the species level. For the species that we were not able to identify in the field, specimen was collected and taken to the lab for identification. Additionally, strategic walks were conducted around the wetlands to identify species that might not be encountered within the plots. Vegetation characteristic data of interest to this study were; species diversity, species richness, and species evenness. Geographic coordinates were recorded at the location of the quadrats using Global Positioning System (GPS) to help in future visits. Photographs were also used for precision in the identification of the plants (Wanda et al., 2015).

2.4 Water Sampling

Water samples were collected in triplicate from 27 sampling sites within the selected wetlands using plastic bottles. Water sampling was carried out during the wet season (October 2020). The wet season was selected because it is during the rainy season that impacts of human activities on the water quality can be adequately assessed (Moges et al., 2016). The sampling bottles were rinsed thrice with water from the sampling site before being used for collecting the final sample (Wanda et al., 2015) to minimize risk of contamination. Temperature, pH, Electrical conductivity (EC), Total Dissolved Solids (TDS) and Dissolved oxygen (DO) were measured in situ using portable digital Multiparameter probes (HQ 40d for DO) and (Hanna 991301 for pH, Temp, EC, TDS). The sampled water was stored in a cooler and transported for analysis to the central water-testing laboratory managed by Water Resources Authority of Kenya (WRA) in Nairobi. Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS) were analysed following the standard methods by APHA (2005).

2.5 Metric Selection and Scoring

Metrics that respond to human disturbance were selected from literature review, and tested for their strength (Rothrock et al., 2008) using Mann-Whitney U tests. Only metrics that met the test criteria of non-intersection of all or some 50% of the whiskers were used to develop the index. Some of the metrics selected from literature include sKpecies richness, diversity, sensitive species

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richness, total taxa richness, tolerant species richness, shrub richness and number of sedges. To select the core metrics, spearman rank order correlation coefficients (r_s) were used to select the core metrics and avoid redundant metrics. Consequently, only metrics that had r_s greater than ±0.50 and had significant *p* values were selected (Toroitich et., 2022). Finally, five metrics were selected to develop the final PIBI.

2.6 Development of Plant Index of Biotic Integrity and Validation

The final index was developed by doing a summation of the scores of the core metrics. To validate the index that had been developed, the PIBI scores were compared to the physicochemical parameters employing spearmen's correlation (r_s). Finally, the index range was classified into three categories; healthy, moderate and poor, depending on the biotic integrity of the wetlands.

2.7 Data Analysis

Statistical analysis was done using Statistical Package for Social Sciences (SPSS) version 26 and Paleontological Statistics (PAST version 3.21) software. Species diversity was analyzed using the PAST software. The potential metrics were analyzed using the box-and-whisker plots and Mann-Whitney U test (Miller et al., 2006; Achieng et al., 2014; Moges et al., 2016) to examine the ability of metrics to differentiate between impaired wetlands and reference wetlands. Redundant metrics were eliminated from the final index by carrying out a spearman correlation (rs) analysis (Achieng et al., 2014). Spearman correlation was also used to test the relationship between the core metrics and the water parameters (DO, EC, TURB, pH) and the PIBI.

3.0 Results and Discussion

3.1 Characteristics of Wetland Vegetation in Mathioya Watershed

A total of 209 plant species belonging to 87 families were identified within wetlands in Mathioya watershed during the study. Family Poaceae had the highest number of species (26), followed by Cyperaceae (17) and Fabaceae (16). Other than Rubiaceae (8) and Lamiaceae (5), the rest of the plant families registered only one or two species. Poaceae family has about 11,500 species and approximately 768 genera making it the fifth largest family of flowering plants in the world (Soreng et al., 2017). Some crops in the Poaceae family include rice, wheat, bamboo and maize, which have economic importance. Plants in the Poaceae family play a critical role in preventing soil erosion by holding the wetland soils together (Zhang et al., 2014). Cyperaceae has about 4,000 species and 70 genera making it the third largest family of monocots (Akram et al., 2018). Cyperaceae are commonly referred to as sedges and they include the Cyperus *papyrus* found in most wetlands. Fabaceae is the third largest family among the angiosperms, and it is sometimes called Leguminosae (Lakshmanan & Ganthi A, 2020).

Similarly, Spellmeier et al. (2019) while studying the impacts of grazing on wetlands identified 50 species distributed in 18 families. Rothrock et al. (2008) in their study identified 226 species, which belonged to 55 families, with Cyperaceae (23) being the largest family. Poaceae,

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Cyperaceae and Asteraceae were the main families with the highest number of species. Various authors (Alemu et al., 2018; Patel & Sahoo, 2021) who conducted studies on wetland vegetation also identified these families to be having the highest number of species.

Thakume wetland had the highest number of plant families (47), closely followed by Morare wetland which had 43 plant families, while Karurumo wetland had the least number of plant families (18). Morare and Thakume wetlands had the highest number of species (89) followed by Kango (81), while Karurumo wetland registered the lowest number of species (43) (Table 1).

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Table 1: Distribution of Plant Species across the Studied Wetlands

Wetland	No. of Families	No. of Species
Morare	43	89
Kirima	32	74
Kagira	35	77
Thakume	47	89
Kango	41	81
Itariro	23	57
Kigumo	31	75
Karurumo	18	43
Mukongai	24	56

Morare, Kirima and Kagira wetlands had a high number of plant species despite being located within Murang'a town, exposing them to high human activities. Karurumo wetland had the least number of species even though there were minimal signs of human activity within the wetland. Cyperus *latifolius* was the dominant specie in Karurumo wetland. Mukongai wetland which had 56 species was largely under intense agricultural activity. Some studies (Achieng et al., 2014; Beuel et al., 2016) have associated low number of plant species to human activities within and around the wetlands. For instance, fewer species were recorded in a wetland where there was cattle grazing than in a wetland with no cattle grazing activities (Spellmeier et al., 2019).

Increase in species due to disturbance can be linked to the introduction of new species. For instance, *Coix-lacryma jobi* and Mirabilis *jalapa* which are invasive species, were only present in Morare wetland. *Coix-lacryma jobi* is a weed mainly found in disturbed sites such as in wetlands and along waterways. Thom and Seidl (2016) in their study established a positive relationship between disturbance and species richness. According to the authors, species richness was increasing with increase in disturbance. This was attributed to possible introduction of non-native species into the wetlands. Yang et al. (2018) recorded higher species richness (22) at a site surrounded by agricultural activities and human settlement, while low species richness (4) was recorded at a site with minimal disturbance. Invasive and non-native species poses unique characteristics (such as highly reproductive, shorter life cycle, fast growth rates) that favor their establishment in disturbed environments. The aforementioned traits enable the invasive species to quickly colonize their habitat thus thriving at the expense of the native wetland plants.

3.2 Species Richness, Diversity and Evenness

Commelina *diffusa* was the dominant (34) specie in Mathioya wetlands. It was followed by Cyperus *latifolius* (24), Ageratum *conyzoides* (23), and Colocasia *esculenta* (20). Commelina *diffusa* is mainly found in habitats that have undergone some form of anthropogenic disturbance (Behn et al., 2018). Hence, its dominance in wetlands in Mathioya watershed is an indication of anthropogenic disturbance on the wetland resources. Vernonia *glabra* was only found in Kirima

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wetland despite its use in the treatment of gastrointestinal issues by local herbalists (Kitonde et al., 2012).

Thakume wetland had the highest species diversity (4.4) closely followed by Morare (4.3) and Kango (4.3) wetlands (Figure 4). Karurumo wetland had the lowest species diversity (3.7). High species diversity (3.5) gives an indication of a healthy ecosystem (Moges et al., 2016). All the studied wetlands had an evenness index of 0.9 except for Kirima wetland which recorded an index of 0.8 (Figure 5). The evenness index ranges between 0 and 1, and the value 1 indicates that the distribution of species within that ecosystem is perfectly even. Our results show that species were evenly distributed across all the studied wetlands.

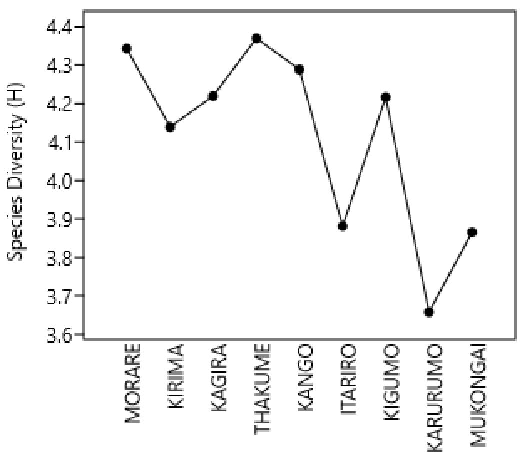

Figure 4: Species Diversity of Wetlands in Mathioya Watershed

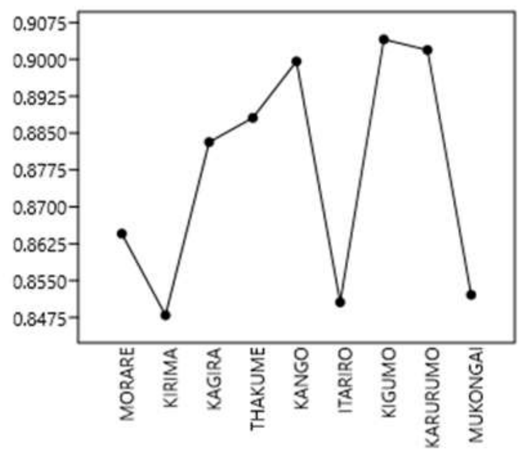

Figure 5: Species Evenness of Wetands in Mathioya Watershed

There was no significant difference $(p > 0.05)$ in species diversity between Kirima wetland and all the other wetlands, except Karurumo $(p < 0.05)$. Similarly, Kigumo wetland had no significant difference $(p > 0.05)$ in species diversity with all the wetlands except for Karurumo wetland. A significant difference $(p < 0.05)$ was noted in species diversity between Karurumo wetland and all the other wetlands except for Itariro and Mukongai wetlands (Table 2).

Table 2: Relationship between Species Diversity across the Studied Wetlands

	Morare	Kirima	Kagira	Thakume	Kango	Itariro	Kigumo	Karurumo	Mukongai
Morare									
Kirima	0.1002								
Kagira	0.2822	0.5698							
Thakume	0.8932	0.1312	0.3467						
Kango	0.4551	0.3707	0.7434	054					

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Itariro	0.0034	0.2	0.0643	0.0053	0.0296			
Kigumo	0.1535	0.8285	0.725	0.1961	0.4972	0.1341		
Karurumo	5.351E-06	0.0037	0.0005	1.004E-0.5	0.0001	0.1041	0.0018	
Mukongai	0.0012	0.1078	0.0295	0.0018	0.0124	0.7441	0.0681	0.194

Species diversity across sites is significantly different at $p < 0.05$

3.3 Physico-Chemical Parameters

The sampled wetlands showed differences in the water quality parameters. This can be attributed to the different human activities that each wetland is exposed to. The water temperatures ranged between 21.6℃ and 31.2℃, with the highest temperature recorded in Morare wetland, and the lowest temperature recorded in Kigumo and Karurumo wetlands. There was no significant difference in temperature between the studied wetlands $(p > 0.05)$. Water temperature plays a significant role in influencing physiological activities of living things. High temperatures have an impact on the wetland ecosystem, since it reduces the solubility of oxygen in water (Alemu et al., 2018). Further, high temperatures has been associated with an increase in conductivity due to increased release of ions (Gashaw et al., 2018). Increased water temperatures alters the biological activities of organisms, and can lead to death, consequently altering the functioning of the wetland.

The pH values of the water samples ranged between 6.67 and 7.74, an indication that the wetland water was basic. The mean pH of the sampled water was 7.29. Highest pH was recorded in Thamake and Mukongai wetlands (7.74), while lowest pH was recorded in Kigumo wetland (6.67). pH did not vary significantly across the wetlands p>0.05. According to Ahipathy and Puttaiah (2006), pH is one of the most important factors in determining water quality. The World Health Organization (WHO) recommends a pH range of 6.5 to 8.5 for wetland water (WHO, 2004). pH changes can be influenced by discharge of chemicals into the water, these could be from anthropogenic activities such as use and application of the agricultural fertilizers (John et al., 2023). Some organisms are sensitive to pH changes and would not survive in extreme pH conditions. Thus, minimizing human activities around wetlands would ensure that the pH levels of water in the wetland would remain within the National Environmental Management Authority (NEMA) quality standards for sources of domestic water recommended range of 6.5-8.5.

Highest value of electrical conductivity (500 µS/cm) was recorded at Kirima wetland, and it varied significantly $(p < 0.05)$ with EC recorded in Kango, Itariro, Kigumo, Karurumo and Mukongai wetlands. The lowest EC value was recorded at Karurumo wetland, and it varied significantly with values recorded at Kirima, Morare, Kagira and Thakume wetlands. Electrical conductivity varied among the wetlands across the watershed. Highest EC was recorded in Kirima wetland, also located within Murang'a town. EC is an indirect result of the amount of dissolved salts. High EC can be caused by natural atmospheric factors, certain sedimentary rocks or human sources such as industrial or sewage outputs (WHO, 2004).

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With respect to nutrient loading, highest value for Total Phosphorus (TP) were recorded in Karurumo wetland (0.08), while the lowest value was recorded in Thakume and Kango wetlands (0.01 mg/l). Total Nitrogen (TN) concentration was highest at Mukongai wetland (0.31) and it differed significantly ($p < 0.05$) with values recorded at Kagira, Kango, Itariro and Kigumo wetlands. Lowest value of TN concentration was recorded at Thakume and Itariro wetlands (0.04 mg/l).

Nutrient loading has an influence on the composition of species and functioning of the wetland ecosystems. Agriculture is being practiced in or around most wetlands in Mathioya watershed, thus potentially exposing them to nutrient loading, from the use of chemical fertilizers. Further, Kirima wetland which had the highest concetration of TN experience intense farming, and it is likely that the farmers use fertilizers rich in Nitrogen. Increase in nutrient loading can potentially result to the lose of some plant species (Cooper et al., 2018).

Wetlands are known to absorb excess nutrients and prevent it from getting into various waterbodies, however, excess nutrient loading in the wetland negatively impacts the ecosystem services offered by wetlands. Cooper et al. (2018) reported that an increase in nutrient loading in a wetland causes a shift from slow growing, nutrient conserving species to fast growing helophytes. Thus, nutrient loading has an effect on species dominance and composition in a wetland. Yang et al. (2018) established that degradation of water quality in Lake Poyang in China was being caused by increase in TN and TSS. Increase in TN levels in the lake was attributed to intensive farimng around the lake.

3.4 Metric Selection, Testing and Scoring

To develop the PIBI, 22 metrics were selected from literature review and evaluated statistically (Table 3).

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Table 3: Description of the Potential Metrics Used to Develop PIBI, and their Response to Disturbance

Metrics	Description	Response	U test (*p*)
Sensitive species richness	Native species with C-values ranging from 8-10	Decrease	0.001*
Exotic species richness	# of exotic species in a wetland	Increase	0.003*
Total taxa richness	Total number of species in a wetland	Increase	0.476
Species diversity (H)	$H = -\sum \quad Pi \times ln\, ln\, Pi$ (Eqn 1)	Increase	0.762
Species evenness	$e = \frac{H}{ln ln\, S}$ (Eqn 2)	Variable	0.172
Invasive species richness	# of invasive species in a wetland	Increase	0.739
Native species richness	# of native species in a wetland	Decrease	0.273
Tolerant species richness	Native species with C-values ranging from 0-2	Increase	0.000*
Graminoids richness	# of graminoids species	Increase	0.482
%graminoids	(# of graminoids/# of species) $\times 100$	Increase	0.321
%cover of graminoids	% cover of graminoids/# of sample sites	Increase	0.072
Shrub richness	# of species in shrub layer	Increase	0.014*
% shrub richness	(# of shrubs/# of species) $\times 100$	Increase	0.017*
Perennial species richness	# of perennial species	Increase	0.652
% perennials	# of perennial species/# of species $\times 100$	Increase	0.732
%invasive species	(# of invasive species/# of species) $\times 100$	Increase	0.543
%tolerant species richness	(# of tolerant species/# of species) $\times 100$	Increase	0.002*
%sensitive species richness	(# of sensitive species/ # of species) $\times 100$	Decrease	0.000*
%native species richness	(# of native species/# of species) $\times 100$	Decrease	0.003*
Number of tree species	# of trees in a wetland	Variable	0.853
Annual species richness	#of annual species	Increasing	0.641

*Significant difference at p<0.05; U-test (Mann-Whitney U test); (# = number)

The metrics were evaluated based on their response to anthropogenic disturbance and Mann-Whitney U test (Rothrock et al., 2008; Moges et al., 2016; Alemu et al., 2018). Of the 22 metrics, only 4 were selected for the inclusion into the final index of biotic integrity. The 4 selected metrics were; (i) number of sensitive species, (ii) number of tolerant species, (iii) number of exotic wetland species, and (iv) number of shrub species. The four metrics were selected because they showed a strong relationship with anthropogenic disturbance.

Metric (i) was based on the number of sensitive species in a wetland. Sensitive species are often associated with ecosystems that are least disturbed, and they are among the first species to disappear when there is human disturbance (Moges et al., 2016). Changes in wetland hydrology as a result of ditches, pollution and reclamation of wetland area through filling are some of the anthropogenic activities that lead to decline of sensitive species in a wetland (Rothrock et al.,

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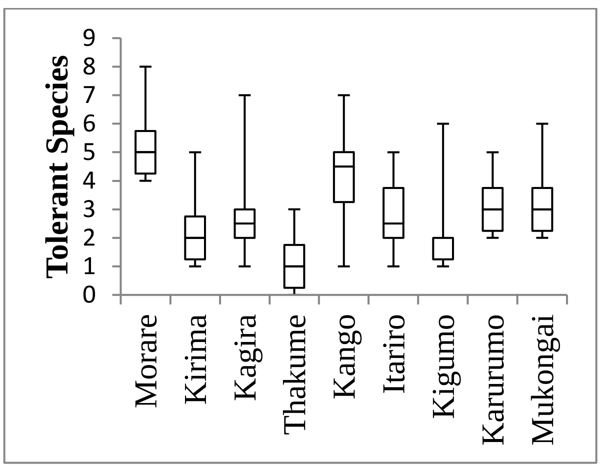
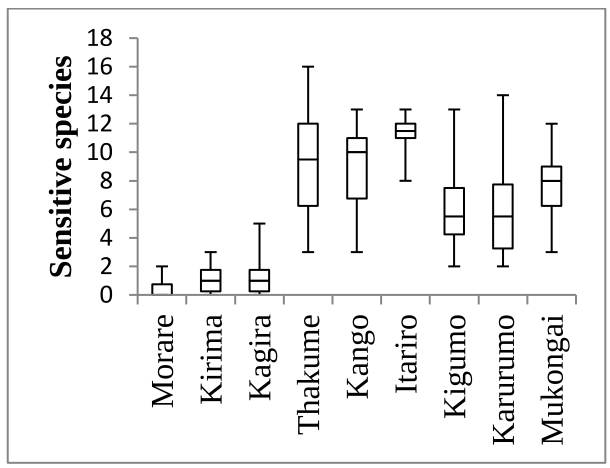
2008). Conversely, tolerant species (metric ii), exotic species (metric iii) and shrub species (metric iv) tend to thrive in ecosystems that are disturbed. Rothrock et al. (2008) reported that tolerant species were increasing in wetlands that were experiencing high rates of sedimentation.

Similarly, Moges et al. (2016) selected four core metrics after screening 35 potential metrics. Alemu et al. (2018) in their study evaluated 22 potential metrics, but only five were included in the final index. Beck et al. (2010) included 7 core metrics in the final index while Rothrock et al. (2008) chose 11 core metrics from a pool of 35 potential metrics. The variation in the number of core metrics included in the final index is attributed to the wide range of anthropogenic disturbances among wetlands. Additionally, some of the metrics were eliminated because they were highly correlated to each other, hence provided similar information. For instance, percent tolerant species richness was highly correlated to tolerant species richness. Hence, only tolerant species richness was selected to be included in the final index.

Further, the range value for each of the core metric was determined using the interquartile value from their box-and-whisker plots (Figure 6 a-d).



(a)



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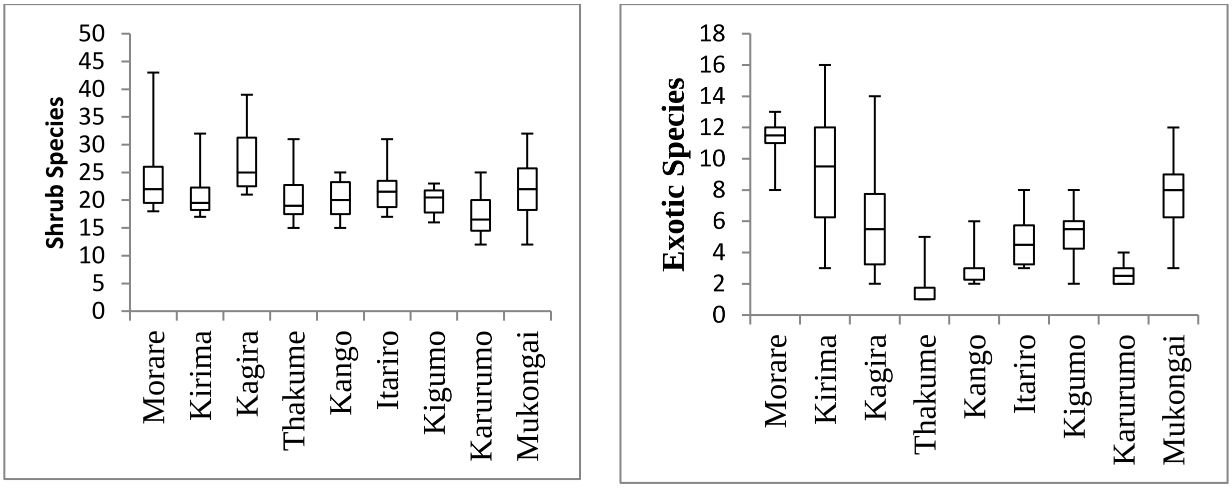

Figure 6 (a-d): Box-and-Whisker Plots for the Core Metrics

For metric scoring, the scoring system developed by Karr (1986) was used. According to the system, a value of 5 is assigned to a site (wetland) with the highest environmental quality, 3 is assigned to a site with moderate quality, while 1 is assigned to a site with low environmental quality. Thus, to determine the value of the core metrics depending on how they respond to disturbance, the researchers used threshold values of the box-and-whisker plots (Moges et al., 2016) (Table 4).

Table 4: Interquartile Values and Scoring Criteria of the Four Core Metrics

Core metrics	Interquartile Values					Scoring Criteria		
	Min	25%	Median	75%	Max	5	3	1
No. of sensitive species	3	6	10	12	16	>6	3-6	<3
No. of tolerant species	4	5	5	6	8	<4	4-5	>5
No. of exotic species	3	6	10	12	16	<3	3-6	>6
No. of shrub species	18	20	22	26	20	<18	18-20	>20

No. = Number, Min = minimum, Max = maximum.

3.5 Correlation between the Core Metrics and Water Quality Parameters

The core metrics selected showed significant correlation with at least one of the water quality parameters (Table 5).

Table 5: Spearman Rank Order Correlation between Core Metrics and Water Quality Parameters

Core metrics (Number)	Water Quality Parameters							
	Temp	pH	D.O	E.C	TDS	TSS	TN	TP

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Sensitive species	-0.8*	-0.111	-0.492	-0.564*	0.271	0.009	-0.536	0.299
Tolerant species	0.425	-0.167	0.085	0.125	0.197*	-0.386	0.653*	-0.384
Exotic species	0.769*	0.227	0.485	0.565	-0.301	0.21	0.223	-0.207
Shrub species	0.775*	0.475	0.65	0.719*	-0.363	0.114	0.364	-0.511

*Significant difference at $p<0.05$;

Sensitive species showed a negative significant correlation with water temperature (r_s = -0.8) and EC (r_s = -0.564). Conversely, while tolerant species showed a positive correlation with water temperature (r_s = 0.425) and a positive significant correlation with TDS (r_s =0.197). Exotic species showed a positive significant correlation with water temperature (r_s = 0.769), while shrub species showed a positive correlation with temperature (r_s=0.775) and E.C (r_s =0.719).

Moges et al. (2016) and Alemu et al. (2018) reported that the core metrics showed significant correlation with at least one of the environmental variables. From the results, it was noted that an increase in water temperature resulted to a decrease in sensitive species. On the other hand, tolerant, exotic and shrub species were found to increase with increase in temperature. Similar results were reported by Rothrock et al. (2008). However, Moges et al. (2016) reported that tolerant species were declining with increase in water temperature. Wetlands combine both the land and water systems, hence monitoring their health would give an indication of the general health of the watershed (Alemu et al., 2018). Moreover, the decline of sensitive species, and increase of tolerant species under anthropogenic disturbance indicates that they are reliable indicators of the wetland health.

3.6 Plant Index of Biotic Integrity

To develop an index of biotic integrity, it is critical to first identify a reference site (Moges et al., 2016). Consequently, several surveys were conducted within the watershed to establish a reference wetland. However, due to the extensive impact of human activities on wetlands in Mathioya watershed, it was difficult to find a pristine wetland. Hence, we selected Thakume wetland, which had minimal human interference compared to the other wetlands as our reference wetland.

The scores from the selected four metrics were then summed to come up with the final plant index of biotic integrity. Consequently, the final index scores ranged from 4 (most disturbed wetland) to 20 (least disturbed wetland). The range was achieved by summing up the minimum scores (1+1+1+1 =4) and the maximum scores (5+5+5+5 =20) for each core metric.

Thakume wetland had the highest number of sensitive species (16), while Morare wetland only had 2 sensitive species. Conversely, Morare wetland had the highest number of tolerant plant

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species (8) and Thakume had the least number of tolerant species (3). Kirima wetland had the highest number of exotic species (16), while Karurumo had the least number of exotic species (4). Also, Morare recorded the highest number of shrub species (43) and the least value of shrub species was recorded in Kigumo wetland. The value of the metrics in each of the studied wetland is presented in Table 6.

Table 6: Value of the Core Metrics in Each of the Studied Wetlands

	Maximum Number of Species								
Metric of each spp	Morare	Kirima	Kagira	Thakume	Kango	Itariro	Kigumo	Karurumo	Mukongai
Sensitive	2	3	5	16	13	13	13	14	12
Tolerant	8	5	7	3	7	5	6	5	6
Exotic	13	16	14	5	6	8	8	4	12
Shrub	43	32	39	31	25	31	23	25	32

Spp- species

Sensitive species often thrive in ecosystems that are least impacted, and are likely to disappear with increasing human activities in a wetland. Morare, Kirima and Kagira wetlands are located in the urban areas, hence exposed to more anthropogenic disturbances. This explains the low number of sensitive species in the aforementioned wetlands compared to the other wetlands. On the other hand, tolerant species are common in disturbed environments. Accordingly, Morare wetland which is exposed to various human activities such as cultivation, car washing, disposal of raw sewage, had the highest number of tolerant species. Also, studies have shown that exotic species and shrubs tend to be more in disturbed environments compared to the pristine environments (Moges et al., 2016).

Finally, ecosystem health was evaluated by summing up the total scores for each studied wetland. Thakume wetland had the highest score (14), closely followed by Karurumo wetland (12), while Morare wetland had the least score (4) (Table 7).

Table 7: Metric Scores for Each of the Studied Wetland

Metrics of Each	Wetlands								
Species	Morare	Kirima	Kagira	Thakume	Kango	Itariro	Kigumo	Karurumo	Mukongai
Sensitive	1	3	3	5	5	5	5	5	5
Tolerant	1	3	3	5	1	3	1	3	1
Exotic	1	1	1	3	3	1	1	3	1
Shrub	1	1	1	1	1	1	1	1	1

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The score range (4-20) was further categorized into 5 classess of biotic integrity, corresponding to wetland health groups (Moges et al., 2016); 4-6 (very poor health), 7-10 (poor health), 11-14 (moderate health), 15-17 (good health) and 18-20 (very good health). From the results, only two wetlands (Thakume and Karurumo) were found to be of moderate health, Kirima, Kagira, Kango, Itariro, Kigumo and Mukongai wetlands were found to be of poor quality, while Morare wetland was the only wetland found to be of very poor quality (Table 8). The average score shows that wetlands in Mathioya watershed are generally of poor biotic quality.

Table 8: Biotic Integrity Classes for the Studied Wetlands in Mathioya Watershed

Wetland	Biotic integrity class
Morare	Very poor health
Kirima	Poor health
Kagira	Poor health
Thakume	Moderate health
Kango	Poor health
Itariro	Poor health
Kigumo	Poor health
Karurumo	Moderate health
Mukongai	Poor health

Morare wetland is located within Murang'a town and is exposed to numerous anthropogenic activities. From the field observations, we noticed three car wash activities along the wetland, filling of the wetland with hardcore material to create room for construction, release of sewer into the wetland and removal of wetland vegetation, coupled with intensive agriculture as some of the common human activities within Morare wetland. Indeed, it is the result of such activities that has contributed to the poor state of the wetland. Conversely, Karurumo and Thakume wetlands were not under immense anthropogenic activities, however, by the time this study was carried out, there was increasing agricultural activities within Karurumo wetland. Consequently, if no action is taken, all the wetlands are likely to be of very poor quality. This will significantly impact the ecosystem services provided by wetlands, particularly the regulation of water quality. In a study conducted by Moges et al. (2016), wetlands surrounded by urban and agricultural land uses were found to be of poor quality, while forested wetlands were found to be of very good quality. Similarly, Alemu et al. (2018) reported that deforestation was responsible for the change in species diversity and richness in wetlands. Loss of wetland plant species such as Acmella *calirrhiza* has been associated with a reduction in stream water quality (Patel & Sahoo, 2021).

After developing the PIBI, it was tested and validated using spearman correlation and Kruskall-Wallis tests (Alemu et al., 2018). From the results, PIBI was negatively correlated with temperature (-0.558), DO (-0.289), EC (-0.366) and TN (-0.514) (Table 4.16). Further, the Kruskall-Wallis test revealed that PIBI was significantly (p<0.05) correlated with temperature, DO, EC, TN and TP. However, PIBI was not significantly correlated with PH, TDS and TSS (Table 9).

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Table 9: Validation of the PIBI Using Spearman Rank Order Correlation (r_s)

	Temp	pH	DO	EC	TDS	TN	TP	TSS	PIBI
Temp									
pH	0.513								
DO	0.611	0.126							
EC	0.633	0.135	0.992						
TDS	-0.142	-0.117	-0.217	-0.286					
TN	0.437	0.164	-0.067	-0.038	-0.109				
TP	-0.633	-0.325	-0.714	-0.669	-0.294	-0.152			
TSS	0.13	0.504	0.201	0.219	-0.552	-0.244	0.051		
PIBI	-0.558*	0.066	-0.289*	-0.366	0.061	-0.514*	0.145	0.132	

*Significant difference at $p<0.05$

Table 10: Validation of the PIBI using Kruskal-Wallis test (Mann-Whitney pairwise)

	Temp	pH	DO	EC	TDS	TN	TP	TSS	PIBI
Temp									
pH	0.01464								
DO	0.02052	0.01474							
EC	0.2201	0.01454	1						
TDS	0.01474	0.01474	0.01484	0.01464					
TN	0.01464	0.01464	0.01474	0.01454	0.01474				
TP	0.01454	0.01454	0.01464	0.01444	0.01464	0.1431			
TSS	1	0.01464	0.03887	0.2474	0.01474	0.01464	0.01454		
PIBI	0.01365	0.2116	0.01375	0.0355	0.1218	0.01365	0.01355	0.3041	

Significant difference at $P<0.05$

Alemu et al. (2018) reported a significant relation between Riparian index of Biotic Integrity and DO, temperature, TSS and turbidity. Similarly, Moges et al. (2016) reported that PIBI was significantly correlated with temperature, EC, and TN. Thus, the PIBI we developed was able to differentiate between a healthy wetland and an impaired wetland. This shows that plants can be used to effectively assess the ecological health of wetlands.

4.0 Conclusions

Wetland plants are easy to sample and identify. They are also immobile and are found in any wetlands that make them suitable to be used as bio indicators. As a result, practical rapid assessment of wetland conditions using the plants has relatively been getting attention in developed nations. However, plant-based index development was so little or not at all in Kenya, where Murang'a County is the case in point. Hence, we developed a plant-based index of biotic

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integrity (PIBI) using four core metrics derived from the plant communities that were significantly correlated with human disturbance. The PIBI was found to be a robust tool that can distinguish the reference sites from impaired sites along the disturbance gradients.

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6.0 Conflicts of Interest

The authors declare no conflict of interest.

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