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Linking citizen science with contamination levels of small water bodies for generation of essential information for conservation and investment

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Abstract

Socio-ecological characteristics of small water bodies (SWBs) are useful in determining the required level of rehabilitation and rebranding for possible blue economic investments. The current study assessed the socio-ecological aspects of 74 SWBs in central and western counties in Kenya to determine their contamination status. The SWBs were selected to account for sub-county representation, coverage and permanence of the water source. Respondents assessed in the selected SWBs catchments were identified from riparian communities and policymakers. Physicochemical parameters were assessed using standard methods. Regionally, the SWBs showed significant variations ($p < .05$) in the main occupation, ownership, restricted access and perceived alternating extreme precipitation ranges. Significant differences in the selected citizen science attributes and SWBs' dimensions of both depth and size, were linked to higher total and faecal coliforms in western as compared to central Kenya and higher water transparency in the latter. Thus, localized human activities that had significant variations between the two regions are highly likely to have affected the differences in the contamination levels. The socio-ecological indexing herein can be of general use for determining the contamination status of SWBs as an integrative management tool for possible investment.

KEYWORDS

citizen science, integration, physicochemical parameters, region, small water body (SWB), socio-economic

1 | INTRODUCTION

Small water bodies (SWBs) constitute an important part of the inland aquatic systems and could be defined as standing waters that have been created as a result of erected barriers that prevent or restrict the flow of water or underground channels (Søndergaard et al., 2005). Various sizes are attributed to the threshold of a small water body (SWB) (Haycock et al., 1996) but they are usually > 1.0 ha and < 100 ha (Downing & Duarte, 2009). In many countries around the world, SWBs are vital for poverty alleviation, fish-food security, gender empowerment, cultural services, ecosystem function and biodiversity (Lynch et al., 2016). However, they are under-represented in national and international policy discussions (Casas et al., 2011). The low profile of SWBs exemplifies their marginalized status in major policy arenas (Kadoya et al., 2011). In the United Nations Sustainable Development Goals (SDGs), SWBs are represented in SDG 14 (Life below water) and SDG 15 (Life on Land) due to their land-water interphases characteristics (Beard et al., 2011; Lynch et al., 2017).

Inland aquatic systems such as SWBs have been experiencing changes over the last couple of years impacting ecological systems and climate-sensitive activities (Kizza et al., 2009). These changes have been attributed to anthropogenic and climate shifts being experienced at the global level and making human and climate-lake interactions a critical concern (Nyamweya et al., 2016). Unfortunately, due to human activities, the ecological condition of SWBs is poor in many places in the world (Beketov et al., 2013). SWBs often constitute a small volume of water and have only a limited ability to dilute and retain pollution, and therefore, they are highly susceptible to inputs of even small amounts of pollutants from their surroundings, such as pesticides from agriculture (Rasmussen et al., 2012). In addition, dry periods and water abstraction can greatly reduce their water flow and water level (Bond et al., 2008). Their natural-physical state is often deteriorated. In the lowlands, many SWBs have been altered from natural, meandering channels into straight drains to enhance the draining of agricultural fields, and many barriers are affecting connectivity (Lauge Pedersen, 2009).

To understand how the consequences of anthropogenic and climate shifts will impact different fisheries and aquatic ecosystem resources, timely data and the use of indigenous information in all hydrological systems will play a critical role (Aura et al., 2018, 2021). For instance, a variety of sectors in the developing world – fisheries ecology and management, food security, land use planning, hydrologic modelling and resource management planning – will require robust aquatic ecosystems' data for predictions (Saah et al., 2019). In this case, national and transboundary development plans will use SWB's data as a basis for understanding changes in a country's natural capital, which in turn forms the basis for budget priorities and allocations (Foley et al., 2005; Running, 2008). The SWBs resource information will also underpin the requisite models that will be used by governments to inform the level of preparedness to build resilience to various impacts (Tolentino et al., 2016). Furthermore, aquatic resource managers and stakeholders will use the SWB's resource information to develop sustainable harvest management plans, integrate biodiversity conservation for sustainable management and develop appropriate mitigation measures (Potapov et al., 2019).

Notwithstanding, SWBs and inland systems are experiencing the effects of acceleration in the rate of land cover change, population growth and ecosystem changes that are impacting the long-term sustainability of such ecosystem services including food, water and energy (Kayanda et al., 2017). Local decision-makers are using infrequently updated national and regional maps with little or no ability to monitor in a timely or integrated fashion other less investigated systems such as SWBs (Balirwa et al., 2003). Furthermore, existing classification systems do not always meet the local community's needs, data products are often not widely shared between agencies and institutions, and accuracy assessment is often lacking. The users and developers of these information packages do not necessarily involve the riparian and local communities who may have the requisite indigenous knowledge (Aura et al., 2021). This could be because the project developers are typically from different organizations, with different priorities and technical understandings (Juma et al., 2004). These differences and variations pose a variety of challenges that often create roadblocks to the effective use of appropriate reservoirs' data for policy formulation, planning, management and other decision contexts (Etiegni et al., 2017). Such inconsistencies hinder more widespread and effective use of existing data to valuably contribute to SWBs policy formulation, planning, management and other processes where effective, transparent and defensible decisions are known to lead to better real-world outcomes.

As a result of these inconsistencies, citizen science has emerged as one of the methods which involve volunteer participation by community members in providing or collecting information following a protocol, designed and or validated by experts in the field and hence provided for such applications (Aura et al., 2021; Conrad & Hilchey, 2011). The development of citizen science as an environmental assessment and monitoring approach is quite limited, and in most cases, it is at its nascent state (Requier et al., 2020). Regionally and in most developing countries and given the sensitivity of SWBs, there is limited information involving the integration of a large number of stakeholders who are associated with such aquatic systems to directly connect with scientists in the generation of data and information for planning and development.

However, various researchers are embracing the use of citizen science to enhance their ability to monitor and manage natural resources by incorporating local knowledge in the assessment of the status of aquatic ecosystems (Reid et al., 2010). This is due to the riparian interactions that stimulate such physical surroundings (Tol, 1995). Thus, the indigenous knowledge of individuals who have long interaction with aquatic ecosystems can be utilized in the understanding of ecosystem integrity (Zhang et al., 2018). Furthermore, knowledge on the integrity, structure and functioning of natural ecosystems such as SWBs, passed down over generations, can be harvested in research activity and end up offering some benefit on management and conservation of such ecosystems (Aura et al., 2021).

The current study explored the linkage of citizen science with physicochemical parameters to assess the contamination levels of selected SWBs in central and western Kenya. The approach herein has a potential for application in the assessment and monitoring of the condition of vulnerable SWBs and their ecosystems as potential areas of investments for the emerging economies.

2 | MATERIALS AND METHODS

2.1 | Study area

The current study was conducted in the months of June to October 2021 in 8 counties in Central (Nyeri, Kirinyaga, Meru, Tharaka Nithi, Embu, Kiambu, Kajiado and Machakos) and 7 counties in Western (Migori, Kisii, Homabay, Kisumu, Siaya, Busia and Kakamega) Kenya

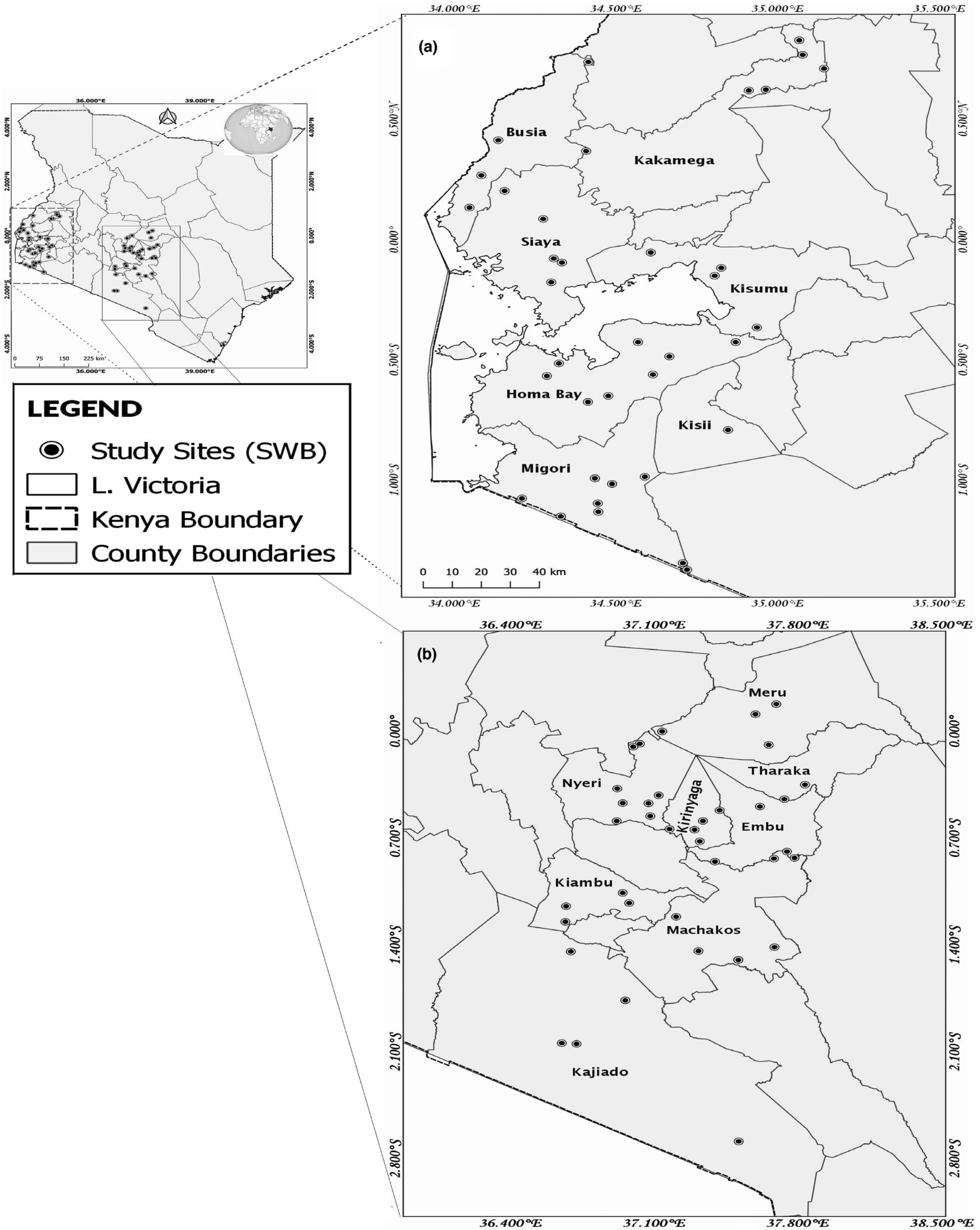

FIGURE 1 Study sites in (a) western and (b) central regions of Kenya

(Figure 1). The counties targeted are associated with high concentrations of agriculture, water use, fish farming potentiality and production and an evolving sectoral infrastructure (processing, marketing and research) (ABDP Aquaculture Blue Book, 2021). The sampled counties are known to have the highest number of SWBs in the country with increased tendencies for conflict of use and possible contamination and pollution (Government of Kenya Report, 2007).

2.2 | Linkage of citizen science to SWBs contamination

Figure 2 shows a schematic diagram linking the selected citizen science features with indicators of SWBs contamination levels. The approach involved the use of SWB's citizen science characteristics, selected physicochemical and morphological parameters.

2.2.1 | Citizen science characteristics

Sampling for citizen science parameters was based on the features of the SWBs for which a criterion for selection was set. The SWBs were selected to account for sub-county representation, dam acreage (preferably ≥5 acres) and permanence of the water source. The target human population in the selected SWBs catchments was identified from riparian communities. This consisted of residents living within 5 km off the SWB boundary and the leaders of the community SWBs' associations. It has been shown that usage of natural systems reduces beyond this distance (Bolgrien et al., 2009). Other than the proximity of stay to the SWB system, the participants were purposively chosen based on their involvement in socioeconomic and cultural activities related to the SWB system (Zhang et al., 2018). The central riparian catchment had a total population of 257,114 people while the western part had a total population of 264,213 people (National Population Census, 2009). The sample size was arrived at using the equation by Cochran (1963) and Conrad and Hilchey (2011):

$$n = \frac{z^2 pq}{d^2}$$

where:

n = the desired sample size (if the population is > 10,000);

z = the standard normal deviate at the required confidence level;

p = the proportion in the target population estimated to have had characteristics being measured (0.15);

$q = 1{-}p$; and

d = the level of statistical significance set at (0.05).

By using the above equation, 259 people were sampled with central and western regions having 127 and 132 participants, respectively, from the entire population to be used for the study. In this case, the sample size methodology was chosen to ensure evenness in the distribution of the targeted sample population.

A closed and open-ended questionnaire, built and modified from Aura et al. (2021) was used to assess the sampled SWBs on main occupation, ownership and management, access and resource use conflicts and climate risks as the main threats and opportunities associated with SWBs (Casas et al., 2011; Haycock et al., 1996; Kadoya et al., 2011). Potential participants were briefed on the objectives of the study prior to the administration of questionnaires. They were also given an opportunity to ask for any clarifications and to indicate their verbal consent if they agreed to volunteer information. Confidentiality with information relating respondent's identity was also emphasized. It was generally observed that respondents were very willing to volunteer information, with most of them indicating that they were delighted by the fact that their SWBs had started gaining attention in development research after a long period of neglect. Open-ended questions provided an opportunity for the respondents to explain their responses in detail; this aspect also encouraged them to volunteer more information when probed. The climatic risks factors that included temperature and precipitation variations were validated using existing historical record of numerical data available at https://en.climate-data.org/africa/kenya and https://tradingeconomics.com/kenya/temperature#:~:text=Temperature%20in%20Kenya%20averaged%2024.12,celsius%20in%20July%20of%201922. These websites present trends of precipitation and temperature data in Kenya. Observations on the general environmental conditions of the SWB catchment, including the land use patterns and resource uses were used to moderate and validate the collated perceptions at the site.

2.2.2 | Physicochemical and small water body parameters

The selected physicochemical parameters that were measured using standard methods for *in situ* data collection and sampling included temperature (°C), dissolved oxygen (DO, mg L^{-1}), pH and conductivity (µS cm^{-1}). These physicochemical parameters were measured using portable electronic water quality meters. Water transparency (photic depth) measured as Secchi depth was determined using a standard Secchi disk (APHA, 2005). The water samples were further collected directly from the sampling sites using pre-treated 1 Litre polyethylene sample bottles for nutrient analyses. The bottles were individually labelled, filled, preserved using sulphuric acid and stored in cool boxes, for onward laboratory analysis using photometric methods for total nitrogen (TN, µg L^{-1}) and total Phosphorus (TP, µg L^{-1}) (APHA, 2005). On the other hand, chlorophyll-a as a measure of levels of primary production was also measured by seston filtration method using GF/C filters, securely wrapped in aluminium foil before refrigeration at about 4°C. The samples were later on transported to the Kenya Marine and Fisheries Research Institute (KMFRI), Kisumu laboratory and analysed according to methods adopted from APHA (2005).

Total and faecal coliforms were analysed according to methods described in APHA (2005). Water samples were collected in the

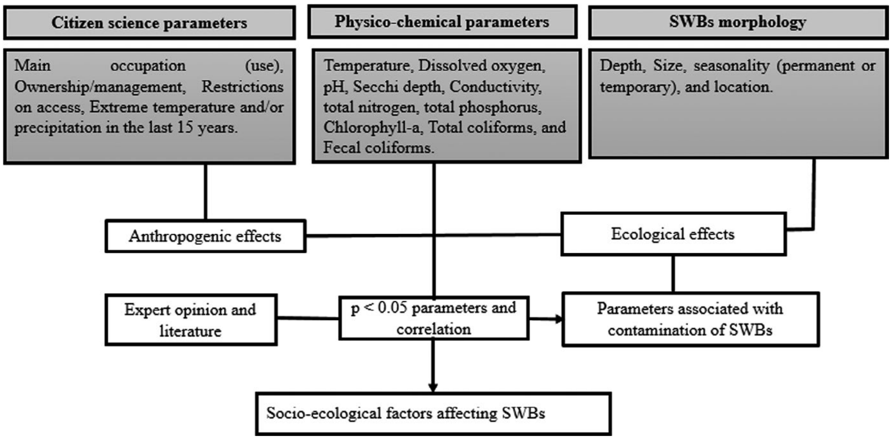

FIGURE 2 Schematic representation towards linking citizen science with indicators associated with contamination levels to establish socio-ecological factors affecting characteristics of small water bodies (SWBs) in central and western Kenya

field and analysed immediately by using a portable incubator test kit Wagtech Potalab +(M). The membrane filtration method was used to determine the total coliforms and faecal coliforms at 37°C and 44°C respectively. Total and faecal coliforms were detected and quantified using selective and differential culture media. Lauryl Sulphate Broth (LSB) was used for cultivation of the organisms, where three composite samples were analysed for each SWB. Sample volumes depended on the water turbidity of the sampled dam. The depth and sizes of SWBs was determined using a depth finder.

2.2.3 | Data analyses

Lack of significant variations for both citizen science and physicochemical data between SWBs within regions led to the pooling of data into central and western Kenya as the major independent variables. Significant variations between citizen science parameters were assessed using Pearson chi-square (χ^2) in order to compare spatial variations among the attributes. Coding of the data was done to allow for thematic analyses that involved identification of patterned meaning in the dataset (Aura et al., 2021). The physicochemical data was compared using the non-parametric Kruskal-Wallis one-way ANOVA to examine the uncertainty of values and variations through pairwise comparisons. Correlation scatterplots for case wise MD deletion were used to show relationships between SWBs parameters that showed significant variations in relation with varied ($p < .05$) contaminant indicators. The study employed the use of SPSS version 21 (SPSS Inc., Chicago, IL, USA) and R version 4.0.2 (R Core team, 2018) for statistical analyses and visualizations. Significant differences for all analyses were determined at $p < .05$.

3 | RESULTS

3.1 | Citizen science characteristics

Crop farming as the main occupation (58.30%; $n = 151$) affecting the SWBs recorded highly significant ($\chi^2 = 28.07$; $p = .00$) proportions in western (54.30%; $n = 82$) as compared to central (45.70%; $n = 69$) region. Other human activities that had <2.0% coverage included livestock rearing, fish farming, fishing, rice farming and hospitality industry.

Significant variations ($\chi^2 = 151.24$; $p = 0.00$) were noted in the ownership and management of SWBs between central and western regions (Table 1). Most SWBs were owned by the government in central region (89.29%; $n = 116$) than the western part (10.72%; $n = 12$) of Kenya. Similar trend was witnessed for privately owned SWBs. Similar to ownership, restrictions on access of SWBs was significantly different ($\chi^2 = 42.54$; $p = 0.00$) between the central and western regions. A large proportion (66.93%; $n = 85$) of unrestricted access of SWBs was evident in western part of Kenya as compared to the central region (23.47%; $n = 23$). Notably, higher proportions of SWBs restrictions for access was common in central region (76.53%; $n = 75$) than the western (33.07%; $n = 42$) counterparts.

There were insignificant ($p > 0.05$) variations in respondents' perceptions in the changes in extreme temperatures for the last 15 years between central and western regions. However, extreme precipitation changes for the same period were significant ($\chi^2 = 6.94$; $p = .03$) with interchanging rankings between central and western regions.

3.2 | Physicochemical and SWBs parameters

Dissolved oxygen, chlorophyll-a, TN, TP, SWB depth and size were significantly different ($p < .05$) between central and western regions (Table 2). Though insignificantly different ($p > .05$), temperature levels were generally higher in the western SWBs as compared to the central systems. Figure 3 shows selected parameters that are associated with contamination and pollution of SWBs. Secchi depth ($F = 9.86$, $p = .003$), total ($F = 7.21$, $p = .01$) and faecal coliforms ($F = 2.12$; $p = .03$) were significantly higher ($p < .05$) in western SWBs than those in the central region. Conductivity was insignificantly ($F = 2.11$, $p = .15$) high in central SWBs than those in the western region.

Generally, increase in SWB's size and depth was linked to decrease in concentration levels of total and faecal coliforms, but

TABLE 1 Selected citizen science parameters for the sampled small water bodies (SWBs) in central and western, Kenya

Citizen science parameters		Region (%; n) Central	Western	χ^2; *p*
Ownership/Management	Community	11.45; 15	88.55; 100	151.24; 0.00*
	Government	89.29; 116	10.72; 12	
	Other (NGO's owned)	100; 1	0.00; 0.00	
	Private	73.33; 11	26.66; 4	
Restriction on access	Less restricted	55.88; 19	44.12; 15	42.54; 0.00*
	Not restricted	23.47; 23	66.93; 85	
	Restricted	76.53; 75	33.07; 42	
Extreme temperature in last 15 years	Decrease	49.15;29	50.85; 30	2.40; 0.30
	Increase	45.11; 60	54.89; 73	
	Stable	56.72; 38	43.28; 29	
Extreme precipitation in last 15 years	Decrease	55.56; 55	44.44; 44	6.94; 0.03*
	Increase	39.45; 43	60.55; 66	
	Stable	56.86; 29	43.14; 22	

χ^2 = Pearson chi-square, *p* = probability value and the use of asterisk (*) indicates significant difference at $p < .05$.

TABLE 2 Selected physicochemical parameters for the sampled small water bodies (SWBs) for both western and central regions of Kenya

Parameter	Central Mean ± SE	Range	Western Mean ± SE	Range	F; *p*
Temperature (°C)	22.91 ± 0.4	20.30–26.4	24.57 ± 0.36	19.7–30.2	4.88; 0.05
Dissolved Oxygen (mg L^{-1})	6.82 ± 0.22	4.81–8.23	5.13 ± 0.35	1.07–9.71	14.71; 0.00*
pH	8.22 ± 0.11	7.08–9.08	7.40 ± 0.10	5.64–8.46	6.99; 0.07
Total nitrogen (μg L^{-1})	521.44 ± 97.91	234.95–1487.05	425.86 ± 45.39	86.53–1103.37	0.14; 0.01*
Total phosphorus (μg L^{-1})	102.65 ± 39.97	1.86–657.57	96.48 ± 10.98	14.71–310.4	1.35; 0.02*
Chlorophyll-a (μg L^{-1})	31.21 ± 4.71	1.80–85.05	52.04 ± 6.75	5.63–310.4	12.70; 0.00*
Depth (m)	3.9 ± 0.61	1–18.1	2.14 ± 0.18	1.0–6.0	7.66; 0.01*
Size (ha)	435.80 ± 353.15	0.10–12,000	5.92 ± 0.92	0.25–20.00	1.8; 0.02*

Use of asterisk (*) indicates significant difference at $p < .05$.

with an increase in Secchi depth (Figure 4). There was a very weak relationship between SWB's size versus Secchi depth and faecal coliforms and weak and negative association with total coliforms. Notably, most of the correlation points were outside the 95% confidence level. The SWBs depths were weakly but positively related to Secchi depth and faecal coliforms and negatively and weakly related to total coliforms.

4 | DISCUSSION

The current study gives preliminary findings on SWBs stakeholders' information, herein referred to as citizen science, and in combination with physicochemical and morphological characteristics of such systems. The findings herein are expected to trigger the up-scaling of research and investment activities in SWBs in the region. This is because, globally, SWBs are only to a limited extent included in environmental protection schemes and partly neglected in water and nature policies (Søndergaard et al., 2005).

The use of indigenous knowledge to account for anthropogenic activities formed qualitative and quantitative results that were linked to selected ecological parameters. This approach could be applied in the management of SWBs since they are spread all over and would rely more on threats and uses that are reported by the stakeholders. Notably, there are various authorities in the world that protect all waters, but managing a large number of SWBs has resulted in a large administrative burden (Natural England, 2008).

In the quantification of both observations and indigenous knowledge, the western part of Kenya had a higher significant ($p < .05$) proportion of crop farming as the main human activity affecting SWBs. This is a typical example of threats to small ecosystems of inland waters that most frequently result from inappropriately conducted

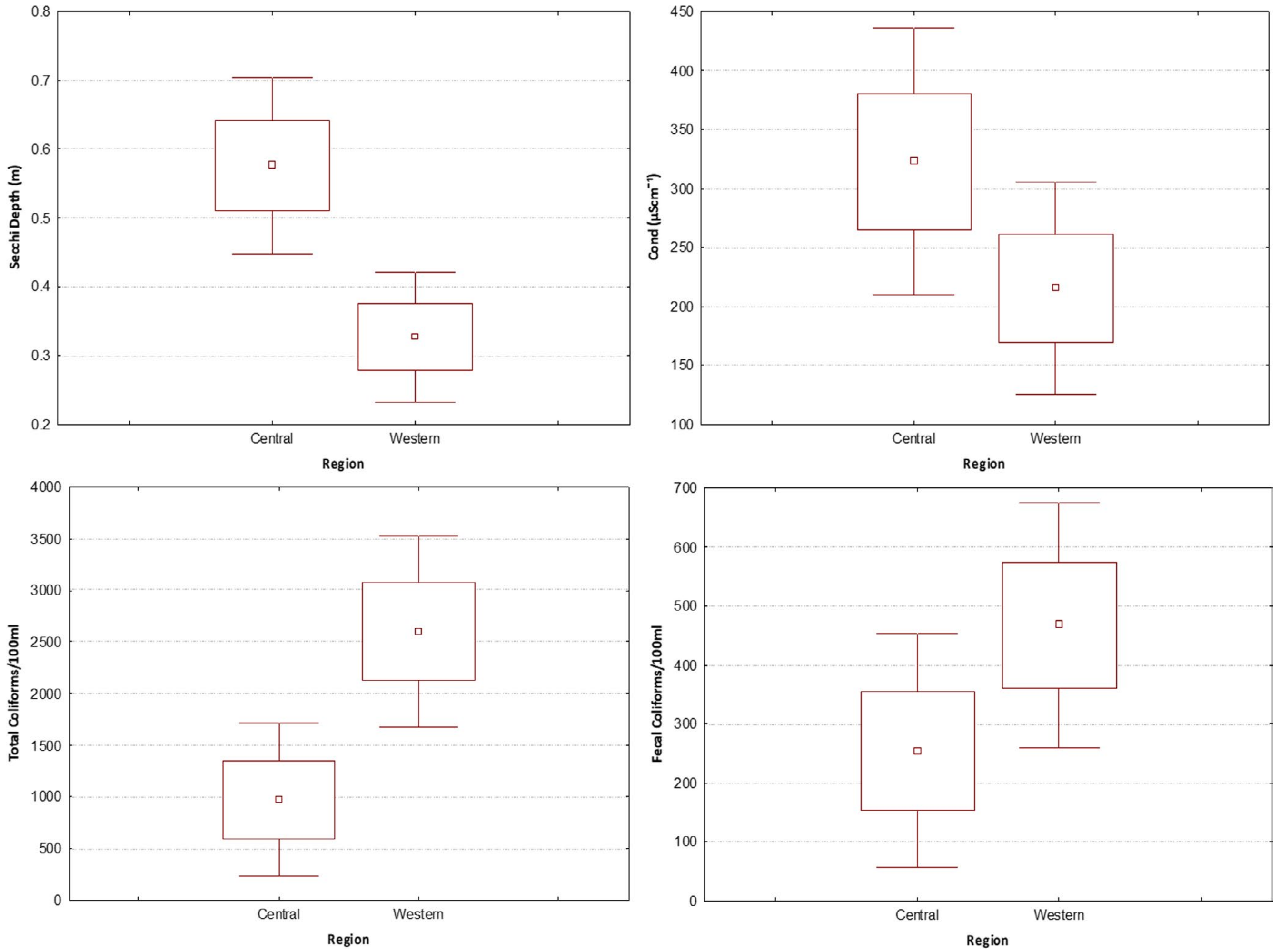

FIGURE 3 Box-plots (mean ± SE at 95% confidence level) showing concentrations of selected physicochemical parameters as indicators of varying ($p < 0.05$) contaminations of the sampled small water bodies (SWBs) in central and western Kenya. Cond = conductivity

agricultural activity, connected most typically with an intensification of production and directly with the increasing area of arable fields and the destruction of in-field SWBs (Haycock et al., 1996). The western SWBs are also compounded with a lack of restrictions on access, which could be attributed to poor control as a result of communal ownership (Table 1). The SWBs that were managed by community associations experienced challenges due to group dynamics and pressure for resources such as water and fish. This scenario is similar to other co-managed natural resources (Kundu et al., 2010).

The use of selected physicochemical parameters and indicators of contamination was to assess the pollution and degradation status of the SWBs since their water quality characteristics are strongly influenced by local conditions (Casas et al., 2011). In SWBs, physical and chemical factors are highly variable as a consequence of the limited size of these water bodies, which experience slight water exchange and high susceptibility to the effect of land and the atmosphere (Kadoya et al., 2011). Insignificantly ($p > .05$) high temperatures recorded in western (24.57 ± 0.36°C) than in central (22.91 ± 0.40°C) regions showed SWBs to be devoid of thermal stratification due to limited size, slight water exchange and high susceptibility to the effect of land and the atmosphere (Table 2) (Casas et al., 2011). Furthermore, perceptions from respondents on changes in temperature in the last 15 years were not significantly different between the two regions (Table 1). Notwithstanding significant but varying perceptions on extreme precipitation levels over the same period as an indication that SWBs are strongly linked to changes in the local environment. Validation of perceptions from aggregated precipitation trends available at https://en.climate-data.org/africa/kenya/ and both precipitation and temperature data at https://tradingeconomics.com/kenya/temperature#:~:text=Temperature%20in%20Kenya%20averaged%2024.12,celsius%20in%20July%20of%201922. Both sources indicate that Kenya has seen relative increase in both rainfall and temperature levels in all regions within the last 10 years. These findings demonstrate that SWBs as aquatic systems with climate-sensitive zones (Kizza et al., 2009).

Significant variations in dissolved oxygen, nutrients and chlorophyll-a in the two regions could be linked to slight changes in temperature in some SWBs due to variations in sizes and depth, which may have triggered water mixing. The difference may have occurred such that water bodies may have a profundal pelagic zone, a thermocline or a deeply situated bottom (Downing & Duarte, 2009). Such differences and human activities in the surroundings could have

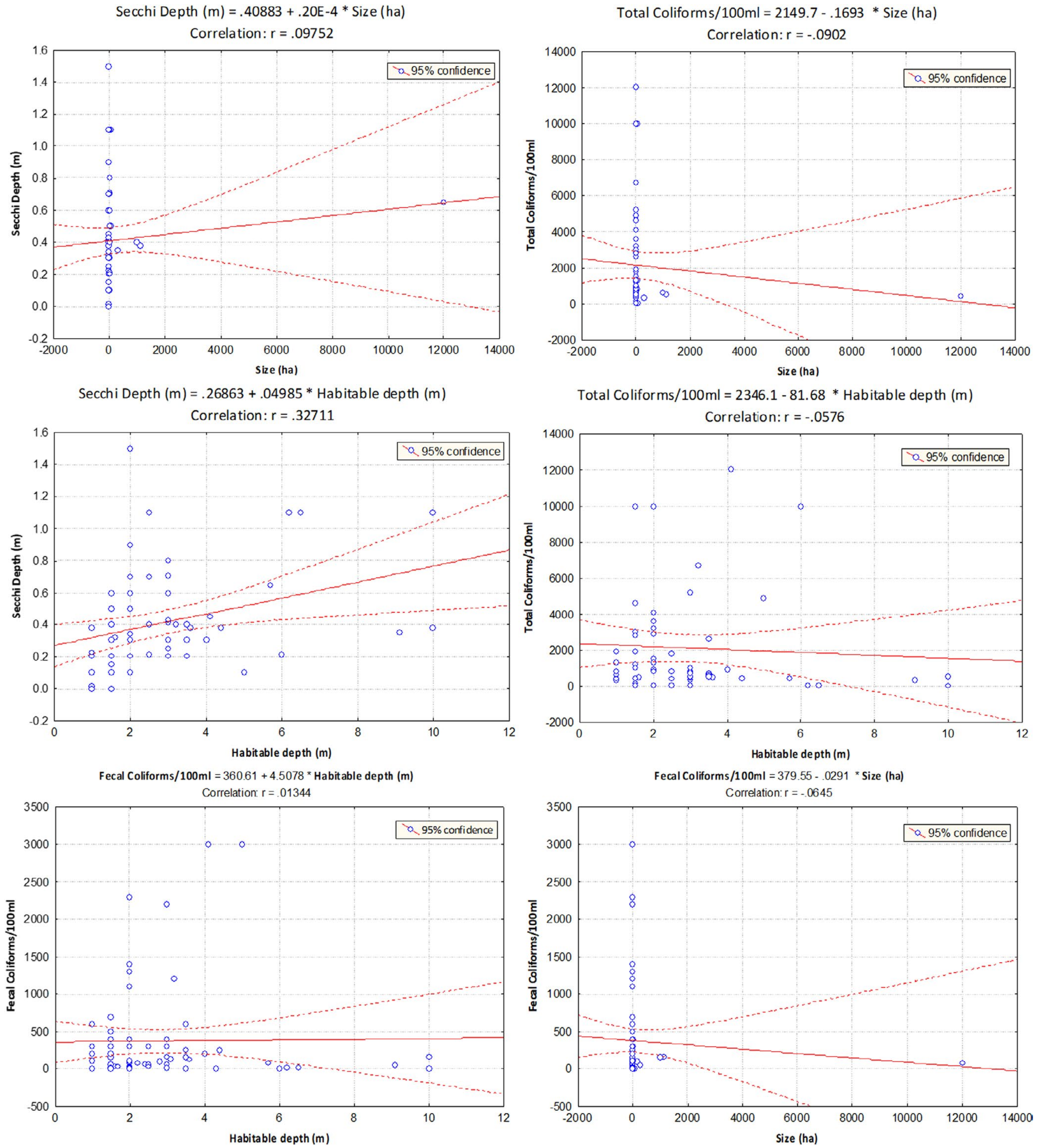

FIGURE 4 Correlation scatterplots of depth and size of sampled small water bodies (SWBs) versus selected (p < 0.05) physicochemical parameters that are associated with water quality contamination for central and western Kenya

accounted for variations in water transparency and microbial indicators between western and central regions (Figures 3, 4). The SWBs sizes and depths had a weak link with contamination indicators with an increased human activities' and discharges' pressure being susceptible to small-sized SWBs as compared to larger ones (Figure 4).

Since the impact of human activities is potentially greater on small SWBs than on larger ones, it is crucial to develop a structural framework to systematically include SWBs into spatially integrated management plans (Lauge Pedersen, 2009). To protect SWBs, there is now an urgent need to raise awareness about their ongoing destruction and their many beneficial functions to society (Meyer et al., 2007). This awareness-raising should boost political recognition of their importance for maintaining a healthy and diverse aquatic environment. Coordinated activities with the protected habitats under the citizen science perspective would be of value in the conservation, utilization and management of SWBs.

5 | CONCLUSION AND RECOMMENDATIONS

The current study involved evaluation of SWBs using socio-ecological parameters to provide information for possible conservation and blue economic investments. The higher and significant variations ($p < .05$) in the main occupation (crop farming), community management and unrestricted access in western SWBs as compared to central systems may have led to poor water transparency and increased discharges that consisted of microbial agents. The impact and pressure of human activities were potentially greater on small SWBs as compared to small-sized ones. The study recommends a coordinated approach in further research, utilization and management of SWBs and with the involvement of the local community in awareness platforms, rebranding and investment.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data used in the manuscript will be provided upon request.

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