Journal of Environmental Science, Ecology & Chemistry

JESEC, 1(3), 114-129, 2025
https://doi.org/10.58985/jesec.2025.v01i03.12
eISSN: 0000-0000

Research Article

Effects of anthropogenic activities on plant community structure and water quality along a peri-urban freshwater stream: The Bwitingi-Bwiteva water course, Cameroon

Queenzabel Mambo Fru[1], Miranda Egbe Awo[1*], Pascal Tabi Tabot[1, 2], Lucienne Human[3, 4], Sob Charleine Djouego[1] and **Beatrice Ambo Fonge[1]**

1. Department of Plant Science, Faculty of Science, University of Buea, Cameroon.
2. Department of Agriculture, Higher Technical Teachers' Training College Kumba, University of Buea, Cameroon.
3. South African Environmental Observation Network (SAEON) Elwandle Node, Ocean Science Campus, Nelson Mandela University, Port Elizabeth, South Africa.
4. Department of Botany, Nelson Mandela University Summerstrand South Campus, Port Elizabeth, South Africa.

Article Information
Received: 18 February 2025
Revised: 26 March 2025
Accepted: 10 April 2025
Published: 15 September 2025

Academic Editor
Prof. Dr. Giuseppe Oliveto

Corresponding Author
Miranda Egbe Awo
E-mail:
awo.miranda@ubuea.cm,
awomiranda1@gmail.com
Tel: +237-650938282

Keywords
Eutrophication, enteric bacteria, phytoplankton, plant diversity, water quality.

Abstract

Inland freshwater streams are increasingly exposed to anthropogenic pressures that affect their quality. This research aimed to determine the relationship between land use, water quality, plant and phytoplankton community structure. Water samples were collected in triplicate from six stations along the stream and subjected to ecological analyses, phytoplankton counts, bacteriological analyses as well as determination of physico-chemical characteristics. Data were analysed using the MINITAB Version 17 statistical package with ordination to establish relationships. The results showed that settlement, and agriculture have the greatest impact on the system. The physicochemical parameters recorded included water temperature (21.14–22.56 °C), pH (6.52–7.53), conductivity (152.33–253.67µS/cm), nitrates (3.68–68.01ppm), dissolved oxygen (3.32 – 5.17ppm), and phosphates (1.13–3.30 ppm). Four of the six sites were highly degraded with no tree species, and the phytoplankton community structure at these sites also reflected disturbances. Disturbed sites were highly eutrophic (chlorophyll a > 10µg/L at 4 sites) and contaminated with human pathogenic bacteria. Total bacterial counts ranged from 3633 CFU at Site 3, with *E. coli*, *Salmonella* sp. and *Shigella* sp. measuring 513, 27 and 77 CFU, respectively, to 5510 CFU for total bacteria counts in Site 6, with *E. coli*, *Salmonella* sp. and *Shigella* sp. measuring 1631, 544 and 110 CFU. Less disturbed sites (Sites 1 and 2) had more trees and good water quality indicators. Total bacterial counts at Sites 1 and 2 were 12 CFU and 23 CFU respectively with no *E. coli*, *Salmonella* sp or *Shigella* sp. Existing conservation measures at the catchment sites were effective in preventing this level of contamination. A proper landscape planning is necessary in the Buea municipality to ensure that land use and development activities are compatible with the ecological integrity of the numerous streams and their watersheds.

1. Introduction

Inland freshwater systems are a veritable resource for rural and peri-urban populations worldwide.

Although pipe borne water coverage has increased over time, dependency on freshwater streams and rivers for water for various uses, fishing, sand mining and other ecosystem services remains high among the underprivileged across the world, especially in the developing world [1-2]. Simultaneously, urbanization and population growth mean that in urban and peri-urban areas, freshwater streams are increasingly subjected to various anthropogenic pressures, which degrade or have the potential to degrade their associated ecosystem services [3]. At the same time, these streams are needed for the increased production of pipe-borne water for the increasing population [4]. These competing pressures affect the ecology of water bodies, which in turn determines the extent of their use.

Pristine or near-pristine freshwater sources typically have a stable ecology, climax or near-climax vegetation structure, are oligotrophic or mesotrophic, with phytoplankton communities typical of well oxygenated water [5]. These water bodies provide numerous ecosystem services to the surrounding communities. They are typically found at the source, in areas with a strong environmental use ethics or good conservation policies that are well applied. In contrast, degraded water bodies or freshwater rivers and streams that are subjected to anthropogenic pollution are characterized by eutrophication and a high dominance of pollution-indicating vegetation [3, 6-7]. This category of freshwater systems provides reduced ecosystem services, and contributes to water scarcity, as it cannot be used without treatment [8]. Whether in the developed world or the global south, freshwater rivers and streams in urban and peri-urban areas are increasingly subjected to anthropogenic disturbances and hence ecosystems services degradation. The pressures and drivers are similar in both cases, but may differ in magnitude from site to site. For example, in North America fecal contamination of freshwater lakes in Florida was strongly associated with anthropogenic activities and storm water runoff [9]. Similarly, a Europe-wide study of freshwater rivers found severe degradation in two-thirds of the rivers, which was strongly associated with anthropogenic activities such as urbanization and nutrient leaching [10]. In the Abaxe Dam Reservoir in Northern Spain, the increasing incidence of eutrophication with harmful cyanobacterial blooms was strongly associated with livestock farming and sewage disposal [11]. As summarized by Gao et al., [12], freshwater systems in China can generally be considered heavily eutrophic, with a few exceptions, and this eutrophication is heavily related to urbanization, agriculture and wastewater discharge. Heavy eutrophication has been reported in two freshwater systems in Nigeria under urbanization pressures [13-14] and this can be seen as a microcosm of the situation nationwide. This pattern could be expected in Cameroon's urban and peri-urban zones where there are high levels of population growth and associated pressure on the existing infrastructure. In Cameroon, while studies have been carried out on the larger river systems because of their size, ecological and historical significance. Few studies exist on the inland freshwater streams that actually animate the potable water systems in most towns. For example, [15] found significant levels of fecal coliforms and human intestinal protozoa in springs and wells from the Monatele and Obala towns in Cameroon. Several phytoplankton taxa were identified in streams in Tiko (Cameroon) as bio-indicators of poor water quality [31]. These studies are essential in the context where the lone water provision corporation is experiencing a severe shortfall in its ability to supply pipe borne water to most communities. As a result, community water projects that rely heavily on these smaller inland streams are increasing. In Buea, the Regional capital of the South West Region of Cameroon, the Bwitingi-Bwiteva water project provides potable water to a large segment of the population. People drive from far and near to fetch water from the overflow outlet, since potable water supply from both this project and the water provisioning company is significantly insufficient. Downstream populations also use the watercourse for bathing, irrigation and fishing. These activities affect both ecosystems and human health, and reduce the potential for further potable water projects downstream along this watercourse. Therefore, the aim of this study was to assess the plant and phytoplankton community structure, as well as other water quality parameters, at six stations along the watercourse to determine the ecological state of the watercourse in this peri-urban setting, and how

https://doi.org/10.58985/jesec.2025.v01i03.12

the water quality is influenced by associated land uses. The findings would serve as an indicator of the state of similar inland streams that are becoming increasingly important in urban freshwater-dependent ecosystem service provisioning.

2. Materials and methods

2.1. Description of study area

This research was carried out in Bwiteva and Bwitingi villages in the Fako Division, South West Region of Cameroon. The section of the water course studied stretches from latitude 004°10’172 to 004°10’574N and longitude 009°16’28 to 009°18’166E of the equator. Water characteristics and related parameters were assessed from two sites within the catchment, and four other sites along this stretch of the watercourse. The choice of this catchment was based on the number of nearby villages (approximately 12) which depend on it for freshwater and related resources. Some of these villages include Bokwai, Bwiteva, Bwitingi, Bova I, Bova II, Bonakanda, Bokova, Bomaka, Lysoka, Upper Muea and Lower Muea. Apart from these villages, a vast population of the Buea urban area also benefits from this watercourse (Plate 1).

Plate 1. High anthropogenic pressure on the Bwitingi-Bwiteva outflow channel.

At various points along its course, this water is used by the inhabitants for cooking, washing cars, building construction, irrigation, drinking and many other activities. Fig. 1 presents the sites selected in this study, while Table 1 presents different sites.

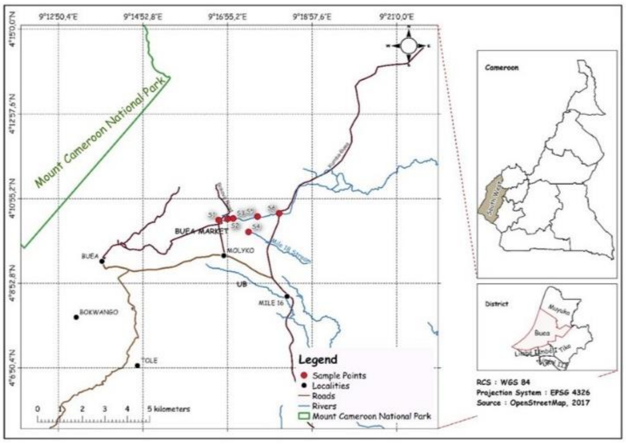

Figure 1. Map showing Sampling Points in the study area.

2.2. Sample collection and handling

Water samples were collected in triplicate at six (6) points from the main source and at intervals along the stream where there was a change in land use, for physicochemical and biological analyses. Some physicochemical parameters such as temperature, pH, turbidity, and colour of the stream were measured and recorded onsite using YSI multi parameter (HANNA HI 9829). Sterilized 1L containers were coded and used for the water sample collection. At each point, three sets of water samples were collected; for phytoplankton analysis, determination of some nutrients and bacteriological parameters. For the phytoplankton analyses, the containers were first rinsed with the sampling water at least twice before sample collection and three drops of 10 % Lugol’s iodine were added to each of the samples for phytoplankton analyses to fix and preserve the phytoplankton. Uptake of Lugol’s iodine is also particularly effective in increasing cell density and aiding the process of sedimentation for the concentration of the phytoplankton sample [16]. The samples were placed in a cooler box with ice blocks and transported to the Biological Science Laboratory of the University of Buea. Water samples for chemical analysis were sent to the Nelson Mandela University, South Africa, for the analyses of nitrates, phosphates and ammonium. Phytoplankton identification was done with the aid of light microscope (Olympus BH2 binocular microscope, equipped with Normaski optics at magnification of 100X and 400X. The wet mount technique was used as described by Awo et al.

https://doi.org/10.58985/jesec.2025.v01i03.12

Table 1. Description of sampling points and GPS coordinates.

Study site	Coordinates		Description
Site 1 (Catchment)	Latitude	004°10′172″N	Activities around the catchment include oil palm (*Elaeis guinensis*) farming, laundry and refuse disposal including plastics and non – biodegradable objects.
	Longitude	009°16′28″E	
	Elevation	656m	
Site 2 (Catchment)	Latitude	004°10′475″N	The wetland biodiversity around this area was highly conserved. The catchment had four different water sources but only two were being exploited.
	Longitude	009°16′6″E	
	Elevation	671m	
Site 3	Latitude	004°10′428″N	The water at this point came from the two catchments, flowed through a car wash point, a pig farm found along the stream, a toilet also built along the water course with a lot of reclamation for construction built very close to the water course.
	Longitude	009°17′062″E	
	Elevation	630m	
Site 4	Latitude	004°10′389″N	Agricultural practices like farming of vegetables, tomatoes, and piggery are carried out
	Longitude	009°17′310″E	
	Elevation	614m	
Site 5	Latitude	004°10′526″N	The site was mainly used as a dump site for those houses around although there was an official trash can some few meters away
	Longitude	009°18′018″E	
	Elevation	552m	
Site 6	Latitude	004°10′574″N	This site had a slaughter house and an open dump. A pig farm was also built very close to the stream
	Longitude	009°18′166″E	
	Elevation	550m	

[45] and Kenko et al. [46]. Algal identification was carried out using comparative morphology and with the aid of journal articles and identification keys including algal databases such as algaebase.org [16].

2.3. Plant identification

Two transects of 500 meters were placed along the stream. Measurements were taken across the entire width of the stream, up to 4 m off the banks to capture riparian plants. Within each transect, three plots of 100 m were laid, each separated by 50 m. Sub-plots of 10m by 10m were labeled. Quadrats measuring 1m by 1m were mapped, and demarcated. Within each quadrat, all plant species were counted, identified and recorded and special notes were taken of their life forms. Plant sampling was carried out for two weeks in October, at the end of the rainy season. Individual plant species were counted in each quadrat and the numbers from all other plots were summed to obtained the total. Plant identification was performed using comparative morphology and identification keys in relevant textbooks and journals. Plants which could not be identified in the field were taken to the Limbe Botanic Garden Herbarium for proper identification.

2.4. Determination of bacteriological parameters

Total coliform counts were carried out to assess the levels of coliforms in the water samples. A set of samples was subjected to a presumptive test, for the presence of different bacteria such as *Salmonella typhi, Shigella sp*. and *Escherichia coli* using different agar media; Salmonella-Shigella agar (SS agar) for *Salmonella* and *Shigella* and Eosin methylene blue agar (EMB agar) for the identification and differentiation of *E. coli* from other gram-negative bacteria.

Water samples for chlorophyll-a concentration were collected in darkened coded containers to prevent light passage and further reactions. The samples were filtered on the day of collection. Two hundred and fifty (250 mL) of water was passed through a Rund filter MN (GF-3) glass filter paper. Each filter paper was then placed in 10 mL 90% ethanol. All samples were agitated and left to undergo pigment extraction in the dark at 4°C for 24 h. The extract was then filtered, and absorbance was read for each sample at 665 and 750 nm on a 722 s spectrophotometer (UNICO 1200 spectrometer, B-BRAN Scientific Instrument

https://doi.org/10.58985/jesec.2025.v01i03.12

Company, England). Chlorophyll a was calculated using the formula described by Talling et al. [17].

$$\text{Chlorophyll a } (\mu g1\text{-}1) = \frac{11.99(A665 - A750)S}{Vp} \quad (1)$$

Where:
A665 = absorbance at 665 nm,
A750 = absorbance at 750 nm,
S = solvent extraction volume (mL),
V = the sample volume in litres
p = the path length of cell, cm

A set of samples for nutrient analysis was sent to the Nelson Mandela University in South Africa for the analysis of nitrates, ammonium and phosphorus using standard methods [18].

2.5. Data analyses

2.5.1. Phytoplankton and plant analysis

2.5.1.1. Species abundance

The abundance of each alga per milliliter was obtained from the sum of its occurrences on the three slides (drops).

$$\text{Abundance(mL)} = \frac{(n1+n2+n3)}{0.15} \quad (2)$$

Where;
n1, n2 and n3 are algal count in drops
0.15 is the volume of three drops in mL

2.5.1.2. Euglenophycean index

The Euglenophycean index was used to determine the trophic status and was calculated according to Bellinger et al. [16]:

$$\text{Euglenophycean Index} = \frac{\text{No. of Euglenophyta}}{\text{No. of Cyanophyta} + \text{Chlorophyta}} \quad (3)$$

If the Euglenophycean Index < 1, the system is eutrophic and if > 1 it is oligotrophic

2.5.1.3. Species richness

The Species Richness Index (d) according to Margalef [19] was used to evaluate the community structure of the phytoplankton and plants.

$$\text{Species Richness, D} = \frac{(S - 1)}{\ln} \quad (4)$$

Where:
ln = natural log
D = Species richness index
S = Number of species in a sit
N = Total number of Individuals in all sites

2.5.1.4. Shannon-Wiener diversity (H)

Shannon-Weiner (1949) diversity index of phytoplankton and plant species within the different sites were equally determined using the following formula:

$$\text{Shannon } H' = \sum_{i}^{i=1} \text{pilnpi} \quad (5)$$

Where,
H' = Index of species diversity,
Pi = Proportion of total sample belonging to i^{th} species,
ln = natural log.

2.5.1.5. Evenness of phytoplankton and plant species

Evenness of phytoplankton communities and plants were also calculated using Shannon Index of diversity.

$$\text{Evenness} = \text{Shannon} \frac{H}{\ln S} \quad (6)$$

Where,
S is the total number of species,
ln = natural log

2.5.2. Correlation and simple correspondence analysis

Spearman's correlation was used to relate physico-chemical parameters and phytoplankton diversity and abundance to anthropogenic activities. The physico-chemical parameters were compared with WHO 2006 [20] the standards for surface and drinking quality. Ordination was done to determine the spatial association of parameters with the sites and land uses. Descriptive statistics were used to obtain figures and tables using Microsoft Excel and Minitab version 17.

3. Results and discussion

3.1. Anthropogenic land uses along the Bwitingi-Bwiteva water course

Table 2 shows the various land uses which were identified along the watercourse at each site. Settlement and construction were observed at all sites. Agriculture was observed at all sites including Site 4, which was mostly used for water extraction. These land uses are the key drivers of land use change in urban and peri- urban areas. It has been reported [21] that agriculture is expanding rapidly in wetland areas

https://doi.org/10.58985/jesec.2025.v01i03.12

Table 2. Anthropogenic activities observed along the Bwitingi-Bwiteva water course, Cameroon.

Site	Anthropogenic activity	Possible impacts
1.	Agriculture (tomato farming) Settlement (construction, Laundry)	Nutrient loading into stream Loss of biodiversity Conversion of wetland into dry land Improper waste disposal
2.	Settlement construction Agriculture (pig farming on stream)	Loss of plant biodiversity Conversion of wetland into dry land Improper waste disposal. Nutrient loading into stream. Improper waste disposal
3.	Agriculture Settlements construction, reclamation, toilets on stream, water extraction laundry and Swimming	Nutrient loading into stream Loss of plant biodiversity
4.	Modified for water extraction Settlement (construction, dumpsite).	Loss of plant biodiversity Conversion of wetland into dry land. Improper waste disposal
5.	Agriculture Settlement (Construction) Toilets along stream, dumpsite	Nutrient loading into stream Nutrient loading into stream Improper waste disposal
6.	Agriculture (slaughter house) Settlement (construction, Municipal dumpsite)	Nutrient loading into stream Loss of plant biodiversity Conversion of wetland into dry land, improper waste disposal

due to population pressure, thereby potentially jeopardizing the ecosystem services of wetlands, including the provision of freshwater for agriculture. In most of the farms, both systemic and contact agrochemicals, such as Grefonsec complex 210WP (carbendazim (50 g/kg), sulfur (120 g/kg), imidacloprid (20 g/kg), and lambda-cyhalothrin (20 g/kg), MOCAP (ethoprophos (O-Ethyl S, S-dipropyl phosphorodithioate), Cotzeb 80WP (800.000 g/kg mancozeb) (contact fungicide), Mancostar 80WP (Mancozeb), Emacot (*emamectine benzoate 50 g/kg)* (insecticide) and Plusfort 45SC (thiocarbamates) (systemic and contact insecticide) were used in crop management especially at Sites 3 and 4. These agrochemicals were one of the main sources of chemical loading in the stream during heavy rainfall through leaching. Several studies have been carried out in Cameroon, documenting the eco-toxicological impacts of pesticides in both terrestrial and aquatic ecosystems, ranging from acute to chronic risks [22, 47-48]. Most of the agrochemicals documented in this study have eco-toxicological implications for both aquatic and terrestrial ecosystems as revealed by Fai et al. [48]. Macozem found at some of the sampling sites has been documented as one of the eight pesticides posing acute ecological risks in the Ngouoh Ngouoh watershed of the Foumbot municipality, Cameroon [22]. At Sites 3 and 5, toilets were constructed that discharged into the watercourse. Other activities included laundry, swimming and refuse disposal (Table 2 and Fig. 2). Sewage disposal into freshwater streams and rivers is an emerging global issue, with severe consequences for ecosystem and human health. This has been reported, for example, in the South African Diep River in Dunoon [23], the rivers of Lagos, Nigeria [24], as well as the in River Wouri, Cameroon [25].

3.2. Plants identified along the Bwitingi-Bwiteva water course

The only sites with natural vegetation were Sites 1 and 2. These sites are within the water catchment where deforestation and other anthropogenic activities are restricted. Sites 3, 4 and 5 had no natural vegetation but they did have cultivated plants. Site 5 had neither trees nor shrubs. Therefore, the protective measures in the catchment sites were still effective to the extent that they were more pristine than the rest. This is consistent with the findings of Issii et al. [26] who showed that establishing and respecting protective measures is essential forest conservation, even in

https://doi.org/10.58985/jesec.2025.v01i03.12

Figure 2. Anthropogenic activities along the Bwiteva/Bwintingi water course.

urban areas. Table 3 presents a checklist of the different plants with respect to the sampling sites. A total of 51 plant species (18 trees, 15 shrubs and 18 herbs) were identified in the study area. These plants belong to 34 families and Asteraceae was the most represented family, with six species, followed by Solanaceae (4 species) and Poaceae (3 species). Site 2 had the highest number of tree species (10 trees), followed by Site 1 (7 trees). These were water catchment areas, protected by traditional authorities. Sites 3 and 5 had the highest number of herbs (11 and 8, respectively), while Site 6 had the lowest (3 herbs). Sites 1 and 4 had the highest number of shrubs (5 and 4, respectively). The richness of tree species in the catchment sites contrasts with the degraded nature of the rest of the sites which is consistent with anthropogenic deforestation, with species present in the degraded sites being indicators of deforestation and agriculture [27].

The spatial association of plant species and anthropogenic activities with the sampling sites are presented in Fig. 3. Site 3 was strongly associate with land reclamation, swimming, sewage disposal, water abstraction and laundry. Site 5 was also strongly associated with water abstraction and laundry. Few plant species (17) are associated with these two sites including *Eromostax speciosa*, *Commelina benghalensis*, *Commelina communis*, *Cyperus rotundus*, *Capsicum annuum*, *Dacryodes edulis* etc. which are either herbs or planted fruit trees indicative of strong anthropogenic disturbance. Site 6 was also less pristine, and strongly associated with only five species, namely *Chromolaena odorata*, *Citrus sinensis*, *Amaranthus spinosus*, *Colocasia esculenta* and *Hibiscus rosa-sinensis*, consistent with a strong association of Site 6 with construction, agriculture and refuse disposal. Sites 1, 2 and 4 were strongly associated with the majority of the plant species, and showed no strong association with any specific anthropogenic activity. Globally, practices such as clearing, grazing, tillage, intercropping etc. associated with agriculture have been shown to have a deleterious effect on biodiversity [28].

3.3. Vegetation community structure of all the sites in the study area

Even within farming systems, the diversity of crop species typically reduced. The species diversity, richness and evenness indices are presented in Table 4. Site 4 was the most diverse (H′= 0.365), followed by Sites 1 and 2 (0.347), while Site 6 was the least diverse (H′= 0.167). Species diversity could generally be

https://doi.org/10.58985/jesec.2025.v01i03.12

Table 3. Plants identified along the water course in the Bwitingi-Bwiteva water course.

Family	Scientific Name	Common name	Growth form	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Acanthaceae	*Eremomastax speciosa* (Hochst.) Cufod.	Two side leaf	herb	-	-	+	-	-	-
Asteraceae	*Ageratum conyzoides* L.	King grass	herb	-	-	-	-	-	+
Asteraceae	*Chromolaena odorata* (L.) King and Robinson	Acha kasara	shrub	+	-	-	-	-	-
Asteraceae	*Vernonia amygdalina* Delile	Bitter leaf	shrub	+	-	-	+	-	-
Asteraceae	*Bidens pilosa* L.	Black jack	herb	-	-	-	+	-	-
Asteraceae	*Tithonia diversifolia* A. Gray	Sun flower	shrub	-	-	-	-	+	-
Asteraceae	*Emilia coccinea* (Sims) G. Don	Rabbit grass	herb	+	-	+	-	+	-
Araceae	*Colocasia esculenta* (L.) Schott.	Cocoyams	herb	-	-	+	-	+	+
Arecaceae	*Elaeis guineensis* Jacq.	Palm kernel	tree	+	-	-	-	-	-
Arecaceae	*Raffia hookeri* G. Mann &H. Wendl.	Raffia palm	tree	-	-	+	-	-	-
Anarcadiaceae	*Mangifera indica* L.	Mango	tree	+	+	-	+	-	-
Apocynaceae	*Tabernaemontana divaricate* (L.) R. Br. ex Roem. & Schult	Pinwheel flower	shrub	-	+	-	-	-	-
Apocynaceae	*Voacanga africana* Stapf	Voacanga	tree	+	+	-	-	-	-
Amaranthaceae	*Amaranthus spinosus* L.	Bush green	herb	-	-	+	-	-	+
	Amaranthus cruentus L.	Green	herb	-	-	-	+	+	-
Bignoniaceae	*Spathodea campanulata* P. Beauv.	African tulip tree	tree	-	+	-	-	-	-
Burseraceae	*Dacryodes edulis* (G. Don) H.J. Lam	Plum	tree	-	-	+	-	-	-
Cecropiaceae	*Musanga cecropioides* R. Br. ex Tadlie	Umbrella tree	tree	+	+	-	+	-	-
Commelinaceae	*Commelina communis* L.	Commelina	herb	-	-	+	-	+	-
Convolvulaceae	*Ipomoea batatas* (L) Lam	Sweet potato	herb	+	+	+	-	-	-
Costaceae	*Costus afer* Ker Gawl.	Monkey sugar cane	herb	+	-	+	-	-	-
Caricaceae	*Carica papaya* L.	paw paw	tree	-	+	+	+	+	-
Cyperaceae	*Cyperus rotundus* L.	Sedge	herb	+	+	+	-	+	-
Dryopteridaceae	*Rumohra adiantiformis (*G. Forst.) Ching.	Leaderleaf fern	shrub	-	+	-	-	-	-
Fabaceae	*Erythrina sp.*	Coral tree	tree	-	-	-	-	+	-
Euphorbiaceae	*Manihot esculenta* Crantz.	Cassava	shrub	-	+	-	+	-	-
Euphorbiaceae	*Mallotus philippensis* (Lam.) Mull. Arg.	Chewing stick	shrub	-	-	-	+	-	-
Irvingiaceae	*Irvingia gabonensis*(Aubry-Lecomte ex O'Rorke) Baill.	Bush mango	tree	+	-	-	-	-	-
Lauraceae	*Pearsea americana* Mill.	Avocado	tree	+	+	-	+	-	-
Malvaceae	*Theobroma cacao* L.	Cocoa	tree	-	+	+	-	-	-
Malvaceae	*Hibiscus rosa- sinensis* L.	Hibiscus flower	shrub	-	-	-	-	-	+
Moraceae	*Ficus benjamina* L.	Weeping fig tree	tree	-	+	-	-	-	-
Moraceae	*Ficus coronata* L.	Sand paper	tree	+	-	-	-	-	-
Musaceae	*Musa sapientum* L.	Banana	herb	+	-	-	-	-	-
Musaceae	*Musa paradisiaca* L.	Plantain	herb	-	+	+	+	+	-
Myrtaceae	*Psidium guajava* L.	Guava	tree	-	-	-	+	-	-
Myrtaceae	*Sizygium malaccense* (L) Merr. & L. M. Perry	Buea apple	tree	-	+	-	-	-	-
Osmundaceae	*Osmunda cinnamomea* L.	Cinnamon fern	shrub	+	+	-	-	-	-
Poaceae	*Pennisetum purpureum* Schumach.	Elephant grass	herb	+	-	-	+	+	-
	Zea mays L.	Maize	shrub	-	-	-	+	-	-
	Pennisetum sp	Grass	herb	-	-	-	+	-	-
Pteridaceae	*Adiantum aethiopicum*	Maidenhair fern	shrub	+	+	-	-	-	-
Phyllanthaceae	*Bridelia micrantha* (Hochst.) Baill	Mitzeerie	tree	-	+	-	-	-	-
Rutaceae	*Citrus sinensis* (L.) Osbeck	Orange	tree	-	-	-	-	-	+
Solanaceae	*Solanum scabrum* Mill.	Huckle berry	herb	-	-	+	-	+	-
Solanaceae	*Capsicum annuum* L.	Pepper	shrub	+	-	+	-	+	-
Solanaceae	*Solanum lycopersicum* L.	Tomato	herb	+	-	-	+	-	-
	Capsicum sp.	Green pepper	shrub	-	-	+	-	-	-
Talinaceae	*Talinum triangulare* (Jacq.) Willd.	Water leaf	herb	-	-	+	-	-	-
Urticaceae	*Urera cordifolia* Engl.	Urera	shrub	-	+	-	-	-	-
Lamiaceae	*Vitex doniana* Sweet	Blacking tongue	tree	+	-	-	-	-	-
Verbenaceae	*Lamprocapnos spectabilis* (L.) Fukuhara	Bleeding heart	shrub	+	-	-	-	-	-

https://doi.org/10.58985/jesec.2025.v01i03.12

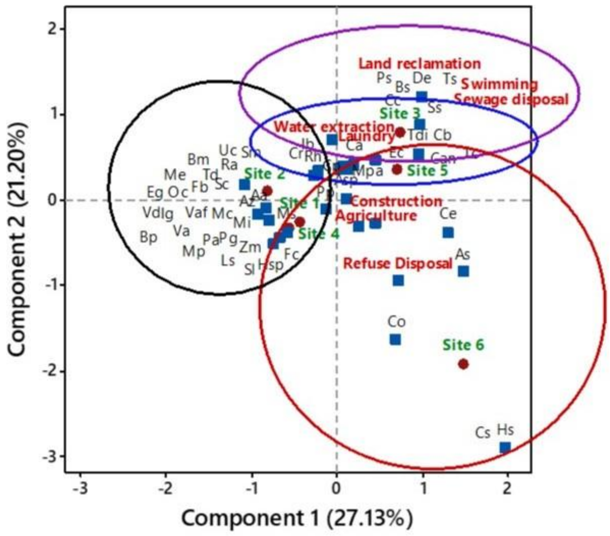

Figure 3. Ordination plot of the association of species and anthropogenic activities across sites.

Table 4. Plants community structure across sites in the study area.

Sites	Diversity	Richness	Evenness	Species abundance
Site 1	0.355	10.209	0.128	37
Site 2	0.347	8.507	0.122	31
Site 3	0.252	1.985	0.182	8
Site 4	0.365	5.104	0.152	19
Site 6	0.167	0.284	0.240	2

considered to be low. The species richness along the watercourse ranged from 0.284 (Site 6) to 10.21 (Site 1). Species richness could also be considered to be low. Community evenness ranged from 0.122 at Site 2 to 0.240 at Site 6, on a scale of 0 to 1. Species were not evenly distributed since the evenness index was below 0.5 in all cases (indicative of disturbance). In terms of species abundance, Site 1 had the highest species abundance (31 species), whereas Site 6 had the lowest abundance (two species). The eight most abundant plants in the study area were *Solanum lycopersicon* (15), *Adiantum aethiopicum* (7), *Bambusa vulgaris* (7), *Vernonia amygdalina* (6), *Osmunda cinnamonea* (6), *Theobroma cacao* (6), *Elaeis guineensis* (4) and *Manihot esculenta* (4). These species are typically associated with agricultural activities. Studies have shown that there is degradation in genetic diversity in farming systems in the Caucasus, both within the farming zones (due to crop selection and use of agrochemicals), and in the forest areas (that used to serve as repositories of genetic resources) due to habitat destruction, fires etc. [29]. Similar findings have been reported by José-María et al. [30] who showed decreased plant diversity and richness under different scales of agricultural intensification, as well as changing plant assemblages in the Mediterranean cereal fields. Sorensen similarity indices indicate how closely related the sites were in terms of species composition. Sites 3 and 5 were the most similar sites with the highest similarity index of 0.50 followed by Sites 4 and 5 with similarity index of 0.28. Sites 1 and 6 (Sorensen index = 0), 2 and 6 (Sorensen index = 0) and 4 and 6 (Sorensen index = 0) were totally dissimilar. Sites showing a Sorensen Index of 0 typically have no species in common. This similarity between Sites 4 and 5 could be due to their proximity to each other and the fact that they contained plants in families like Poaceae which are easily dispersed by both water and wind. They readily colonise the empty un-vegetated plots due to their abundant seed production strategy.

Anthropogenic activities affect not only the terrestrial space, but also water quality. Physicochemical characteristics of the water samples are presented in Table 5. The water temperature (21.14 – 22.46 °C) and pH (6.52 – 7.53) were within the WHO permissible limits for drinking water [20]. The temperature was mild and the water was neutral in pH. The electrical conductivity (152.33 – 223.67 μS/cm), TDS (76 – 114.67 ppm) and salinity (0.07 – 0.11psu) were all within the limits for drinking water and highly characteristic of freshwater. This is in line with the findings of Fai et al. [31] on the Benoe and Ndongo streams which are located within the same agro-ecological zone in Cameroon and are subjected to similar anthropogenic pressure. Dissolved oxygen was lowest (4.67 mg/L) at Site 2 and highest (5.17 mg/L) at Site 5. The dissolved oxygen was much lower than the range expected for freshwater within the measured water temperature. At temperatures of 20–30 °C, the expected DO levels are 9 – 7 mg/L respectively, with DO expected to decrease as water temperature increases. This could be attributed to the increased kinetic energy of water molecules as the temperature rises, which causes oxygen to readily escape from water into the air. Chlorophyll a concentration ranged from 1.2 μg/L at

https://doi.org/10.58985/jesec.2025.v01i03.12

Table 5. Physico-chemical characteristics of the water across sites in the study area.

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	WHO (2006)
Temperature (°C)	21.14	21.2	22.12	21.17	22.44	22.46	<40
pH	6.63	6.52	7.07	7.17	7.53	7.41	6.5 – 9.5
ORP (mV)	139.7	134.17	119.63	109.2	107.6	100.3	__
EC (µS/cm)	229	152.33	223.67	209.3	203	213	500
TDS (ppm)	114.67	76	112	104.3	101.7	106.3	250
Salinity (psu)	0.11	0.07	0.11	0.1	0.1	0.1	__
Dissolved oxygen (ppm)	4.88	4.67	4.86	4.81	5.17	5.02	__
Turbidity (NTU)	53.9	18.57	26.53	22.87	36.5	47.03	< 70
Flow rates (m/s)	0	0	0.67	0.29	1	1	__
TSS (ppm)	0.021	0.017	0.05	0.037	0.043	0.32	__
Chlorophyll a (µg/L)	4.4	1.2	35.57	19.98	17.59	41.97	__
Nitrates(mg/L)	23.24	44.48	3.68	68.01	45.34	42.01	10
Phosphates(mg/L	3.3	3.02	1.13	2.03	1.67	2.57	<5
Ammonium(mg/L)	2.9	3.48	6.15	3.21	6.45	4.06	<0.5

Site 2 to 41.97 µg/L at Site 6, with the concentrations at Sites 3, 4, 5 and 6 exceeding the threshold of 10 µg/L, which is indicative of phytoplankton blooms at these sites. Except for Site 3 (3.68 mg/L), the nitrate concentrations were higher than the WHO (2006) threshold for drinking water. While phosphate concentrations ranged from 1.13 to 3.3 mg/L and were within the WHO (2006) limits, concentrations of ammonium (2.9 to 6.45 mg/L) were well above the WHO (2006) limits. Low levels of DO in water track levels of chlorophyll a that indicate bloom concentrations of phytoplankton, as well as higher-than-acceptable levels of nitrates and ammonia. This suggests the disposal of organic waste into the stream [32]. Similar findings were made by Zia et al. [33] in Nwaorie river, Owerri (Nigeria), where low DO levels (6.9-7.4 mg/L) were associated with the disposal of untreated organic waste around the river's vicinity. Typically, the decomposition of organic waste in water exerts a high oxygen demand, which depletes DO levels in the water column.

Fig. 4 presents an ordination plot showing the spatial association of the physicochemical parameters measured in the water samples across sites with the associated land uses. Agriculture and construction were the main land uses responsible for the observed trends in the physicochemical parameters of water. There was a strong association between these land uses and nutrients (nitrates, phosphates and

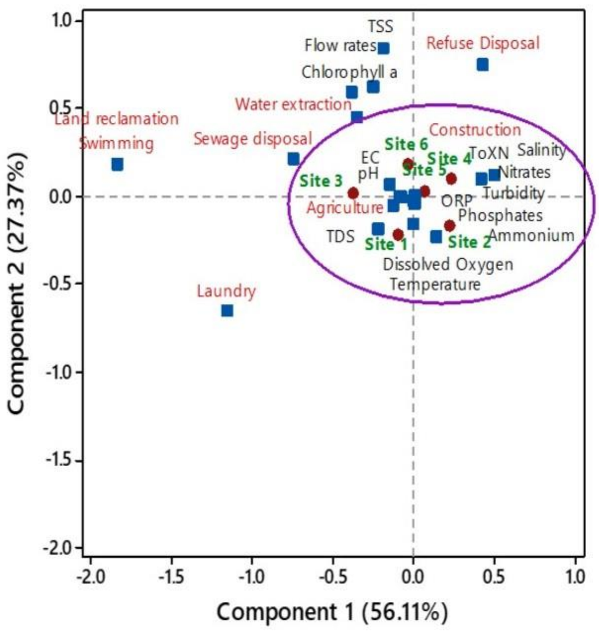

Figure 4. Ordination plot showing the association of physicochemical parameters of the water column with the different land uses in the Bwitingi Bwiteva water course.

ammonium), as well as salinity, turbidity and water pH. These were all strongly associated with different sites. This strongly indicates the impact of anthropogenic activities on water quality. In this case, agriculture and construction of settlements lead to the discharge of nutrients, agrochemicals and other organic wastes associated with human settlements along the Bwitingi-Bwiteva watercourse, altering the physicochemical characteristics. This is consistent with the findings of Zeid et al., [34] who found that

https://doi.org/10.58985/jesec.2025.v01i03.12

Table 6. Bacteria load of water samples from sampling sites in Bwintingi-Bwiteva.

Sites	Total bacteria CFU/mL	*Escherichia coli* CFU/ mL	*Salmonella* sp. CFU/ mL	*Shigella* sp. CFU/ mL	Conclusion
Site 1	12	0	0	0	Low pollution,
Site 2	23	0	0	0	No faecal contamination
Site 3	3633	513	27	77	
Site 4	3730	483	33	98	Pollution with faecal
Site 5	4493	1517	45	96	contamination
Site 6	5510	1631	544	110	

agriculture and urban development are key drivers of poor water quality in rivers. Similar findings have been reported in a review by Khan et al. [35]. Land reclamation, water abstraction, swimming, refuse disposal, sewage disposal and laundry contributed less to the observed physicochemical characteristics of water samples across sites.

3.4. Bacteria load of water samples from Sites along the Bwitingi-Bwiteva water course

Anthropogenic contaminants can also be tracked by the bacterial picture, and our results (Table 6) show a strong indication of fecal contamination of the watercourse. Apart from the sites within and close to the source of the stream (Sites 1 and 2), the remaining sites were heavily contaminated with bacteria. While total bacterial counts in Sites 1 and 2 were 12 CFU and 23 CFU, respectively, with no *E. coli*, *Salmonella* sp. or *Shigella* sp., total bacterial counts in the rest of the sites ranged from 3633 CFU in Site 3, with *E. coli*, *Salmonella* sp. and *Shigella* sp. measuring 513, 27 and 77 CFU, respectively, to 5510 CFU for total bacteria counts in Site 6, with *E. coli*, *Salmonella* sp and *Shigella* sp. measuring 1631, 544 and 110 CFU respectively. *Escherichia coli* and other enteric bacteria have been shown to be strong indicators of contamination with vertebrate faeces [36] and species of *Salmonella* and *Shigella* are highly pathogenic, causing a wide variety of diseases if ingested [37, 38]. So far, conservation measures at the catchment (Sites 1 and 2) have been effective in preventing this level of contamination, but care needs to be taken to prevent downstream pressures from overwhelming the catchment.

3.5. Phytoplankton diversity, distribution and abundance

The aesthetics of a water body and sometimes its health quality are often a consequence of the phytoplankton community structure. A total of 44 phytoplankton species belonging to 9 divisions, ten (10) classes and 39 families were identified along the watercourse in the study area. The most abundant division was Bacillariophyta, with 19 species. Bacillariophyta have a great potential to survive in polluted and contaminated water bodies and they undergo endosymbiotic events between red algae and heterotrophic flagellates [39]. Fonge, et al. [40] assessed phytoplankton diversity and abundance in water bodies affected by anthropogenic activities within Buea and diatoms were the most abundant and diverse group of phytoplankton. Similar findings were recorded by Prasertphon et al. [41] in the phytoplankton community structure of streams flowing through an agro-plantation in Tiko, Cameroon.

The second most abundant divisions were Cyanophyta and Chlorophyta, which had the same number of species (6). Cryptophyta, Xanthophyta, Chrysophyta and Charophyta were the least represented divisions with only one species each. With respect to species, the most abundant were *Nitzchia sp*. (8.4%), *Euglena sp*. and *Achnanthidium sp.* (7.2%) while the least abundant species were *Amphipleura sp.* (0.3%)., *Cladophora sp* (0.3%)., *Pediastrum sp*. (0.3%). and *Strombomonas sp*. (0.3%). The most frequent family was Euglenaceae with four species followed by Tabellariaceae with two species. Species such as *Amphipleura sp., Anabaena sp., Cladophora sp., Nostoc sp., Pediastrum sp., Pleurosigma sp., Selenastrum sp., Strombomonas sp., Tetraspora sp.* and *Tracheolomonas sp*. were found only at one site (Site 6) (Fig. 5). Therefore, the phytoplankton community structure in this study was dominated by

https://doi.org/10.58985/jesec.2025.v01i03.12

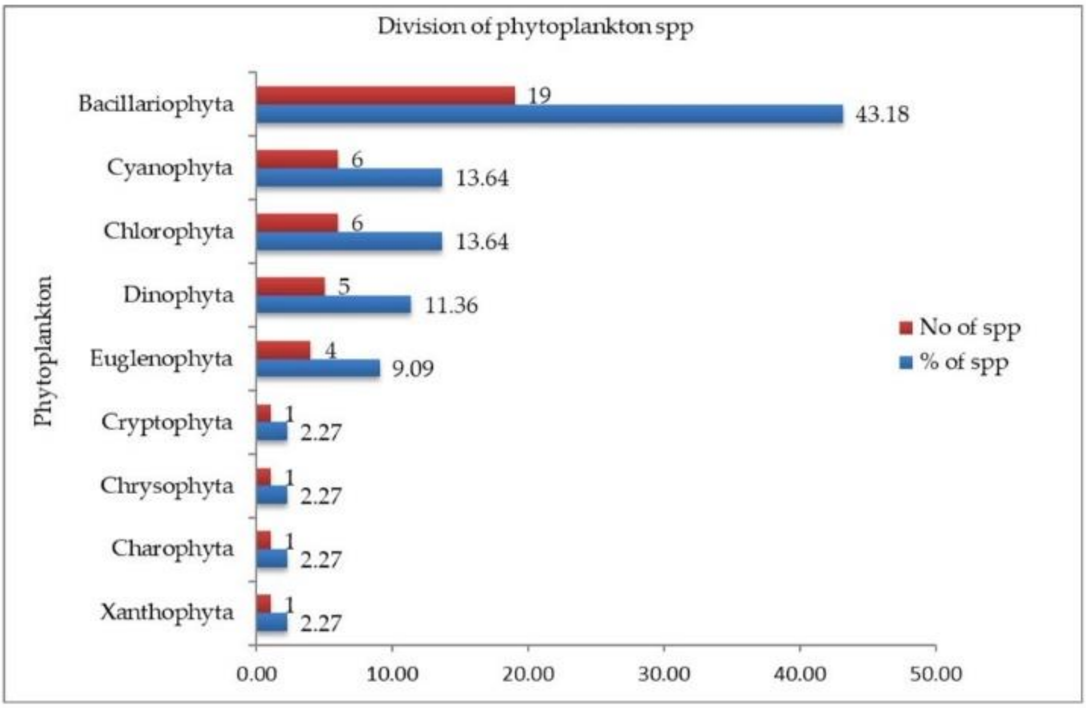

Figure 5. Phytoplankton distribution in the Bwitingi-Bwiteva water course.

Table 7. Phytoplankton community structure and trophic status of different sites in Bwintingi-Bwiteva.

Sites	Diversity	Species richness	Evenness	abundance/L	Euglenophycean index	Trophic status
Site 1	0.22	0.79	0.16	40000	2.0	Oligotrophic
Site 2	0.32	2.10	0.15	81000	1.0	Mesotrophic
Site 3	0.35	5.45	0.11	300000	0.3	Eutrophic
Site 4	0.35	2.89	0.14	137000	0.5	Eutrophic
Site 5	0.36	3.42	0.14	167000	0.2	Eutrophic
Site 6	0.18	9.19	0.05	380000	0.3	Eutrophic

species that thrive in polluted water. This was evident in the diversity and abundance across sites.

3.6. Phytoplankton diversity and trophic status across sites

The phytoplankton species richness, evenness, and abundance along the watercourse are presented in Table 7. Species diversity was low at all sites. Although, Site 6 had the lowest diversity (0.18), it was the most species-rich (9.19) with the highest phytoplankton abundance (380000 /L). Site 1 had the lowest species richness (0.79) with the fewest phytoplankton per litre (40000/L). Sites 1 and 2 were oligotrophic and mesotrophic, respectively, while the rest of the sites were eutrophic. Sorensen Similarity indices showed that Sites 3 and 6 were the most similar (similarity index = 0.62), as they shared similar species, while Sites 1 and 6 are the least similar (similarity index = 0.10). Sites that had more anthropogenic activities were richer in phytoplankton especially members of the Bacillariophyta and Euglenophyta, thereby rendering the waters at these sites eutrophic. As reported by Bibi et al. [42], such eutrophication is driven by nutrient inputs and results not only in degraded aesthetics but also in harmful algal blooms.

The results of the correlation (Table 8) show that there were no physicochemical drivers of the phytoplankton community structure at the sites studied along the Bwitingi-Bwiteva watercourse. pH

Table 8. Reduced correlation table showing relationships between physiochemical drivers and phytoplankton and bacterial community characteristics in Bwintingi-Bwiteva.

	pH	DO	Flow rates	Chla	Species richness	Abundance	Total bacteria	*E. coli*	*Salmonella*
DO	0.824 0.044								
Flow rates	0.925 0.008	0.827 0.042							
Chla	0.709 0.114	0.425 0.401	0.785 0.064						
Species richness	0.631 0.179	0.390 0.444	0.773 0.072	0.921 0.009					
Abundance	0.652 0.160	0.397 0.435	0.800 0.056	0.969 0.001	0.975 0.001				
Total bacteria	0.958 0.003	0.672 0.144	0.914 0.011	0.863 0.027	0.790 0.061	0.814 0.049			
E. coli	0.927 0.008	0.856 0.030	0.951 0.004	0.676 0.141	0.735 0.096	0.700 0.122	0.887 0.019		
Salmonella sp.	0.500 0.312	0.389 0.446	0.597 0.210	0.698 0.123	0.881 0.020	0.765 0.076	0.616 0.193	0.696 0.125	
Shigella sp.	0.946 0.004	0.610 0.199	0.842 0.036	0.814 0.049	0.704 0.119	0.734 0.096	0.985 0.000	0.821 0.045	0.524 0.286

Values in the top cell represent r, the Pearson Product moment correlation coefficient; values in the bottom cell represent p – values, the level of significance. Correlations exist where $p < 0.05$.

correlated positively with total bacterial count ($r = 0.958$, $p = 0.003$), *E. coli* count ($r = 0.927$, $p = 0.008$) and *Shigella* count ($r = 0.946$, $p = 0.004$). There was a strong positive correlation between the dissolved oxygen concentrations and *E. coli* counts. Stream flow correlated positively with total bacterial count ($r = 0.914$, $p = 0.011$), *E. coli* count ($r = 0.951$, $p = 0.004$) and *Shigella* sp. counts ($r = 0.842$, $p = 0.036$). A significant positive correlation was also observed between phytoplankton species richness and chlorophyll a concentration ($r = 0.921$, $p = 0.009$), which was expected. These results strongly suggest that the observed phytoplankton structure and related water quality are a direct result of anthropogenic pollution. *Escherichia coli* and other enteric bacteria are indicative of vertebrate fecal pollution [43, 44]. Its presence in unprotected sites coupled with human habitats and agriculture in the vicinity, shows that these activities are responsible for the poor water quality observed at these sites. The implications are that downstream users are exposed to poor quality water, with significant health implications. Such polluted waters are typically treated as waste, contributing to water insufficiency in an area endowed with a significant number of freshwater streams.

4. Conclusions

The Bwitingi-Bwiteva watercourse is well protected at the source, but is exposed to anthropogenic activities downstream. These activities degrade plant diversity, alter phytoplankton communities, introduce pathogenic bacteria into the water and degrade the ecosystem services it can provide overall. There were two main land uses that dominated the study area which were agriculture and construction (settlements) with diverse extensions into the watercourse. Improperly managed agricultural activities along the Bwiteva- Bwitingi water course have impaired water quality, influencing physicochemical properties, bacteriological parameters, plant and phytoplankton community structure. This study has revealed that settlements close to the Bwiteva- Bwitingi water course exposed the stream to fecal contamination, which could have public health implications. The

https://doi.org/10.58985/jesec.2025.v01i03.12

structural simplification of riparian vegetation at some sites/complete disappearance of vegetation in other sites could lead to the complete destruction of the delicate ecological balance between nutrient influx and removal mediated by natural wetland vegetation, thereby causing pollution, eutrophication and ecosystem damage. Very low phytoplankton diversity was recorded during the study. The Shannon Diversity Index ranged from 0.18 to 0.36, with Bacillariophyta recorded as the most dominant taxon. Due to the intensity of anthropogenic activities along the stream, most of the natural aquatic plant species have been cleared for construction and agricultural purposes, leading to a higher diversity of agricultural crops than natural wetland vegetation.

It is recommended that a landscape approach be used in the management of the Bwintingi-Bwiteva watercourse. It is a holistic approach that moves beyond treating streams as isolated ecosystems but views them as integral parts of a larger interconnected landscape which involves the entire watershed, including both natural and human factors to improve health and biodiversity. A proper landscape planning is necessary in the Buea municipality to ensure that land use and development activities are compatible with the ecological integrity of the numerous streams and their watersheds. If this is done, the resultant effect will be improved stream and watershed health, enhanced ecosystem services, and sustainable land use and development. Finally, given the dynamic nature of the Bwitingi-Bwiteva landscape, continuous monitoring is recommended for effective management.

Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

All authors designed the study and agreed on the study design, Authors FQM and MEA collected the samples and processed them; LH did the laboratory analyses; PTT did the statistical analyses; FBA, PTT, FQM and MEA drafted the manuscript; all authors read, edited and approved the manuscript.

Acknowledgements

The authors are sincerely grateful to the Bwiteva and Bwitingi communities for providing access to the watercourse, and the laboratory technicians for sample analyses.

Funding

Funding for this research was partly from personal funds provided by Fru Queenzabel, and partly from the Research Modernization Allowance of the Ministry of Higher Education granted to Fonge Beatrice and Pascal Tabot. Water quality analyses were sponsored by grants from Lucienne Human.

Availability of data and materials

The data used to support the findings of this study can be obtained from the corresponding author upon request.

Conflicts of interest

The authors declare that there is no conflict of interest

References

1. Wolfensohn, K.J.; Lash, J. Freshwater systems. World Resour. J. 2000, 103–18. https://doi.org/10.1016/b978-008043781-1/50006-2
2. Fitzhugh, T.W.; Brian, D.R.: Quenching Urban Thirst: Growing Cities and Their Impacts on Freshwater Ecosystems. Biosci. 2004, 54(8), 741. https://doi.org/10.1641/0006-3568
3. Paul, M.J.; Meyer, J.L. Streams in the Urban Landscape. Annu. Rev. Ecol. Evol. Syst. 2001, 32(1), 333–365. https://doi.org/10.1146/annurev.ecolsys.32.081501.114040
4. McDonald, R.I.; Green, P.; Balk, D.; Fekete, B.M.; Revenga, C.; Todd, M.; Montgomery, M. Urban growth, climate change, and freshwater availability. Proceed. Nat. Acad. Sci. 2011, 108(15), 6312–6317. https://doi.org/10.1073/pnas.1011615108
5. Schipper, A.M.; Zeefat, R.; Tanneberger, F.; Van Zuidam, J.P.; Hahne, W.; Schep, S.A.; Loos, S.; Bleuten, W.; Joosten, H.; Lapshina, E.D.; Wassen, M. J.: Vegetation characteristics and eco-hydrological processes in a pristine mire in the Ob River valley (Western Siberia). Plant Ecol. 2007, 193(1), 131–145. https://doi.org/10.1007/s11258-006-9253-x
6. Gagneten, A.M.: Effects of contamination by heavy

https://doi.org/10.58985/jesec.2025.v01i03.12

metals and eutrophication on zooplankton, and their possible effects on the trophic webs of freshwater aquatic ecosystems. Book Chapter 'Eutrophication: Causes, Consequences and Control'. Springer Nature, 211–23, 2010. https://doi.org/10.1007/978-90-481-9625-8_10
7. Yang, J.R.; Xiaoqing, Y.; Huihuang, C.; Yi-Ming, K.; Jun, Y. Structural and functional variations of phytoplankton communities in the face of multiple disturbances. J. Environ. Sci. 2021, 100, 287–97. https://doi.org/10.1016/j.jes.2020.07.026
8. Khatri, N.; Sanjiv, T. Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. Front. Life Sci. 2014, 8(1), 23–39. https://doi.org/10.1080/21553769.2014.933716
9. Staley, C.; Reckhow, K.H.; Lukasik, J.; Harwood, V.J. Assessment of sources of human pathogens and fecal contamination in a Florida freshwater lake. Water Res. 2012, 46(17), 5799–812. http://dx.doi.org/10.1016/j.watres.2012.08.012
10. Grizzetti, B.; Pistocchi, A.; Liquete, C.; Udias, A.; Bouraoui, F.; Bund, W. Human pressures and ecological status of European rivers. Sci. Rep. 2017, 7. http://dx.doi.org/10.1038/s41598-017-00324-3
11. Bermúdez, X.; Valero, E.; Bessa, S.R.; Varandas, S.; Sanches, L.; Pacheco, F. Anthropogenic nutrients and eutrophication in multiple land use watersheds: Best management practices and policies for the protection of water resources. LUP 2017, 69, 1-11. http://dx.doi.org/10.1016/j.landusepol.2017.08.028
12. Gao, C.; Taolin, Z. Eutrophication in a Chinese context: Understanding various physical and socio-economic aspects. AMBIO. 2010, 39(5–6), 385–93. https://doi.org/10.1007/s13280-010-0040-5
13. Mustapha, A.; Aris, A.Z.; Ramli, M.F.; Juahir, H. Spatial-temporal variation of surface water quality in the downstream region of the Jakara River, north-western Nigeria: A statistical approach. J. Environ. Sci. Health. 2012, 47(11), 1551–60. http://dx.doi.org/10.1080/10934529.2012.680415
14. Kolawole, O.M.; Ajayi, K.T.; Olayemi, A.B.; Okoh, A.I. Assessment of water quality in Asa river (Nigeria) and its indigenous *Clarias gariepinus* fish. IJERPH. 2011, 8(11), 4332–52. http://dx.doi.org/10.3390/ijerph8114332
15. Djuikom, E.; Jugnia, L.B.; Nola, M.; Foto, S.; Sikati, V. Physicochemical water quality of the Mfoundi River watershed at Yaoundé, Cameroon, and its relevance to the distribution of bacterial indicators of faecal contamination. Water Sci. Technol. 2009, 60, 2841–9. http://dx.doi.org/10.2166/wst.2009.702
16. Bellinger E.G.; David, C. Sigee: Freshwater Algae, 2010. https://doi.org/10.1002/9780470689554
17. Talling, J.F. Comparative problems of phytoplankton production and photosynthetic productivity in a tropical and a temperate lake. Primary Productivity in Aquatic Environments, December 31, 1966, 399–424. https://doi.org/10.1525/9780520318182-029
18. Gray, N.F. Water quality assessment. Water Technol. 2005, 193–254. https://doi.org/10.1016/b978-075066633-6/50010-9
19. Margalef, R. Temporal succession and spatial heterogeneity in phytoplankton. Perspect. Mar. Biol. 1958, 323–50. https://doi.org/10.1525/9780520350281-024
20. WHO. Appendix 2 World Health Organization Drinking Water Guidelines. Water Wells and Boreholes, 2006, 463–68. https://doi.org/10.1002/0470031344.app2.
21. McCartney, M.; Rebelo, L.M.; Sellamuttu, S.S.; de Silva, S. Wetlands, agriculture and poverty reduction. IWMI. 2010. https://doi.org/10.5337/2010.230
22. Hughes, R.M.; Robert, L.V. Agricultural effects on streams and rivers: A western USA focus. Water. 2021, 13(14), 1901. https://doi.org/10.3390/w13141901
23. Gqomfa, B.; Thabang, M.; Karabo, S. The impact of informal settlement on water quality of Diep river in Dunoon. Sustain. Water Resour. Manag. 2022, 8(1). https://doi.org/10.1007/s40899-022-00629-w
24. Gbarabe, F.O.; Akue, L.A.; Frederick, A. Socio-spatial implications of sustainable cultural tourism in ikwerre local government area, Rivers State, Nigeria. IJRPR. 2024, 5(5) 11942–50. https://doi.org/10.55248/gengpi.5.0524.1422
25. Fusi, M.; Gian, M.B.; Nicoleta, A.S.; Angela, S.; Marco, T.; Ettore, C.; Daniele, D.; Ndongo, Din, Dahdouh-Guebas, F.; Cannicci, S. Ecological status and sources of anthropogenic contaminants in mangroves of the Wouri River Estuary (Cameroon). Mar. Pollut. Bull. 2016, 109, 2, 723–33. https://doi.org/10.1016/j.marpolbul.2016.06.104
26. Issii, T.M.; Amanda, C.R.; Erico, F.L.; Pereira-Silva, M.R.A.; Elisa, H. The role of legal protection in forest conservation in an urban matrix. Land Use Policy. 2020, 91, 104366. https://doi.org/10.1016/j.landusepol.2019.104366
27. Riar Mandeep, K.; Danesha, S.C.; Chenxi Zhang, M.S.; Schroeder-Moreno, D.L.J.; Theodore, M.W.; Thomas, W.R.: Environmental influences on growth and reproduction of invasive *Commelina benghalensis*. Int. J. Agron. 2016, 1–9. https://doi.org/10.1155/2016/5679249
28. McLaughlin, A.; Mineau, P. The impact of agricultural practices on biodiversity. Agric. Ecosyst. Environ. 1995, 55(3), 201–12. https://doi.org/10.1016/0167-8809(95)00609-v
29. Akhalkatsi, M.; Otte, A.; Togonidze, N.; Bragvadze, T.;

Asanidze, Z.; Arabuli, G.; khelidze, N.C.; Mazanishvili, L. Agrobiodiversity and genetic erosion of crop varieties and plant resources in the central great Caucasus. Ann. Agrar. Sci. 2017, 15(1), 11–16. https://doi.org/10.1016/j.aasci.2016.12.002
30. José-María, L.; Armengot, L.M.; Blanco-Moreno, M.B.; Xavier Sans, F. Effects of agricultural intensification on plant diversity in mediterranean Dryland Cereal fields. J. Appl. Ecol. 2010, 47, 4, 832–40. https://doi.org/10.1111/j.1365-2664.2010.01822.x
31. Fai, P.B.A.; Kenko, D.B.N.; Tchamadeu, N.N.; Mbida, M.; Korejs, K.; Riegert, J.: Use of multivariate analysis to identify phytoplankton bioindicators of stream water quality in the monomodal equatorial agroecological zone of Cameroon. Environ. Monit. Assess. 2023, 195(6). http://dx.doi.org/10.1007/s10661-023-11390-8
32. Acholonu, C.E.; Diagi, B.; Nwufo, R.S.; Ekweogu, C.; Justin, N.O.; Chijioke, U. Solid waste disposal: A potential threat to aquatic environment. Arch. Curr. Res. Int. 2023, 23, (6), 22–32. https://doi.org/10.9734/acri/2023/v23i6577
33. Zia, H.; Nick, R.H.; Geoff, V.M.; Mark, R.; Neil, C. The impact of Agricultural activities on water quality: A case for collaborative catchment-scale management using integrated wireless sensor networks. Comp. Electron. Agric. 2013, 96, 126–38. https://doi.org/10.1016/j.compag.2013.05.001
34. Zeid, M.A.; Asit, K.B.: Impacts of agriculture on water quality. Water Int. 1990, 15 (3), 160–67. https://doi.org/10.1080/02508069008687133
35. Khan, F.M.; Rajiv, G. *Escherichia coli* (E. Coli) as an indicator of fecal contamination in groundwater: A Review. Sust. Dev. Water Environ. 2020, 225–35. https://doi.org/10.1007/978-3-030-45263-6_21
36. Threlfall, E. Antimicrobial drug resistance in salmonella: Problems and perspectives in food- and water-borne infections. FEMS Microbiol. Rev. 2002, 26, 2, 141–48. https://doi.org/10.1016/s0168-6445(02)00092-x
37. Mahagamage, M.G.Y.L.; Pathirage, M.V.S.C.; Pathmalal, M.M. Contamination status of *Salmonella Spp*., *Shigella Spp*. and *Campylobacter Spp.* in surface and groundwater of the Kelani River Basin, Sri Lanka. Water. 2020, 12(8), 2187. https://doi.org/10.3390/w12082187
38. Guțu, N.; Postolachi, O.; Zariciuc, E. Enterobacteria from the genera *Salmonella* and *Shigella* with an etiological role in acute diarrheal diseases, Acta et Commentationes Ştiinţe Exacte Şi Ale Naturii. 2023, 15 (1), 51–58. https://doi.org/10.36120/2587-3644.v15i1.51-58
39. Anyinkeng, N.; Mih, A.M.; Tening, A. S.; Che, C.A. Phytoplankton diversity and abundance in water bodies as affected by anthropogenic activities within the Buea municipality, Cameroon. J. Ecol. Nat. 2016, 8(7), 99–114. https://doi.org/10.5897/jene2016.0566
40. Fonge, B.A.; Tabot, P.T.; Mumbang, C.; Chop, A.M.; Water quality and phytoplankton community structure in mangrove streams under different logging regimes in Cameroon. Afr. J. Ecol. 2015, 54(1), 39–48. https://doi.org/10.1111/aje.12256
41. Prasertphon, R.; Jitchum, P.; Chaichana, R. Water chemistry, phytoplankton diversity and severe eutrophication with detection of microcystin contents in Thai tropical urban ponds. Appl. Ecol. Environ. Res. 2020, 18, (4), 5939–51. https://doi.org/10.15666/aeer/1804_59395951
42. Akoachere, JF.T.K.; Bughe, R.N.; Oben, B.O.; Ndip, L.M.; Ndip, R.N. Phenotypic characterization of human pathogenic bacteria in fish from the coastal waters of southwest Cameroon: Public health implications. REVEH. 2009, 24, 2. https://doi.org/10.1515/reveh.2009.24.2.147
43. Bibi, F.; Shafqat, N.Q.; Mazhar, A.; Mudasser, N.; Atif, N.A.; Mian, M.A.; Bushra, N.K.; Masood, A. Occurrence of endoparasites in some selected fishes of Chenab River, Pakistan. Bangladesh J. Zool. 2018, 46(1), 53–61.
44. Patel, H.; Vashi, R.T. Characterization of Textile Wastewater (Chapter 2). Characterization and Treatment of Textile Wastewater, pp.21–71, 2015. https://doi.org/10.1016/b978-0-12-802326-6.00002-2
45. Khatri, N.; Sanjiv, T. Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. Front. Life Sci. 2014, 8(1), 23–39. https://doi.org/10.1080/21553769.2014.933716
46. Awo, M.; Fonge, B.; Tabot, P.; Akoachere, J. Water quality of the volcanic crater lake, Lake Barombi Kotto, in Cameroon. Afr. J. Aquat. Sci. 2020, 45(4), 401–11. http://dx.doi.org/10.2989/16085914.2020.1737799
47. Kenko, D.B.N.; Ngameni, N.T.; Awo, M.E.; Njikam, N.A.; Dzemo, W.D. Does pesticide use in agriculture present a risk to the terrestrial biota? Sci. Total Environ. 2023, 861, 160715. http://dx.doi.org/10.1016/j.scitotenv.2022.160715
48. Kenko, N.D.B.; Fotio, A.L.; Kenfack, A.D.; Tasse, T.G.C.; Acha, D.A.; Fokam, E.B. Ecological risk assessment of pesticides based on earthworms in soils on the southeast slopes of mount Cameroon. SHE, 2023, 1(4), 100047. http://dx.doi.org/10.1016/j.seh.2023.100047