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Effect of Effluents Produced from Palm oil Processing Industries on Fish Production around Bugala Island, Kalangala District, Uganda

Adrian Kavuma [a] and Alex Barakagira [a,b*]

[a] School of Sciences, Nkumba University, P.O. Box 273, Entebbe, Uganda.
[b] Faculty of Science, Kyambogo University, P.O. Box 1, Kyambogo, Kampala, Uganda.

Authors' contributions

This work was carried out in collaboration between both authors. Author AK formulated study title and objectives, searched for related literature, designed the methodology, collected data and analyzed the data. Author AB formulated the title of the study and objectives, searched for related literature, analyzed the collected data, discussed the findings, typeset and proof read the entire manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

Oil palm *(Elaeis guineensis),* a tree crop that originated from Central and West Africa is primarily planted in tropical regions, mainly in deep soils and humid climatic areas around lakes and wetlands. This has encouraged the setting up of the oil processing industries near or within such highly fragile ecosystems. The study was set out to investigate the impact of effluent discharge from palm oil processing industries on water quality and fish yield in Bugala Island, Kalangala District, Uganda. The research aimed to determine the extent of pollution and its consequences on key water quality parameters, heavy metal concentrations, and fish populations. To achieve these

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**Corresponding author: E-mail: barakalexham2@gmail.com;*

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objectives, the study employed a mixed-methods approach, integrating quantitative analysis of water samples and fish yields with qualitative data from interviews and surveys. Water quality indicators, including turbidity, pH, temperature, salinity, and dissolved oxygen (DO), were measured across control and experimental sites, alongside the concentrations of heavy metals such as cadmium, lead, and mercury. The study utilized one-way ANOVA and Kruskal-Wallis tests to assess the statistical significance of differences between sites. The results indicated significant variations in turbidity, pH, salinity, and DO levels, particularly in areas affected by effluent discharge, while temperature and heavy metal concentrations did not show statistically significant differences. Fish yield analysis revealed significant disparities in the quantity, average weight, and length of fish species, with *Oreochromis niloticus* demonstrating the highest mean weight and length in less polluted areas. The findings underscore the urgent need for stricter environmental regulations and the implementation of advanced effluent treatment technologies. Continuous environmental monitoring is also recommended to mitigate the adverse effects of industrial pollution on aquatic ecosystems and to safeguard the livelihoods of communities dependent on these resources.

Keywords: Industrial effluents; fish production; water quality; Kalangala; Uganda.

1. INTRODUCTION

Oil palm *(Elaeis guineensis),* a tree crop that originated from Central-West Africa is primarily planted in tropical regions (Murphy, 2021). Deep soil and a humid climate around lakes and wetlands, together with elevated temperatures all year round are essentials for the crops to flourish (Barakagira et al., 2017, Barakagira and de Wit, 2019, Barakagira and Kateyo, 2006). Large plantations of the oil palm are used to produce vegetable oil (Surya, 2023). Palm oil is utilized in a variety of goods, including packaged goods, fast food, and cosmetics (Voora, 2023). Oil palm is the leading source of vegetable oil in the world compared to other oil seeds with an annual production of over 50 million tons accounting for 39% of global annual vegetable oil production (Vivek, 2019). Due to its great economic worth, ease of establishment, low production costs, and high yield, oil palm is regarded as a good crop to grow for business (Lemessa et al., 2023). Commercial oil palm cultivation in Uganda was introduced in 1998 through a Vegetable Oil Development Project spearheaded by the government in an innovative public-private-producer-partnership involving a smallholder model in the district of Kalangala. The project has helped to reduce the high poverty rates that existed before the introduction of commercial oil palm production in the then fishing district (Otuba Moses Amugoli, 2022). By minimizing the nation's reliance on imported oils, palm oil has improved food consumption and health standards by providing a conveniently available source of vegetable oil (Otuba, 2022). Financially, the production of palm oil has also raised the social standards of large numbers of workers in oil palm plantations for the smallholder farmers. Many people in the value chain receive monthly payments from the sale of ripe bunches, while the others work for individuals who own large palm fields (Otuba, 2022). Currently, over 5000 people in Kalangala receive regular and reliable monthly payments from the fresh fruit bunch sales as a result of high productivity of the oil palms (Ssemmanda, 2019). Improved infrastructure and service delivery in the production and adjacent areas as a result of investments in oil palm cultivation have directly boosted local economies and increased tourism in numerous locations near Lake Victoria (Mbago-Bhunu, 2021–2027). In terms of nutrition, palm oil is the richest source of dietary pro-vitamin A, vitamin E (30% tocopherols, 70% tocotrienols), vitamin K, carotenoids, and dietary magnesium. Palm oil has an effect of reducing total blood cholesterol and “bad” low-density lipoprotein (HDL)-cholesterol and increases the amount of “good” high-density lipoprotein-cholesterol (Ong, 2002).

The various waste products produced by the extraction and purification procedures of oil palm are collectively referred to as palm oil mill effluent (POME). It is imperative to take remedial steps to lessen the environmental effects of POME before discharging them since their effects cannot be overestimated. Therefore, POME treatment is required in order to comply with increasingly strict environmental requirements and to maintain a friendly, healthy, and pollution-free environment(Kamyab, 2018).

Sterilization, stripping, digesting and pressing, clarifying, separating the fiber and nuts, oil

extraction, and purifying are all steps in the wet extraction process for crude palm oil (CPO). The main product that POMEs produce is the CPO. The most important liquid by-product is POME, whereas the solid leftovers are palm kernels (PKs), shells, and fibers. Decanter cakes and empty fruit brunches (EFB) are categorized as waste as well. PK oil is produced during the PK pressing process in some POMs (Ehsan, 2015).
Industrial pollutants have been documented worldwide to have significant effects on water quality and fish yields(Lemessa, et al. 2023). This issue has garnered attention globally, with studies highlighting the detrimental impacts of industrial activities on aquatic ecosystems and fisheries (Murphy, 2021). Lake Erie for example, which is found in North America shared by the United States and Canada has been impacted by Industrial pollution, particularly effluent waste which contributed to harmful algal blooms. These blooms depleted oxygen levels in the water, creating dead zones where fish cannot survive, thus reducing fish yields (David, et al., 2012). The pollutants are believed to disrupt freshwater ecosystems, choking habitats and diminishing biodiversity hampering reproductive capabilities of aquatic organisms, threatening their survival and overall health of the ecosystem (Pule, et al. 2022, Lemessa et al., 2023). Similar concerns have been raised from the East African region, particularly in areas with a high concentration of industrial activities near water bodies (Mora et al., 2008).

In Uganda, the presence of industries, including palm oil processing industries on islands such as Bugala Island in Kalangala District, raises concerns about the quality of water and its potential impact on fish production. These industries discharge effluents into surrounding water bodies, which may contain pollutants that could disrupt the natural balance of the ecosystem and harm fish populations vital to local economies (Ssemmanda, 2019). Understanding the effects of industrial pollutants on water quality and fish production in Bugala Island is crucial for informing conservation efforts and sustainable development initiatives in the region. Therefore, the current study focused on the extent to which effluent pollution from palm oil processing industries affected the water quality of the surrounding waters and its consequences on fish production. Hence, the study sought to: determine the physico-chemical parameters of water quality in areas affected by effluent discharge compared to control sites; determine the heavy metal concentrations in areas affected by effluent discharge; and to determine the density and diversity of fish yields around Bugala Islands, Kalangala district. The results from the study were envisaged to provide valuable insights to local authorities and key stakeholders aimed at developing effective mitigation strategies against possible environmental degradation.

2. MATERIALS AND METHODS

The study set out to examine the impact of effluent pollution from palm oil processing factories on fish production in Bugala Island, Kalangala District, Uganda (Fig. 1). A descriptive and experimental research design was employed to carry out the study. A mixed methods approach was employed, integrating both quantitative and qualitative approaches to provide a comprehensive understanding of the effects of industrial pollutants on the aquatic ecosystem. Quantitative data was gathered through precise measurements of water parameters and fish yields, while qualitative insights were obtained from interviews and discussions with some key informants like the local leaders, environmental experts, and key community members.

Bugala Island, the study area is a key ecological site in Lake Victoria which was selected due to its proximity to palm oil factories that discharge effluent into the surrounding waters. Water and fish samples were systematically collected from effluent discharge points, areas near the factories, and control sites away from industrial activity, allowing for a comparative analysis of water quality and fish population health across impacted and non-impacted zones. The quantitative design included precise measurement, and numerical data to describe, predict, or determine the cause-and-effect relationships. An experimental design (with a controlled experiment) was used to determine the effect of effluent pollution on fish population (Newman et al., 1998). Fish have been widely documented as indicators of water quality because of their sensitivity to pollution (Mora et al. 2003, Mora et al., 2008, Gratwicke, Gratwicke 2004, Gratwicke, 2005, Mora, 2005, Sekiranda, 2006, Das, 2007). Estimating the number of species from a particular area remains a fundamental theme of ecology. Species diversity is related to the functioning of ecological systems and helps understand the mechanisms and effects of environmental disturbances such as pollution (McGill, et al., 2007, Tokeshi and

Arakaki, 2007, Mora et al., 2008). Estimation of species diversity is also useful for detecting trends, impacts, or recovery of ecosystems, and quantification of extinction risks and thus prioritization of conservation of biodiversity hot-spot areas (Mora et al. 2008).

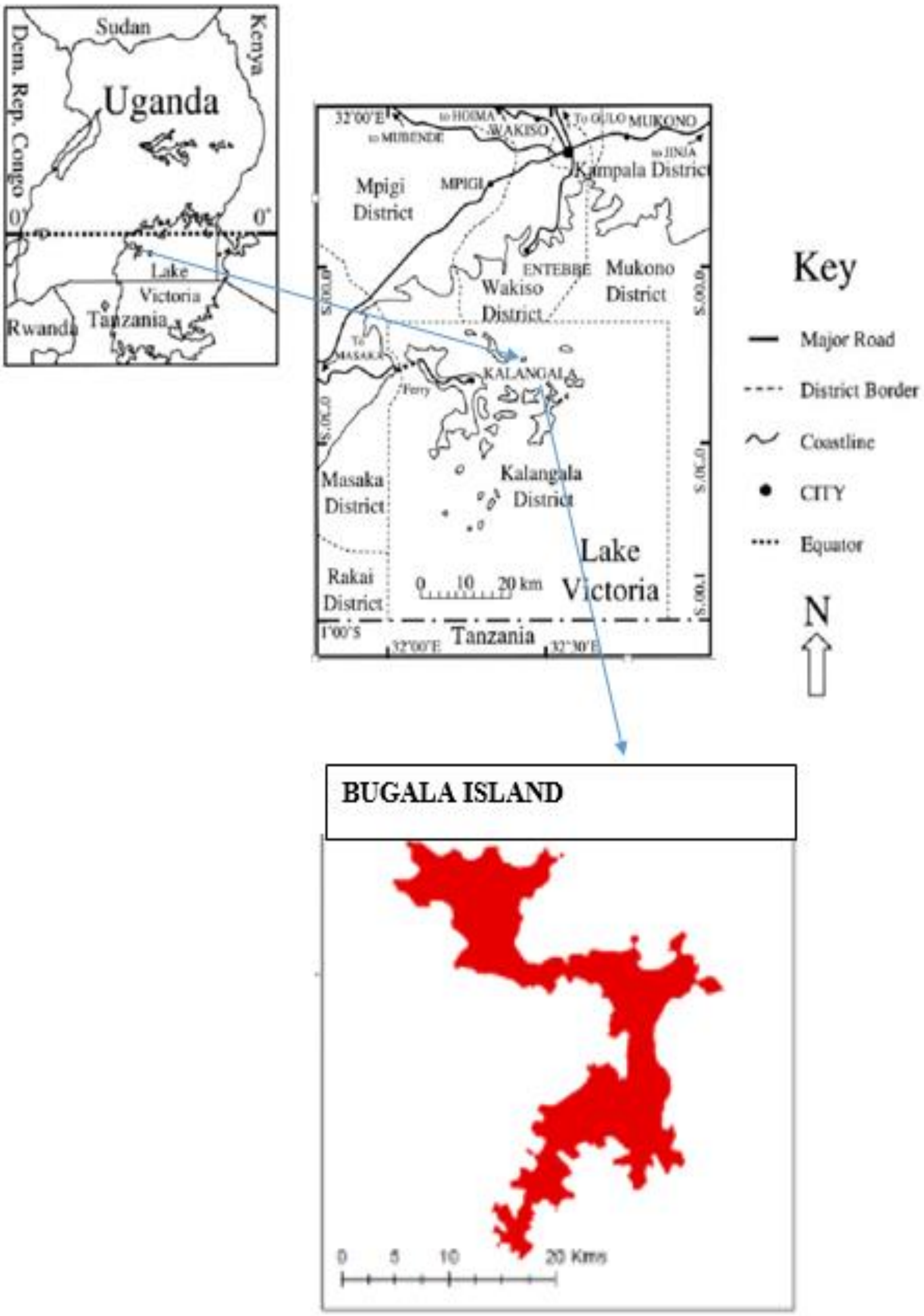

Fig. 1. Location of Bugala Island, Kalangala District (2024)

Water samples were collected directly from the discharge points of palm oil processing factories on Bugala Island. These locations represent the primary sources of effluent pollution in the study area and are critical for assessing the immediate impact on water quality. Additional water samples were collected from areas near the palm oil processing factories to capture the spatial extent of effluent dispersion and its influence on surrounding water bodies. Typically, samples were collected twice a day for two weeks. During periods of high industrial activity or potential pollution events (e.g., after heavy rainfall). Sampling at different times of the day provided a more representative snapshot of water quality, helping to identify any temporal patterns or trends. By collecting samples during peak production hours, research could assess the water quality under maximum load conditions. Off-peak sampling helped to understand baseline conditions and assess the effectiveness of pollution control measures during periods of lower activity. Control sites were established in areas farther away from the industrial sources of pollution. These sites served as reference points for comparing water quality parameters and determining the extent of pollution impact on the aquatic environment.

Samples for heavy metal analysis were collected from the discharge points of palm oil processing factory. This ensured the assessment of heavy metal concentrations in the effluent directly released into the water bodies. Additional samples were collected from areas adjacent to the factories to evaluate the spatial distribution of heavy metals in the vicinity of industrial activities. Control sites located away from industrial sources were included for heavy metal analysis. These sites provided baseline data on background levels of heavy metal concentrations in the absence of industrial pollution, facilitating comparisons and impact assessments.

To accurately estimate the density and diversity of fish yields around Bugala Island, a comprehensive sampling strategy was implemented, taking into account of various factors influencing fish populations. These included habitat characteristics, fishing pressure, and seasonal variations. The sample size for fish yields assessment were determined systematically, ensuring that it aligns with the research objectives and enabled the detection of significant differences between control and experimental sites. To calculate the sample size, statistical power analysis was employed. This analysis considered the variability in fish populations within each sampling stratum, as well as the desired confidence level and effect size. By utilizing statistical power analysis, it ensures that the sample size is sufficient to detect meaningful differences in fish densities and species diversity. Standardized fishing techniques, such as gill nets of mesh size 4, was employed to capture fish specimens at 8 hourly intervals. The sample size was calculated based on the expected variability in fish populations, ensuring adequate representation of different species and size classes.

Water samples were collected using clean, sterilized containers made of high-density polyethylene (HDPE) with tight-fitting lids to prevent contamination. Each sampling container was labelled with the location, date, time, and any other relevant information. Notes of any observations about water color, odor, clarity, or any visible signs of pollution were recorded. Samples were kept cool and out of direct sunlight during transport to the laboratory to minimize changes in water quality. The samples were delivered to the laboratory as soon as possible after collection to ensure accurate analysis. In the laboratory, the water samples underwent a series of analyses to measure various physico-chemical parameters, pH levels were determined using a calibrated pH meter, providing insights into the acidity or alkalinity of the water. Dissolved oxygen concentrations were measured using a dissolved oxygen meter, which quantifies the amount of oxygen dissolved in the water (a critical indicator of aquatic ecosystem health). Additionally, concentrations of heavy metals, including cadmium, lead, and mercury were determined using inductively coupled plasma mass spectrometry. These analyses provided valuable insights into the presence and levels of potentially toxic contaminants in the water, assessing the environmental risks associated with effluent discharge from palm oil processing factories. For qualitative data, key informant interviews were conducted with relevant stakeholders including local leaders, environmental officers, and representatives from palm oil processing factories. These interviews yielded insights into factory effluent management practices and their potential repercussions on the local environment and fishery. Focus group discussions (FGDs) were organized with community members to delve deeper into their perceptions and experiences regarding effluent pollution and its impact on fish density and diversity.

Data collected from the study underwent rigorous analysis to draw meaningful conclusions and insights relevant to the research objectives. Analysing physico-chemical parameters of the water samples were done as: pH: Measured using a pH meter; Turbidity using secchi disc; Salinity using malt-electrolyte meter (Hanna instrument); and Dissolved Oxygen (DO) measured using a dissolved oxygen meter. For heavy metal analysis, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to determine metal concentrations. The research findings were presented using tables, graphs, and correlation matrices, making the results accessible to both scientific and policymaking audiences. The study contributes valuable empirical evidence, supporting targeted interventions aimed at mitigating the negative environmental impacts of industrial effluent on the fragile aquatic ecosystems of Bugala Island.

3. RESULTS AND DISCUSSION

3.1 Water Quality Parameters

A number of the water parameters were determined from the water samples collected around the industries (Experimental) at 0m, 100m and 200m from the point of effluent inlet to the lake. Also, water samples that acted as control were collected at 1000m from the point of effluent in three directions. The water parameters considered for experimentation were turbidity, pH, temperature, salinity and dissolved oxygen (DO) as shown in Table 1.

The turbidity levels (Table 1) at all the experimental sites were slightly less than those at the control sites. The mean turbidity levels were statistically similar at control site A, control site B. Also, the mean turbidity levels were statistically similar at control site C, experiment site 1, and experiment site 2 except for that at experiment site 3 which was significantly different from all the rest. Statistically, there was a significant difference in mean levels of turbidity in different sites at $P>0.05$ as shown in Table 2. However, while these differences suggest localized pollution, they do not indicate severe environmental damage. In relation to some findings by authors like Chen et al. (2021), Mohammad et al. (2021) and Zhou et al. (2021), the low turbidity levels are a sign that the surrounding waters around Bugala Island are less polluted due to the effluents from the industries.

In aquatic environments, pH is crucial because it affects the solubility and biological availability of nutrients and toxins, influencing the health of aquatic organisms and ecosystems. The pH levels as shown in Table 1, showed that samples from all the experimental sites were slightly less than those at the control sites except the affected area at experimental site 3 whose pH was the highest. The mean pH was statistically similar for control site A, and control site B. However, the mean pH was statistically different for control site C, experiment site 1, experiment site 2, and experiment site 3. ANOVA test revealed that there was a statistical difference between the results from the experimental sites and those obtained from the control sites at $P<0.05$ as shown in Table 3. The results obtained are in agreement with those obtained by some authors like Garg et al., 2009. Kristanti et al. (2021) and Khan et al. (2016) who state that when pH ranges are within the permissible levels, they favour fish growth.

In aquatic systems, water temperature is a key factor that influences metabolic rates, growth, and survival of aquatic organisms. It affects the solubility of gases, such as oxygen, and the rates of chemical reactions and biological processes within the water. In this research, monitoring temperature variations at different sites is of significance as it helps assess how thermal conditions may impact aquatic life and the overall health of the ecosystem. Temperature fluctuations can affect the distribution and behavior of fish species, as well as interactions between biotic and abiotic components of the aquatic environment. Understanding these variations provides valuable insights into the effects of environmental changes and pollution on water quality and aquatic biodiversity.

Temperature Tolerance: Tilapia can tolerate temperatures as low as 16°C (60.8°F) and as high as 36°C (96.8°F), but optimal growth and reproduction occur within the 25-30°C range. While Nile Perch can survive in a range of temperatures, its metabolic and feeding activities are optimal between 26°C and 32°C. Temperature extremes below 20°C (68°F) or above 35°C (95°F) can be stressful for the species. Different species have different temperature ranges for optimal growth and reproduction hence temperature plays a significant role in the survival and abundance of fish populations (Ogutu-Ohwayo, 1990).

Table 1. Physico-chemical readings of water parameters of the study area (Primary data, 2024)

Sites	Turbidity (NTU) Mean ± S.D	pH Mean ± S.D	Temperature(^{0}C) Mean ± S.D	Salinity(mg/L) Mean± S.D	DO (mg/L) Mean ± S.D
Experimental site 1	1.9000±0.079	7.300±0.061	26.03±0.07	218.400±0.548	95.730±3.571
Experimental site 2	1.8800±0.057	7.440±0.065	25.96±0.04	213.500±2.2078	87.530±0.383
Experimental site 3	1.8300±0.076	7.730±0.027	26.11±0.07	220.600±0.652	97.670±0.264
Control Site A	1.9845±0.023	7.620±0.045	25.84±0.05	230.000±1.458	94.050±0.542
Control Site B	2.0000±0.117	7.570±0.045	25.79±0.04	228.600±0.418	93.550±0.597
Control Site C	1.9800±0.076	7.660±0.065	25.80±0.04	227.600±0.418	83.900±0.285
Permissible levels	<30	6.0-8.0	27-31	<1000	80-120

Table 2. ANOVA test on turbidity of the water samples (Primary data, 2024)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Sites	0.1188	5	0.023765	4.04	0.008
	0.1412	24	0.005882		
a. R Squared = .457 (Adjusted R Squared = .344)					

Table 3. ANOVA test on the pH of the water samples (Primary data, 2024)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Sites	0.622	5	0.124	43.882	0.000
	0.068	24	0.003		
a. R Squared = .901 (Adjusted R Squared = .881)					

Table 4. ANOVA test on the temperature of the water samples (Primary data, 2024)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Sites	9643.672	5	1928.734	1.660	.183
	27892.920	24	1162.205		
a. R Squared = .257 (Adjusted R Squared = .102)					

Table 5. ANOVA test on the salinity of the water samples (Primary data, 2024)

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Sites	1093.042	5	218.608	162.433	.000
	32.300	24	1.346		

a. R Squared = .971 (Adjusted R Squared = .965)

A one-way ANOVA was conducted so as to determine if the mean temperatures based on sites (location) were statistically significant. The results of the ANOVA model revealed that there was no statistically significant difference in mean temperatures at different sites at P>0.05 as reflected in Table 4.

Salinity is a crucial parameter in aquatic environments as it influences the osmotic balance, distribution, and health of aquatic organisms. Different species have specific salinity ranges within which they thrive, making it a key factor in assessing aquatic habitat quality. The salinity levels of the water samples at all the sites were slightly lower than the salinity levels at the control sites as shown in Table 1. The mean salinity was statistically similar for experiment site 1, and experiment site 3. However, the mean salinity was statistically different for control site A, B, C, and experiment site 2. The difference was confirmed by the ANOVA test which revealed a statistical difference in the results from both the experimental and control sites at P<0.05 as shown in Table 5. In their findings, Cunillera-Montcusi et al. (2022) state that increase in salinity increases stress and mortality of fresh water organisms including fish. When fish are stressed, there is a very high likelihood that their growth rate reduces leading to low yields. Although the study sites and the control had different salinity levels, they were within the permissible units which enabled fish flourishment.

DO is essential for the respiration of fish, invertebrates, and other aquatic life. The DO levels are a critical indicator of water quality, since low oxygen concentrations can lead to hypoxia, adversely affecting aquatic ecosystems and biodiversity. The DO levels at all the experimental sites were lower than the DO levels at the control sites except for the DO levels at the affected area at experimental site 1 which were the highest throughout (Table 1). However, there was no significant difference in the levels of dissolved oxygen at the experimental and control sites at P<0.05 as shown in Table 6.

3.2 Heavy Metal Concentration

Metals are of significant concern due to their potential toxicity to aquatic organisms and their ability to accumulate in the food chain. Monitoring their concentrations provides valuable insights into environmental pollution and the health risks posed to both aquatic life and human populations relying on these water sources. The concentration of some heavy metals from all the water samples collected from the sampling points. The heavy metals considered in the study include: Cadmium, Lead and Mercury. The results obtained are shown in Table 7.

Cadmium is a heavy metal that is widely recognized for its potential toxicity and environmental persistence. It is commonly found in industrial waste, agricultural runoff. In aquatic environments, cadmium can adversely affect the health of fish and other aquatic organisms by impairing their growth, reproduction, and overall physiological function. In unpolluted freshwater systems, cadmium concentrations are generally within the range of 0.01 to 0.1 µg/L (ppb) Al-Hossainy et al. (2017).

The results from Table 7 show that the mean cadmium concentration at experimental site 1 and 2 are slightly higher than the cadmium concentration at all the three control sites. The Cadmium concentration at all sites were not very significant. These results were further confirmed by an ANOVA test, which confirmed that, the results obtained from both the experimental and control sites showed no statistical difference at P>0.05 as shown in Table 8. In relation to cadmium levels, Charkiewicz et al. (2023) and Wu et al. (2010) posit that when the amounts of cadmium exceed the permissible levels, they become toxic and can easily cause death to living organisms including fish. This could have been the reason why at some points, fish yields were low.

Lead is a heavy metal with significant environmental and health concerns, commonly associated with industrial activities, lead-based paints, and contaminated water sources. In aquatic systems, lead can accumulate in the tissues of fish and other organisms, potentially leading to toxic effects that impact their growth, behavior, and reproductive success. Its persistence in the environment poses risks not only to aquatic life but also to human health through the consumption of contaminated water and fish. In unpolluted freshwater systems, lead concentrations are often found within the range of 0.01 to 0.03 µg/L (ppb) (Pattee, 2002). From Table 7, the mean lead concentration at experimental site 2 and 3 was higher than that at control site B and C. However, the highest lead concentration was at control site A. ANOVA test revealed that there was no significant difference in the concentrations of lead at the experimental and control sites at P=0.239 as seen in Table 9. Since the concentration of lead from both the study sites were slightly higher than the permissible levels, they could have caused a reduction in yields of fish in the area and have potential of adversely affecting human beings who may consume the fish (Pule et al., 2022).

Mercury is a highly toxic heavy metal known for its environmental persistence and bio-accumulative properties. It originates from various sources, including industrial discharges. In aquatic environments, mercury can transform into methylmercury, a particularly harmful form that accumulates in the food chain, affecting fish and other wildlife. High mercury levels in fish can pose serious health risks to both wildlife and humans who consume contaminated seafood. Uncontaminated freshwater systems typically exhibit total mercury concentrations ranging from 1 to 10 nanograms per liter (ng/L) which is equivalent to 0.001 to 0.01 parts per billion (ppb) (Barringer, 2006). Therefore, since the amounts of mercury determined in the sample water were higher than the permissible levels, they led to the contamination of the water which might have led to a reduction in the fish yields.

From Table 7, the mercury concentration at experimental site 2 and 3 was slightly higher than that at control site B and C. However, the highest mercury concentration was at experimental site 2. Generally, the ANOVA test showed that there was no significant concentration of mercury levels in the water samples from both experimental and control sites at P>0.05 as shown in Table 10.

It should be noted that the heavy metal concentrations in both experimental and control sites were very low and below the permissible levels. This could have been attributed to the dilution processes since the water samples were drawn from a Lake around the oil palm industries.

Table 6. ANOVA test on the Dissolved Oxygen of the water samples (Primary data, 2024)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Sites	7722.634	5	1544.527	4.879	.003
	7597.679	24	316.570		
a. R Squared = .504 (Adjusted R Squared = .401)					

Table 7. Heavy metal concentration in the water samples from the study area (Primary data, 2024)

Sites	Cadmium (mg/L) Mean ± S.D	Lead (mg/L) Mean ± S.D	Mercury (mg/L) Mean ± S.D
Experimental site 1	0.0093±0.000	0.037996±0.0096	0.032843±0.0029
Experimental site 2	0.0090±0.000	0.041299±0.0358	0.035572±0.0021
Experimental site 3	0.0082±0.001	0.051549±0.0362	0.034204±0.0004
Control Site A	0.0078±0.001	0.077313±0.0283	0.030748±0.0017
Control Site B	0.0077±0.000	0.022213±0.0172	0.033122±0.0020
Control Site C	0.0087±0.001	0.038794±0.0106	0.033781±0.0021
Permissible levels (WHO)	0.005	0.01	0.001

Table 8. ANOVA test for cadmium concentration from the water samples (Primary data, 2024)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Sites	6.608E-006	5	1.322E-006	2.627	.079
	6.037E-006	12	5.031E-007		
a. R Squared = .523 (Adjusted R Squared = .324)					

Table 9. ANOVA test for lead concentration from the water samples (Primary data, 2024)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Sites	.005	5	.001	1.579	.239
	.008	12	.001		
a. R Squared = .397 (Adjusted R Squared = .145)					

3.3 Fish Density and Diversity

Fish yield was assessed by examining various parameters including total quantity, average weight, and average length of different fish species. The study focused on two distances from the shoreline: 500 meters in the experimental area and 1000 meters in the control area. These parameters helped in understanding how environmental factors and pollution levels might impact fish populations and their overall growth and distribution.

Table 10. ANOVA test for mercury concentration in the water samples (Primary data, 2024)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Sites	3.879E-005	5	7.757E-006	1.916	.165
	4.858E-005	12	4.048E-006		
a. R Squared = .444 (Adjusted R Squared = .212)					

Table 11. Quantity, average length and average weight for different fish species (Primary data, 2024)

Distance from Shoreline (m)	Fish Species	Total Quantity (Number)	Average Length (cm)	Average Weight (g)
500m (Experimental Area)	Tilapia (*Oreochromis niloticus*)	10	9.54	367.4
	Nile Perch (*Lates niloticus*)	5	11.98	449.8
	Catfish (*Silurus glanis*)	1	10	501
1000m (Control Area)	Tilapia (*O. niloticus*)	22	10.1	451.6
	Nile Perch (*L. niloticus*)	9	12.08	526.2
	Bagrus (*Bagrus filamentosus*)	2	10	314
	Catfish (*S. glanis*)	2	10.85	495
	Elephant Snout (*Mormyrus caschive*)	3	10.7	450

Table 12. Kruskal-Wallis results for quantity of fish species (Primary data, 2024)

Fish species	Df	Rank Sum	H	Sig.
Nile perch	2	133.50	12.833	0.002
Elephant snout, cat fish		100.00		
Tilapia		231.50		

Table 13. ANOVA results for average weight of the fish species obtained from the study area (Primary data, 2024)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Fish species	992086	2	496043	149.1	1.61e-13
	73182	22	3326		

Table 14. ANOVA results for average length of the fish species from the study sites (Primary data, 2024)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Fish species	470.5	2	235.25	96.5	1.29e-11
	53.6	22	2.44		

By analyzing these parameters, significant differences between the experimental and control areas were identified as seen in Table 11. This shed light on how proximity to the shoreline and potential contamination might influence fish yield.

Considering the quantity of fish species, their variation was investigated by carrying out a Kruskal-Wallis test. The results of the inferential analysis revealed that the median difference in the quantity of fish species was statistically significant at P<0.05 as seen in Table 12. Therefore, the quantity of the different fish species that are found in the study area differ, probably because of the different adaptations the fish species have in varying environments. The areas that were regarded as polluted had fewer fish species as compared to the quantity of fish species found in the control sites. Hence, effluent pollution affected the distribution of fish.

A one-way ANOVA was carried out to determine how conditions within the lake environment affected the average weight of the fish species. The results indicated that there was a significant difference in the weights of the fish obtained from the experimental and control sites at P<0.05 as shown in Table 13. Due to the statistically significant difference reported in the mean weight, multi-comparison test was done using Tukey’s test. The results revealed that the highest mean weight of the tilapia fish recorded was 409.300±90.174 g. Some authors like Aura et al. (2018) are in agreement with the findings where they stated that tilapia has high levels of tolerance which can withstand varied ranges of water quality conditions that would prove a challenge to other fish species.

ANOVA confirmed significant differences in fish weight (F=149.1, p=1.61e-13), with tilapia showing the highest mean weight. Favorable growth conditions, possibly due to reduced competition and better adaptation to environmental factors, explain these differences.

Considering the average length of the fish species, a one-way ANOVA test revealed that there was a significant difference in the length of the fish species obtained from different study sites at P<0.05 as shown in Table 14. It is important to note that the highest mean length of the tilapia fish was 9.93±2.44cm. Reduced competition and better adaptation to growth conditions could have contributed to the tilapia's superior growth rates.

4. CONCLUSION AND RECOMMENDATIONS

This research contributes valuable knowledge to the understanding of how industrial activities, specifically palm oil processing, are affecting aquatic ecosystems around Bugala Island. By highlighting the specific impacts on water quality and fish production, the study provides a strong foundation for future conservation efforts and policy interventions. Addressing the challenges posed by effluent pollution is not only critical for the health of the environment but also for the well-being of the communities that rely on these ecosystems. Collaborative efforts between industry stakeholders, government agencies, and local communities will be essential in achieving sustainable environmental management and protecting the natural resources of Bugala Island for future generations.

This study has demonstrated that effluents from palm oil processing factories significantly impact water quality and fish production around Bugala Island. Further still, the results indicate that effluent discharge leads to increased turbidity, altered pH levels, reduced dissolved oxygen, and changes in salinity. These changes in water quality have adverse effects on fish populations, as evidenced by the significant differences in fish yield between effluent-impacted and control sites.

The presence of heavy metals such as cadmium, lead, and mercury, although not significantly different across sites, poses a potential long-term risk to fish health and human consumers, especially for lead and mercury which were above the permissible levels.

It is therefore recommended that, stringent effluent management and regular monitoring practices to protect aquatic ecosystems and sustain fish production in the region needs to be enforced by regulatory bodies for compliance aimed for sustainable ecosystems. Also, effluent treatment technologies should be adopted by the palm oil processing factories to remove the likely harmful pollutants like construction of wetlands where the effluents could be emptied before they flow into the lake. There should be a continuous environmental monitoring and research, especially by the National Environmental Management Authority (NEMA) so that the industries remain compliant in as far as protecting the environment from further damage is concerned.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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DATA AVAILABILITY

The data presented in the manuscript is available on request.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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