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Full Length Research Paper

Food waste produced lactic acid for pathogen inactivation, urea stabilization and odor control in feces

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Source separated human feces can be used as a valuable source of nutrients if it is properly sanitized and its nutrient is conserved. In this study, the efficiency of fresh cabbage waste produced lactic acid treatment of human feces as a pretreatment to evaluate the sanitizing effect, urea stabilizing, and odor removal was investigated for 33 days. Four reactors were used for the treatment process containing different lactic acid to feces ratio (that is, 1:1, 1:2, 1:3 and control). *Escherichia coli* was used as the indicator of pathogen inactivation, whereas pH and ammonium were used as the main indicators of urea hydrolysis. The result showed that inactivation of the indicator, stabilization of urea and odor reduction improved in 1:1 reactor compared with other treatment reactors. Therefore, human feces is recommended to be treated by food waste produced lactic acid for 9 days for hygienic and stabilization purpose. Under this treatment condition, pH is maintained below 4.1 and ammonium content is maintained at approximately 5.0 mg/g. Moreover, the combination of lactic acid and activated biochar also played important role in odor control for effective treatment of feces.

Key words: Activated biochar, feces, lactic acid, *Escherichia coli*, urea stabilization.

INTRODUCTION

Nowadays, the conventional urban water and sanitation systems are questionable in terms of its adequacy and long-term sustainability both in developed and developing countries. Issues of high energy and water demand, sludge disposal problems, and limited nutrient recycling in developed countries (Brands, 2014) and the high infrastructure costs in developing countries (Larsen et al., 2016) are prohibitive for implementation of the systems. As a result, source separation and control is getting attention since it provides the opportunity for resource recovery and minimizes dilution and contamination of human excreta (Wilsenach et al., 2003; Larsen et al., 2009). Source separation is believed to answer the concern about future fertilizer availability for better nutrient management, including comprehensive recycling of nutrients contained in human excreta to agriculture (Harder et al., 2019). Due to its nutrient contents, human feces are a natural fertilizer that could replace chemical fertilizers (Andreev et al., 2018) to increase the soil fertility for agricultural productivity (Kimetu et al., 2004).

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However, the risk of infecting people with disease via contaminated crops and loss of nutrients are the main challenges (Yemaneh, 2015; Gold et al., 2018).

Different treatment techniques have been used to reduce the amount of pathogens in feces. Storage and composting (thermophilic composting and vermicomposting), which needs at least 1 to 2 years storage for pathogen removal (WHO, 2006). Desiccation along with high pH was proven to be efficient in pathogen destruction during the storage of feces by maintaining moisture content below 25% and a pH > 9, but rarely achieved (Niwagaba et al., 2009). Thermophilic composting that needs to be maintained at least for several days in stored feces is not economical since it requires additional energy source (Kone et al., 2010). Vermicomposting requires an extended time of 3 to 5 months to sanitize the feces during which a significant amount of nitrogen would be lost (Sinha et al., 2009). Lime treatment reduces pathogen present in feces. The concern in this process includes, lime scaling, ammonia odors and pathogen regrowth after a few days (Strande et al., 2014). Ammonia disinfection is effective in urine (Adamtey et al., 2009); however, its effectiveness to feces and disadvantages over the other technologies are not exhaustively studied (Magri et al., 2015).

Fermentation and acidification process is one of the most reliable methods for pathogen inactivation, nutrient loss reduction and odor control. Several studies (Factura et al., 2010; Otterpohl and Buzie, 2013; Bettendorf et al., 2014) showed the use of lactic acid fermentation for treatment of human feces within the terra preta sanitation approach. Lactic acid fermentation is a cheap and simple method that can be achieved through acidification at pH ≤ 4 (Anderson et al., 2015; Andreev et al., 2017). However, several lactic acid species do not produce effective lactic acids for pathogen inactivation in feces (Colehour et al., 2014; Sanni et al., 2013). As a result, effective, cheap and locally available lactic acid from wastes must be produced to sanitize feces, preserve its nutrient value as fertilizer and reduces its odor.

Lactic acid fermentation (LAF) is a cheap and simple method that can be achieved through acidification at pH ≤ 4 (Anderson et al., 2015; Andreev et al., 2017). However, not all lactic acid bacteria (LAB) species are able to produce lactic acid in feces and urine, making them ineffective for pathogen inactivation (Odey et al., 2018). In this study, we set out to have effective, cheap and locally available waste sources likely to contain LAB that could be fermented to produce lactic acid as a sanitizing agent for human feces prior to being used as a fertilizer. Specifically, cabbage waste was evaluated as organic source, for its ability to create LAB inocula that produced enough lactic acid to eliminate fecal indicator bacteria. The lactic acid produced from cabbage waste was evaluated for its ability to inactivate pathogen, inhibit urea hydrolysis and eliminate odor in feces. *Escherichia coli* was used as the indicator of pathogen inactivation, whereas pH and ammonium were used as the main indicators of urea hydrolysis.

MATERIALS AND METHODS

Preparing organic waste sources for fermentation

Fresh cabbage waste served as organic waste sources (heretofore called "substrates"); this substrate was collected in Addis Ababa, Ethiopia and was selected based on availability. It was collected from the big vegetable market in the city. The fresh cabbage waste was pulverized with a heavy-duty blender in the laboratory at Addis Ababa Institute of Technology, Addis Ababa University (AAU). Fifty grams of the substrate were mixed with 50 ml of distilled water and 50 ml of 10% sugar cane molasses to enhance lactic acid fermentation in the fermentation reactor, and sealed to make it air-tight and incubated at 37°C for seven days based on the method of Omar et al. (2009). Change in pH and the concentration of LAB and *E. coli* during the batch fermentation test were enumerated using the method described subsequently. The experiments were conducted in duplicate.

Preparation of lactic acid stock

Lactic acid was recovered for use in feces sanitization and urea hydrolysis inhibition using the methods of Mumtaz et al. (2008), Omar et al. (2009) and Phang et al. (2002). Specifically, the cabbage + sugar fermentation vessels were incubated at 37°C for seven days, then frozen at -30°C overnight followed by thawing in a drying oven at 60°C for 2 to 3 h. The solution was centrifuged and filtered with 0.8 µm cellulose acetate filter paper and a vacuum pump (KNF Neuberger, Germany). Finally, the water was evaporated at 50°C under vacuum for 8 h using a rotary evaporator (ROV 400, Czech Republic). After most of the liquid was evaporated, a clear brownish solution containing lactic acid was recovered (27.64 ± 3.03 ml). The solution pH was measured and found to be 3.90 ± 0.01. This acidic environment was anticipated to be used as an effective conditioner for pathogen inactivation and urea stabilization in feces.

Feces collection and experimental setup

Feces samples were collected from a volunteered family (a man – aged 36, three females – aged 41, 32, and 24) for a day and thoroughly mixed. At the end of the collection, it was stored in a tightly closed plastic container. Chemical analysis was performed and equally separated into four reactors. 130 g of feces sample was added to each of four 500 ml plastic containers (reactors). Three of the four reactors were mixed with different amount of lactic acid (lactic acid: feces) as 1:1, 1:2, and 1:3 (v/w). The fourth reactor was stored in parallel in tightly closed reactor without addition of lactic acid and named as control. All the bottles used for the experiments were disinfected and dried prior to filling. The treatment process was undertaken for 33 days for all reactors. The initial characteristics of the feces, pH and *E. coli*, were measured and found to be 6.89 ± 0.09 and $3.2 \pm 0.00 \times 10^6$ CFU/g, respectively.

The feces treatment experiment was monitored by measuring the *E.coli*, ammonium concentration, and pH. The ability of lactic acid to inactivate the pathogens was determined by evaluating the survival rates of the *E. coli* using Compact Dry ECO plates (HyServe, Germany) and on the basis of the pH changes (measured by using Jenway 3505-UK pH meter) during the treatment process, whereas the ability to reduce nutrient loss was monitored by measuring the ammonium concentration throughout the experiments.

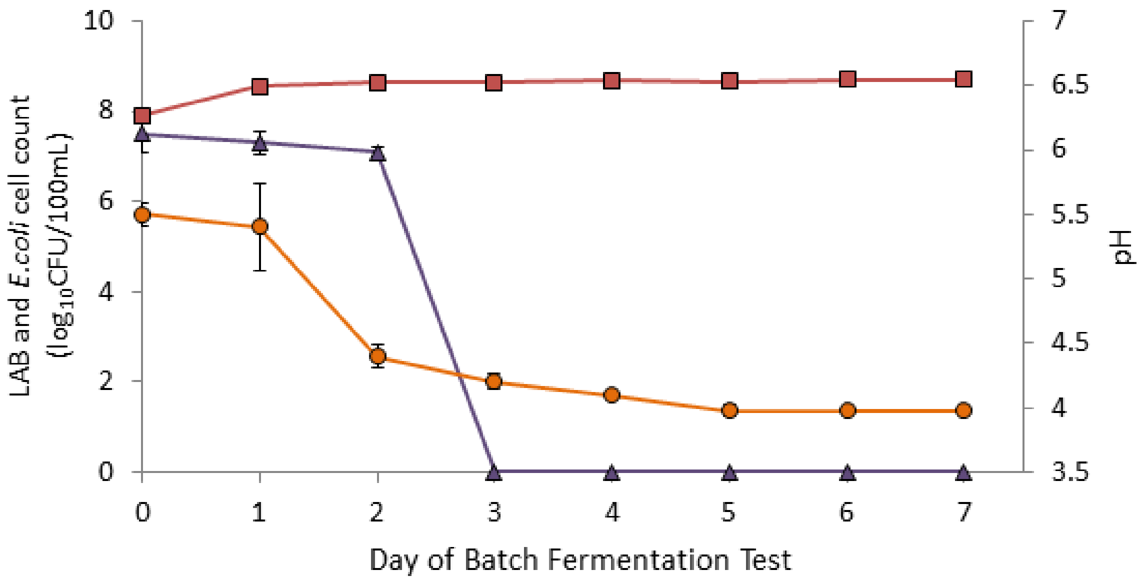

Figure 1. Change in pH (●), lactic acid bacteria counts (■), and *E. coli* counts (▲) during batch fermentation test conducted with cabbage + molasses. Zero data points on the x-axis reflect samples where *E. coli* was not detected. Symbols reflect the average of duplicate samples that are given by the extremes of the error bars.

The pH value during the treatment process was determined by collecting 1 g of sample from each reactor, which was then dissolved in 10 ml distilled water. The dissolved portions were stirred for 15 min. After settling, the pH was measured with pH meter (Jenway3505, UK).

Inhibition of *E. coli* in each reactor was determined using dry chromogenic medium for the detection and enumeration of *E. coli*. Samples taken from each reactor was added to the plates containing the chromogenic medium and incubated for 24(±2) h at 35°C. *E. coli* colonies, present as blue colonies, were counted (HyServe, Germany).

The ammonium content was analyzed using the Spectroquant reagent kit 1.14752.0002 (Merck, 2019). Using a spectrophotometer (Spectro UV-VIS Double Beam PC (UVD-3200), Labomed INC) and 10 mm cells, the absorbance of wavelength 690 nm was measured. For the conversion from absorbance to concentrations a standard curve was prepared with concentrations 0.1, 0.5, 1, and 3 mg NH_4/L prepared from standard solution (1000 mg NH_4/L).

Odor evaluation

The odor strength of the feces during treatment with lactic acid and combination of lactic acid and activated biochar was evaluated by eight people. The activated biochar was prepared from Prosopis wood based on the method laid out by Nahata et al. (2017). The potency of the perceived odour was evaluated by using a scale rank that has been used previously (Andreev et al., 2017). The scale rank categories are: 0 (no odor), 1 (very faint odor), 2 (faint odor), 3 (distinct odor), 4 (strong odor), 5 (very strong odor), and 6 (extremely strong odor).

Culture enumeration

Bacterial culturing was conducted in duplicate by applying 0.1 mL of serially diluted (1/10) sample in sterile distilled water. Lactic acid bacteria were cultured at 37°C for 24 h on MRS agar (Standard Method 9215), a *Lactobacillus* selective culture medium. *E. coli* was enumerated at 37°C for 24 h with Compact Dry ECO plates (HyServe, Germany) that use a dry chromogenic medium that is reconstituted when the liquid sample is applied; *E. coli* colonies present as blue. The method has an accuracy of ±0.5 $\log_{10}$ and a detection limit of 1 CFU/ml.

Statistical analysis

The experimental data were statistically processed via a Tukey test of multiple comparisons within one-way analysis of variance (ANOVA) and using Minitab 17 statistical software. The means of pH and ammonium concentration in all treatment reactors were compared for significance differences (at 95% significance, based on *p* values and confidence interval CI).

RESULTS AND DISCUSION

Fermented cabbage waste produced LAB and inactivated *E. coli*

The waste source produced low pH response to fermentation (Figure 1). Since it reflects the acidification in the experiment, pH variation is one of the most important parameters that must be observed during fermentation. The initial pH of the substrate was 5.5. The pH stabilized at average value of 3.98 ± 0.02 by day five and remained there until day seven. This favored to the rapid growth of LAB during the fermentation process. As a result, LAB metabolized molasses to obtain energy and produced lactic acid as the end product. The increase in LAB concentration resulted in a pH drop. This result shows that cabbage waste produced the lowest sustained pH during the experiment.

Throughout the experiment, the waste resulted in a multifold increase in LAB counts ($0.8 \times 10^8 \pm 0.12$ to $5.0 \times 10^8 \pm 0.22$ CFU/100 ml). Furthermore, the fermented cabbage waste eliminated detectable *E. coli* counts by day three suggesting that acidic pH values lead to *E. coli* inactivation. The average result of duplicate samples is converted into $\log_{10}$ CFU/100 ml (Figure 1).

The fermentation test result indicates that fresh cabbage waste can produce conditions favorable for inactivating pathogens and stabilizing urea in feces. The waste creates acidic conditions so more quickly and rapidly inactivated *E. coli*, an enteric pathogen indicator. While the complete mechanism of inactivation was not determined, acidic pHs are outside of the ideal range for optimum growth (Desmarchelier and Fegan, 2003) and likely contributed to its inactivation.

Finally, the waste showed the potential to generate lactic acid given the proliferation of LAB and decrease in pH under all conditions. Consequently, fresh cabbage can be used to generate lactic acid for feces processing and pathogen inactivation. Cabbage is naturally rich in LAB and support rapid fermentation (Yang et al., 2010), which was seen in this study.

Fermented waste-generated lactic acid inactivated *E. coli* and improved urea stabilization

Addition of fermented waste-generated lactic acid solution (pH 3.98) stabilized the pH in human feces present at a higher volume. The pH value of the control reactor was initially 6.89, which then increased to 7.28 on the fifth day of the treatment. At the end of the treatment process, the reactor had a final pH of 7.94, which is consistent with what happens when urea in the feces is hydrolyzed to ammonia (Chang et al., 2015). The pH rapidly decreased for 1:1 reactor (4.01) followed by 1:2 (4.05) and 1:3 (5.16) reactors in the first five days of the treatment process and remained nearly constant for three of the reactors from day 9 to the final day of the treatment as shown in Figure 2A. The final pH value for 1:1, 1:2 and 1:3 was 4.08, 4.27, and 5.28, respectively. The observed pH value in 1:1 reactor is considered to have nearly the desired characteristics for feces acidification as described by Thimann (1963) and mentioned by Odey et al. (2018) that lactic acid treatment must have a final pH of [4 for feces hygienization. This result implied that food waste produced lactic acid is an effective conditioner for pathogen inactivation in feces, because pathogens rarely survive in acidic environment (Glaser and Guggenberger, 2001).

A one way ANOVA analysis for pH between the four test reactors shows that there was no statistically significant difference between the means of the pH value of the 1:1 , 1:2, and 1:3 reactors (p value < 0.05). However, there was statistically significant difference between the mean of the pH value of the control reactor from the rest of the reactors.

In this study, lactic acid treatment of feces has been hypothesized to prevent urea from hydrolyzing into ammonia/ammonium. Urea hydrolysis is catalyzed by urease from urea producing bacteria. The effect of lactic acid, however, inactivates urea producing bacteria, thus inhibiting urease production during lactic acid treatment. In this study, the initial ammonium content of the feces was 2.11 mg/g. Ammonium concentration of 1:1 and 1:2 reactors on the first day was 2.14 and 2.4 mg/g, respectively, and showed sharp increment on the fifth day (4.13±0.11 in 1:1 reactor and 5.08±0.12 in 1:2 reactor). On day 5 onwards, the ammonium concentration in 1:1 and 1:2 reactors remained nearly constant until it reached 5.16 mg/g in 1:1 reactor and 5.74 mg/g in 1:2 reactor at the end of the treatment process. Although 1:1 and 1:2 reactors showed slight difference in inhibition of urea hydrolysis, both influenced urea hydrolysis nearly equally, as shown in Figure 2B. This was supported by one way ANOVA, which showed that there is no significant difference in ammonium concentration between 1:1 and 1:2 reactors (p value < 0.05). On the other hand, the ammonium concentration in 1:3 and control reactors keep increasing until the end of the treatment process. The final ammonium concentration in the 1:3 and control reactors was 8.32 and 15.2 mg/g, respectively as shown in Figure 2B. The control reactor showed the highest ammonium concentration over the others, indicating that there is continues urea hydrolysis. This was supported by one way ANOVA, which showed ammonium concentration in control reactor is significantly different from the other reactors (p value < 0.05). Therefore, considering urea hydrolysis in feces, both 1:1 and 1:2 reactors after 5 days lactic acid treatment produces the optimal urea stabilization.

E. coli was used in this treatment process as an indicator organism to assess the pathogen inactivation efficiency of fresh cabbage waste and sugar cane molasses produced lactic acid in feces. Accordingly, the result showed that reduction in the concentration of *E. coli* was observed in the 1:1 and 1:2 reactors, whereas the concentration of *E. coli* remained high in the 1:3 and control reactors. On day 5 onwards, *E. coli* was not detected in the 1:1 reactor and on the ninth day of the treatment process in the 1:2 reactor as shown in Figure 2C. On the other hand, slight *E. coli* concentration reduction was observed in 1:3 and control reactors. While the complete mechanism of inactivation was not determined, acidic pHs are outside of the ideal range for optimum growth (Desmarchelier and Fegan, 2003) and likely contributed to its inactivation. According to various studies, pH range of 3.51 to 4.2 could efficiently eliminate various pathogens. Odey et al. (2018) reported that the addition of lactic acid produced from fermented rice flour and brown sugar led to an effective acidification of the

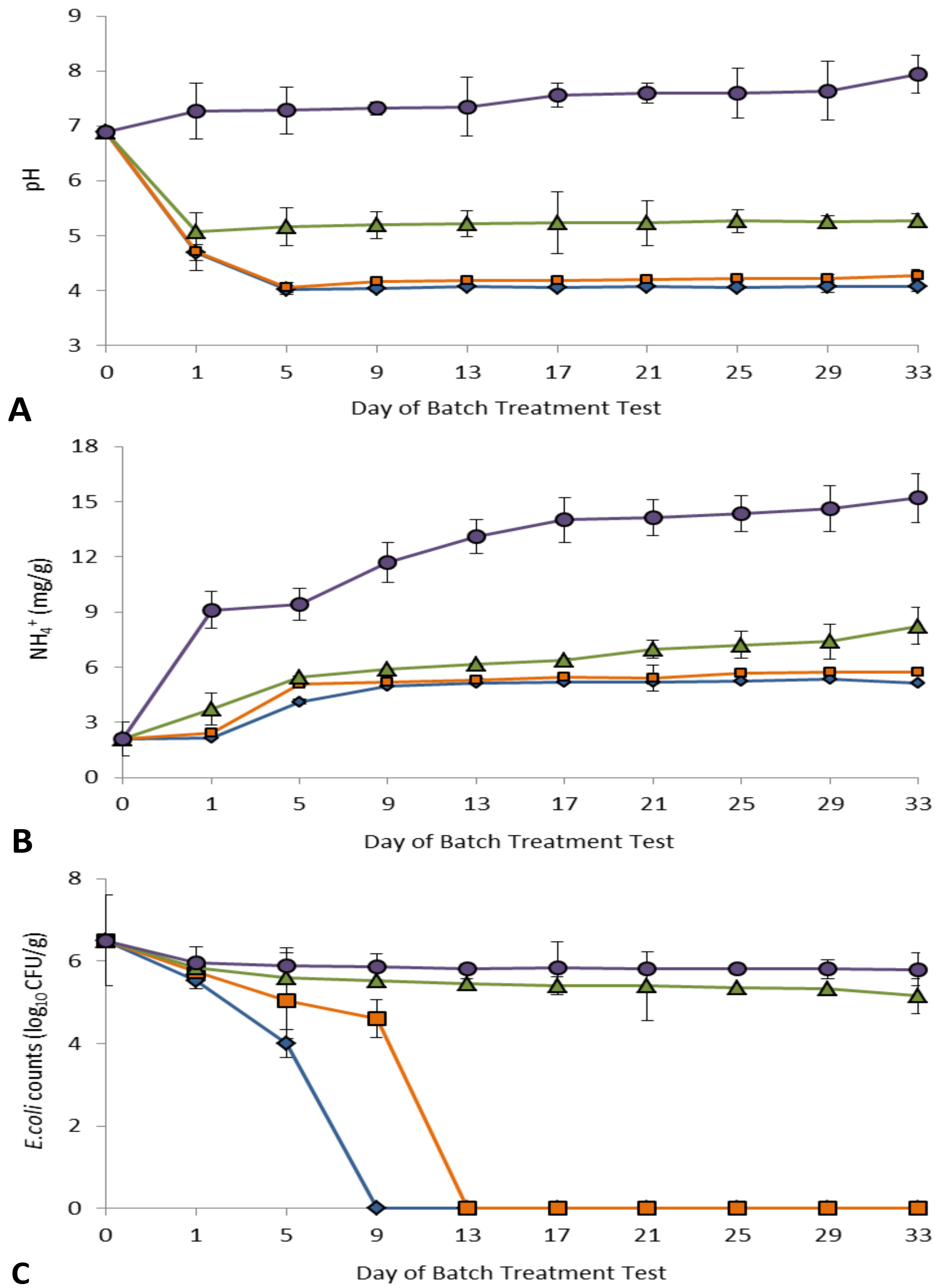

Figure 2. Change in pH, ammonium concentration, and *E. coli* counts during batch treatment tests. Control = ● ; 1:3 = ▲ ; 1:2 = ■; 1:1 = ♦. (A) Changes in pH during batch tests. (B) Changes in ammonium concentration during batch test. (C) *E. coli* distribution during batch test. Zero data points on the x-axis reflect samples where *E. coli* was not detected. Symbols reflect the average of duplicate samples, that are given by the extremes of the error bars.

treatment process to pH of 3.51 to 3.52 and fecal coliform inactivation. Anderson et al. (2015) found that lactic acid fermentation could reduce the *E. coli* count in fecal sludge to below the detection limit at pH 4.2. As it was also found in this study, the addition of lactic acid produced from the fermentation of fresh cabbage waste and sugar cane molasses showed removal of *E. coli* at pH range of 4.04 to 4. 18. This is also consistent with the result reported by Soewondo et al. (2014) who recorded approximately pH 4.5 after 7 days of lacto-fermentation treatment of fecal matter by EM4 and 5% glucose.

In this study, lactic acid treatment of feces in 1:1 and 1:2 reactors reduced the pathogenic microorganism load (*E. coli*) in a more efficient and faster way. Thus, acidification through lactic acid can eliminate pathogen in feces while conserving nutrients that could be lost during collection, transportation and treatment. Therefore, considering disinfection effect and urea hydrolysis, 1:1 treatment produces the optimal pathogenic bacteria inactivation and urea stabilization. However, further investigations are required to see the efficiency of food waste produced lactic acid to remove dangerous pathogens such as *Salmonella*, *Ascaris* and *Schistosoma* before the practical application of lactic acid treatment of feces.

Food waste produced lactic acid and biochar combined treatment of feces reduced the odor to the acceptable level

The presence of feces odor and its acceptability as a pretreatment of feces to be used in collection system was compiled from the qualitative responses of eight panelists. According to the panelists, lactic acid treatment of 1:1 and 1:2 reactors suppressed the odor and changed it with a lactic acid smell compared to the 1:3 and control reactors. In the 1:1 reactor, the odor was ranked as very faint odor by four panelists, faint odor by three panelists, and a distinct odor by one panelist. In the 1:2 reactor, the odor was ranked as a faint odor by five panelists and a distinct odor by three panelists. In the 1:3 reactor, the odor was ranked as strong odor by all panelists. However, the odor in the control reactor was reported by all panelists to be extremely strong odor as shown in Figure 3A.

Other studies also reported the removal of offensive feces odor through application of lactic acid produced from other organic wastes. Wang et al. (2001) reported suppression of odor through lactic acid fermentation of kitchen biowaste and fish waste. Huang et al. (2006) found odor suppression through lactic acid fermentation of swine manure added with lactic acid bacteria. Odey et al. (2018) reported odor suppression through fecal sludge treatment using fermented rice flour with brown sugar. In this study, the odor reduction observed in 1:1 reactor could make the sanitized feces acceptable during collection of the feces for direct application in agriculture as a soil amendment or further treatment to recover nutrients.

In an experiment conducted with the addition of lactic acid and 10 %(w/w) of activated biochar into all reactors, complete suppression of odor in 1:1 and 1:2 reactors were reported by all panelists. Accordingly, in 1:1 and 1:2 reactors, the odor was ranked as no odor by all panelists. In the 1:3 reactor, the odor was ranked as a faint odor by five panelists and a distinct odor by three panelists. In the control reactor, the odor was ranked as extremely strong odor by all panelists as shown in Figure 3B.

As the observation of the researcher, combination of lactic acid and 10% (w/w) activated biochar showed complete feces odor removal. This finding is similar with the study result obtained by Yemaneh et al. (2012) who conducted feces treatment involving LAB microbial inoculant, 10% (w/w) molasses and 10% (w/w) charcoal. According to the study, the combined LAB microbial inoculant, 10% (w/w) molasses and 10% (w/w) charcoal suppressed completely the odor of the feces than the treatment with only LAB microbial inoculant and 10% (w/w) molasses.

Replication tests

Based on the aforementioned experimental results, food waste produced lactic acid was applied to human feces for 9 days in two duplicate tests to test the reproducibility of the selected operational conditions (pH, NH_4^+ and *E. coli*). The experimental results, for the lactic acid treatment of the two feces samples are presented in Figure 4.

No variation in the rate of *E. coli* inactivation was observed between the two test samples. *E. coli* in the two feces samples was completely inactivated on the 9th day of the treatment process. This result is consistent with the previous experimental results. Similar results were obtained for urea hydrolysis that no large variation was found in the pH and ammonium concentration of the two feces samples during the 9 days of the treatment process. Both pH and ammonium content stabilized starting from the 9th day of the treatment process, which is consistent with the previous experimental result. The pH value of the two feces samples on the 9th day of the treatment were 4.03 and 4.07, whereas the ammonium concentrations were 4.96 and 4.99 mg/g. These results further supported the efficiency and reproducibility of the previous experimental results.

Thus, considering the potential of food waste produced lactic acid for hygienization as well as reduction of nutrient loss and odor emissions, this treatment technique can be applied in separately collecting sanitation systems. Moreover, it laid foundation to utilize food waste for feces sanitization. One-third of the food produced globally for human consumption (approximately 1.3 billion tons) is lost. Industrialized and developing countries dissipate roughly the same quantities of food 670 and 630 million tonnes, respectively (News, 2011). Using part of these wastes for the lactic acid treatment

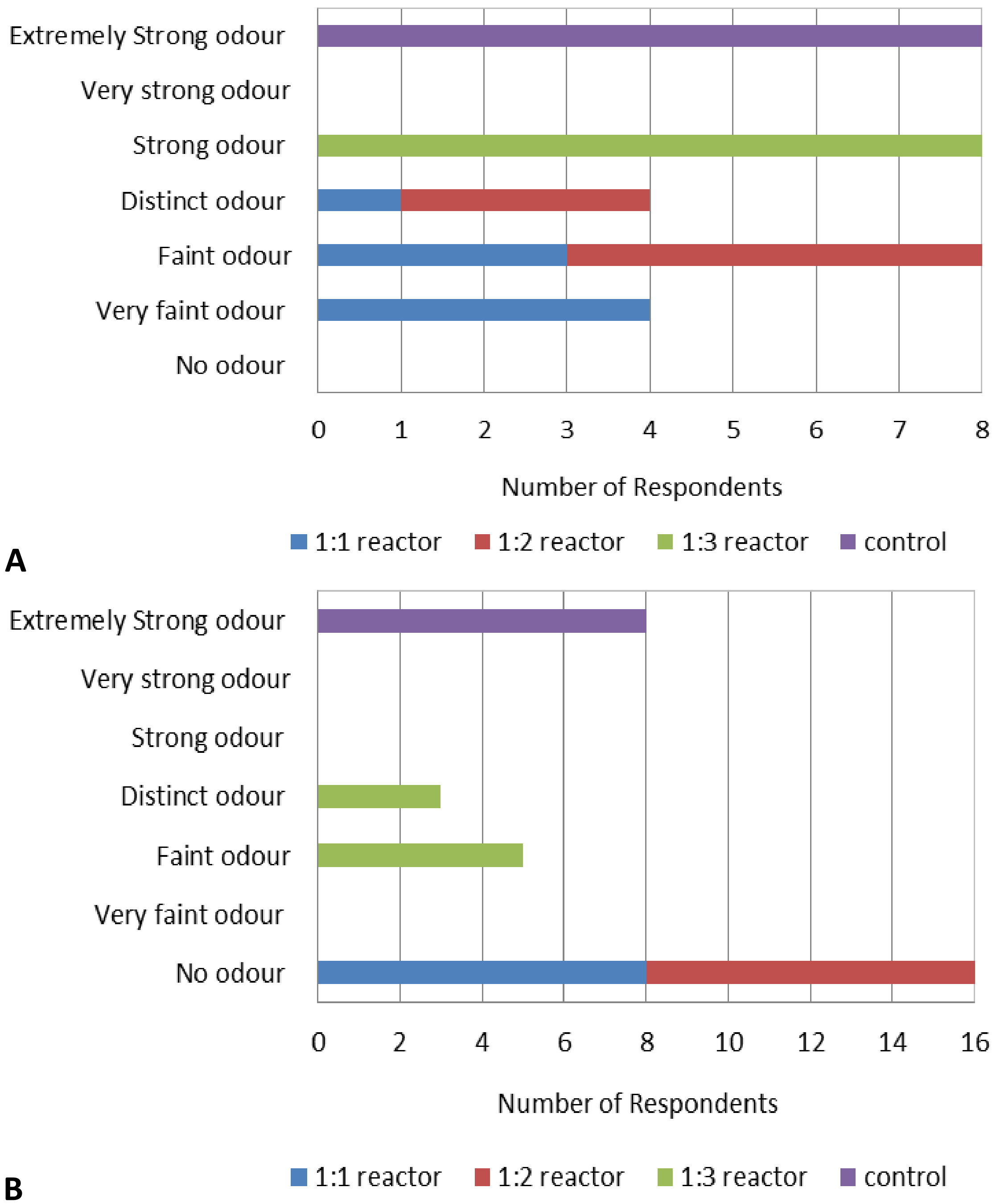

Figure 3. Perception of panelists on feces odor strength (N=8). (A) Perception of panelists on feces treated with only lactic acid. (B) Perception of panelists on feces treated with lactic acid and biochar.

of feces will be an economic advantage.

Conclusion

Lactic acid treatment of source separated feces can be a cost effective method during collection and further treatment. In this study, 1:1 reactor showed better performance in terms of pathogen inactivation, nutrient lose reduction via inhibition of urea hydrolysis, and odor removal over the other reactors. The addition of lactic acid produced from fresh cabbage waste and 10% sugarcane molasses led to an effective acidification of the process to a pH of 4.01 to 4.08 in the 1:1 reactor and *E. coli* inactivation during the treatment process. Ammonium concentration remained constant after fifth

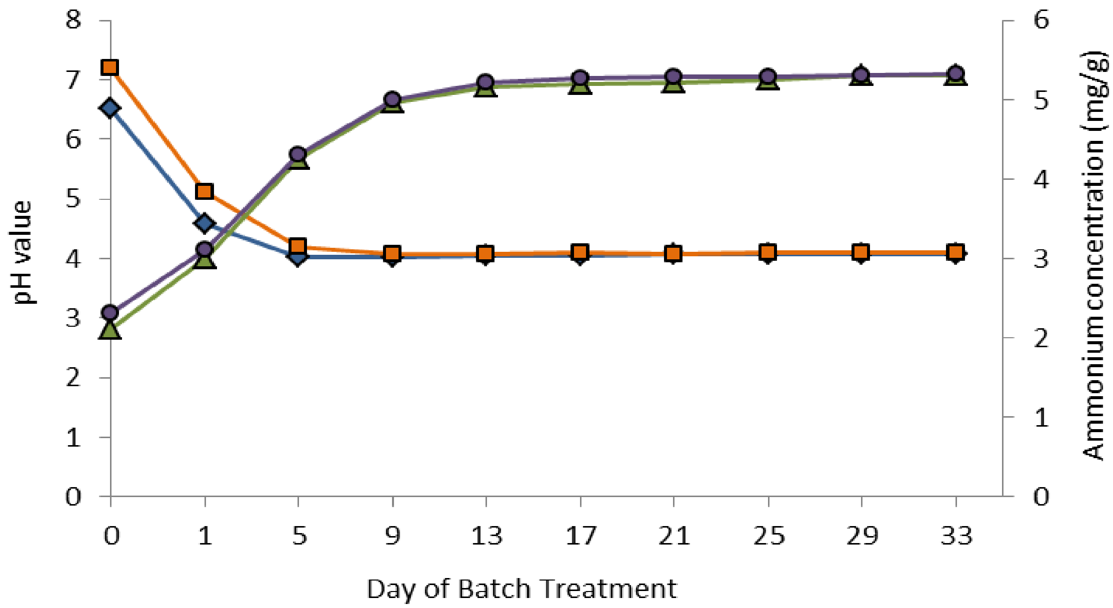

Figure 4. pH value and ammonium concentrations in the two feces samples. pH of sample test-1 (■), pH of sample test-2 (♦), ammonium concentration of sample test-1 (●) , and ammonium concentration of sample test-2 (▲).

day of treatment in 1:1 reactor, thereby showing the efficiency of lactic acid for inactivation of urea hydrolysis. Moreover, in 1:1 reactor lactic acid treatment also played important role in odor control for effective treatment of feces. The combined lactic acid and 10% (w/w) activated biochar showed complete odor removal. Therefore, this study showed that fresh cabbage waste and 10% sugarcane molasses produced lactic acid and 10% activated biochar can be used for feces treatment in terms of pathogen inactivation, urea stabilization, and odor control. The capacity of lactic acid to remove dangerous pathogens such as *Salmonella*, *Ascaris* and *Schistosoma* need further investigation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Spatio-temporal distribution of Naididae tubificids species and bio-evaluation of the quality of some surface water bodies of Yaoundé, Cameroon

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Despite their great interest for the integrated management of water resources, information on the ecology of aquatic oligochaetes is still sketchy in Cameroon. The present study aims at contributing to the knowledge on the distribution, microhabitat and life history of Naididae tubificids taxa in some eight water bodies of the city of Yaoundé. A total of 132 samples were analysed and the morphospecies *Branchiura* spp. and *Limnodrilus* spp. were identified. The most abundant species were *Branchiura* spp. with 2035 individuals versus 880 *Limnodrilus* spp. Both of them demonstrate low seasonal variations. It appeared that, these annelids are more abundant on clay-rich soils than on sand and the herbarium. Assessment of the organic pollution index indicates an organic pollution of the sampled waters ranging from moderate to high (3.67-2). The redundancy canonical analysis shows that *Branchiura* spp. are more present in saline waters revealing high organic pollution factors variables. During the study period, some 10 individuals of *Limnodrilus* spp. presented a shrunken tail. That reveals a strong environmental pressure due to the action of predators or the presence of heavy metals in the aquatic system evaluated. All these characteristics indicate a high pollution and predation pressure in the milieu.

Key words: Annelids oligochaete, ecology, bottom nature, polluted water.

INTRODUCTION

In the city of Yaoundé, which is the political capital of Cameroon, surface water is used for the production of drinking water, irrigation of crops in urban agriculture, fish farming activities (aquaculture), recreation, and the list is very extensive. Nevertheless, due to uncontrolled urbanization, these waters are subject to very high pollution (Kemka et al., 2004; Zébazé et al., 2006; Ebang et al., 2012; Ajeagah et al., 2014; Kapso et al., 2018; Ngong et al., 2019). In fact, since the population grows faster than the basic public services, a drastic lack of sanitary infrastructures is noticed. Consequently, almost 82.8% of the untreated wastewater is directly discharged into the environment (Ngambi, 2015) and this alters the quality of the natural resource.

For a good monitoring of the surface water bodies, aquatic oligochaetes can be an important ecological

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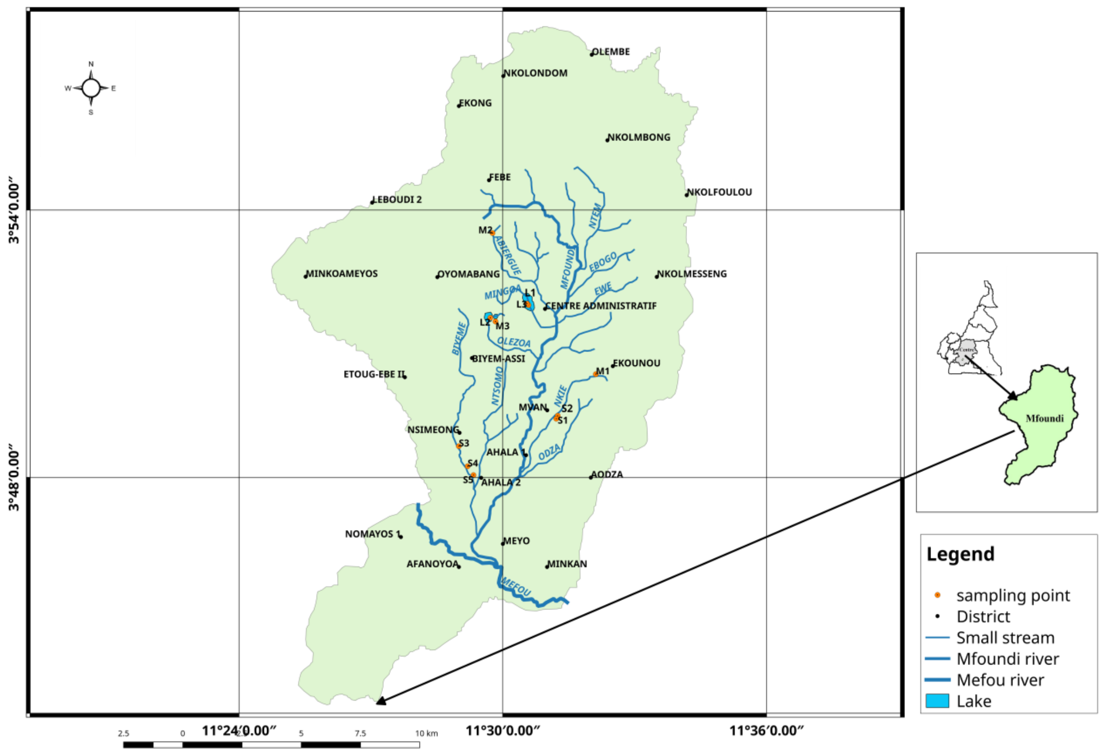

Figure 1. Map showing sites in the aquatic system in Yaounde (Cameroon).

tool. The application of Naididae, especially those belonging to the group of tubificids as bioindicators of water quality, is quite common in ecological studies (Vivien et al., 2011; Rodriguez and Renoldson, 2011; Vivien et al 2020). Naididae tubificids constitute a well-diversified group. It includes 6 subfamilies namely Limnodriloidinae, Phallodrilinae, Rhyacodrilinae, Rhyacodriloidinae, Telmatodrilinae and Tubificinae (Martin et al., 2008). All of them are endobenthic worms (Martin and Ait, 2012).

Due to their high resistance to organic pollution and their bioaccumulative capacity, most of them adapt to harsh environmental conditions (Schenková and Helešic, 2006). Besides being excellent indicators of water quality, Naididae tubificids are also highly involved in the flux and the availability of organic matter and pollutants in the water body. For example, they play both a direct role in the elimination of heavy metals via their own metabolism (biodegradation, bioaccumulation, detoxification), and an indirect role (as the result of their bioturbation activities) through the modification of the physico-chemical conditions and the stimulation of sulfo-reducing and metallo-reducing bacteria (Lagauzère, 2008). However, despite their great interest for the integrated management of water resources, information on their ecology is still sketchy in Cameroon. Although several studies have been carried out on the group of macroinvertebrates (Foto, 2012; Ajeagah et al., 2013; Tchakonté, 2016; Ajeagah et al., 2018; Foto et al., 2019, 2021), the only recorded article dealing with the fauna of freshwater oligochaetes in Cameroon is that of Dahl (1957) on the banks of the Nyong in the localities of Mpoume, Makak and Nenyanga. So this study aims at examining the spatio-temporal distribution of these organisms and evaluating the environmental parameters of the sampling sites in order to assess the quality of water.

METHODOLOGY

Sites and period of study

This study was conducted in the city of Yaoundé, that is located in the forest region of the southern plateau of Cameroon, between longitudes 11°20' and 11°40', latitudes 3°30' and 3°58'. This town is subject to an equatorial climate that is characterized by four seasons: the short rainy season (SRS) from March to June, the short dry season (SDS) from July to August the long rainy season (LRS) from September to November, and the long dry season (LDS) from late December to February (Sighomnou, 2004). This climate combined with the relief characterized by hills, valleys, the high density of the human population (Ngambi, 2015) and the extensive hydrographic network, favours urban agriculture in the city of Yaoundé.

This research was carried out from March 2016 to February 2017. The environmental parameters were measured following a monthly sampling frequency. Since metals are non-biodegradable and persist in the environment for a long time (Briffa et al., 2020), the heavy metals (Cd, Pb, Hg, Zn, Cr, Fe) were measured only once. Physico-chemical and biological data collected were assessed on seasonal basis (SRS, SDS, LRS, LDS). The sampling sites chosen (Figure 1) were taken into account on the different types of hydrosystems that can be found in the city. Five sampling sites were chosen on two streams (S1 and S2 on the Nkie stream, S3, S4 and S5 on the Biyeme stream). Three sampling points were chosen on three lakes (L1 on the Municipal lake, L2 on the Obili lake and L3 on the small Municipal lake). Three other sampling points were chosen on three different marshy areas (M1 at Tsinga, M2 at Ekounou and M3 at Ngoa Ekelle). Some characteristics of these points are given in Table 1.

Table 1. Characteristics of sampling sites.

Hydrosystem name	Sites	Anthropization	Used of the sampling point	Nature of substratum	Geographic coordinates		
					Latitude	Longitude	Altitude (m)
Nkie	S1	Separated two dwellings	Nothing	Sandy-clay	3° 49' 22.7''	11° 31' 15.4''	694
Nkie	S2	Isolated	Nothing	Sandy	3° 49' 18.9''	11° 31' 12.9''	703
Biyeme	S3	Located downstream of a field	Nothing	Muddy	3° 48' 42.3''	11° 29'	675
Biyeme	S4	Located near a car garage and a bar	Car and motor wash	Muddy	3° 48' 15.1''	11° 29' 12.3''	675
Biyeme	S5	located near a road under construction	Pump for irrigation of crops	Sand-muddy	3° 48' 03. 4''	11° 29' 19.6''	678
Municipal Lake	L1	Located in the centre of the city	Fishing	Herbarium	3°51' 52. 3''	11° 30' 34.7''	728
Obili Lake	L2	Bordered by fish ponds	Fishing	Herbarium	3° 51' 35''	11°29' 43''	720
Small Municipal Lake	L3	Located in the centre of the city	Fishing	Herbarium	3° 51' 53.9''	11° 30' 32.7''	727
Swamp at Tsinga	M1	Downstream a market and a car garage	Watering of livestock	Muddy	3° 50' 18.7''	11° 32' 07.2''	675
Swamp at Ekounou	M2	Near a big market garden	Irrigation of crops	Sandy-clay	3° 53' 28. 5''	11° 29' 45. 8''	752
Swamp at Ngoa Ekelle	M3	Behind a student housing estate	Irrigation of crops	Muddy	3° 51' 30''	11° 29' 50''	729

Physico-chemical analysis

The water temperature, potential of Hydrogen (pH), colour, suspended solids (SS), turbidity, alkalinity, salinity, electric conductivity, heavy metals, dissolved carbon dioxide (CO_2), dissolved oxygen (O_2), nitrogen compounds ($NH_4^{+,}$ NO_2^-, NO_3^-) and orthophosphate (PO_4^{3-}) were measured according to the protocol of Rodier et al. (2009) and APHA (1990). The organic pollution index (Leclercq, 2001) was calculated in order to give a synthetic account of the degree of pollution of the water sampled by using the three basic parameters required in organic pollution evaluation, namely: ammoniacal nitrogen (NH_4^+), nitrite (NO_2^-) and orthophosphate ions (PO_4^{3-}). This index allows to define 5 ecological quality classes of water that are: Zero pollution (4.6 ≤ IPO ≤ 5), low pollution (4.0 ≤ IPO ≤ 4.5), moderate pollution (3.0 ≤ IPO ≤ 3.9), high pollution (2.0 ≤ IPO ≤ 2.9), very high pollution (1 ≤ IPO ≤ 1.9) (Leclercq, 2001).

Biological analysis

The sampling of annelids was carried out by means of a net which is 30 cm × 30 cm dimension that is fixed to a handle and equipped with a conical thread of 100 µm Ø opening of mesh and 50 cm deep (Martin and Ait, 2012). The multihabitat approach proposed by Stark et al. (2001) and adapted from Barbour et al. (1999), which consists of a total of 20 shots, equivalent to an approximate surface area of 3 m^2 in a station of 100 m long was applied. After sampling, organisms were fixed in 10% formalin for a maximum of 24 h; they were then rinsed and stored in 70% alcohol-contained in pill bottles (Morgan and Morgan, 1990; Martin and Ait, 2012). In the laboratory, each oligochaete specimen was placed in a drop of glycerine which allows, because of its lightening power, to observe the external and internal structures of the organism under an optical microscope equipped with a camera. The identification was carried out using the keys proposed by Brinkhurst (1985) and Martin and Ait (2012). Mature individuals were distinguished from immature by their larger size and the presence of a clitellum. The species richness (S) of each community and the abundance of each population were sought.

Statistical analysis

The software Microsoft Office Excel 2007, SPSS 20. 0 and XLSTAT 11.0 made it possible to: (i) establish the descriptive statistics of individuals and sites (summaries tables, redundancy canonical analysis); (ii) measure the robustness of the spatio-temporal distribution of biological variables using the Kruskal-Wallis test associated with the Mann-Whitney "U" test. (iii) calculate the Spearman "r" coefficient between the abundance of organisms and the characteristics of the biotope. The differences observed are significant at 1 and 5% safety thresholds.

RESULTS

Spatio-temporal variations of physico-chemical parameters of water

The physico-chemical results of our sampling points are presented in Table 2 (central values of physico-chemical parameters), Table 3 (seasonal values of physico-chemical parameters) and Table 4 (values of heavy metals in each site). As lakes and swamps are stagnant waters, the velocity of water flow has only been assessed in the streams. The highest flow was recorded at S5 and the lowest at S2 ($p < 0.05$). The highest temperature values were recorded in lakes and the lowest in streams. However, within each type of ecosystem the temperature variations were not significant ($p > 0.05$). There was no significant difference for suspended solids, colour turbidity, pH and carbon dioxide contain within or between ecosystems. However swamps more often had relatively higher values. Sampled water, with values ranging from 7.14±0.83 to 7.83±048 were slightly basic while relatively higher values of CO_2 were recorded in swampy areas. Electrical conductivity, total dissolved solid, and alkalinity followed almost the same spatial and temporal variations. Mean values of these parameters were significantly lower in lakes than in swamps and stream sites ($p < 0.05$). In stream sites, the lower values were obtained at stations S1 and S2. In lakes, values obtained at L3 were significantly lower than those obtained at L2 and L1 ($p < 0.05$). In swamps the lower values of that parameters were recorded at M2 ($p < 0.05$).

Values of salinity were more important in streams and marshes than in lakes ($p < 0.05$). Within the stream ecosystem, the salinity of water at S3 was significantly higher than at S1 and S2. In the other types of ecosystems, the salinity of water did not vary significantly between the different sampling sites. Values of orthophosphates, nitrites, nitrates and ammonia nitrogen did not significantly differ from one station to another within each ecosystem. However, nitrates were significantly higher in swamps than in streams and lakes. The mean values of dissolved oxygen did not vary significantly within and between ecosystems, nor the organic pollution index (OPI) values which indicated an organic pollution of the sampled waters essentially ranging from moderate (3.06±0.75 at S2 and 3.00±0.86 at S1) to high (from 2.86±0.73 to 2.42±0.38 in the rest of sampling sites). Values of the physico-chemical parameters, except for OPI, were comparable between the seasons ($p > 0.05$). In streams and lakes, the highest values of OPI were obtained during the SRS and the lowest values during the LDS ($p < 0.05$). In swampy areas, the highest values of OPI were obtained during the SDS. These were significantly higher than those obtained during the LRS and LDS (Table 3).

The highest values of heavy metals were registered in swamps (Cd: 9.51±8.35 µg/L, Pb: 1.02±1.63 µg/L, Hg:7.35±12.60 µg/L, Zn: 1.77±2.98 µg/L, Cr :0.37±0.57 µg/L, Fe: 124.85±171.75 µg/L). Streams were the least rich in Cd (0.43±0.64 µg/L), Pb (0.09±0.08 µg/L), and Hg (0.06±0.08 µg/L), while the lakes were the least rich in Zn (0.82±0.20 µg/L), Cr (0.05±0.04) and Fe (14.88±16.08 µg/L) (Table 4).

Spatial distribution of Naididae

A total of 2035 *Branchiura* spp. individuals (1789 adult and 246 immature) and 880 *Limnodrilus* spp. (678 mature and 202 immature) were identified (Table 5). About 10 individuals of *Limnodrilus* spp. presented shrunken tail. *Branchiura* spp. as well as *Limnodrilus* spp. abundance varied significantly from one ecosystem to another following the profile: swampy areas (30±20 *Branchiura* spp., 14±21 *Limnodrilus* spp.) > streams (15±11 *Branchiura* spp., 6±9 *Limnodrilus* spp.) > lakes (2±2 *Branchiura* spp., 2±2 *Limnodrilus* spp.). No organism was collected at L3. Concerning the distribution of *Branchiura* spp. in streams, with a mean abundance of 31±7 individuals, S3 was the most populated site ($p < 0.05$). *Limnodrilus* spp were not collected at S2. At the other stream stations, their abundance was lower in S5 (1±1 individual).

In lake systems, no significant difference was revealed in spatial distribution of taxa ($p > 0.05$). In swampy areas, the abundance of *Branchiura* spp. was significantly higher at M2 (45±15 individuals) and that of *Limodrilus* spp. at M3 (26±31 indiiduals). *Branchiura* spp. were overall more abundant than *Limnodrilus* spp. in streams and marshes ($p < 0.05$) and not different in lakes ($p > 0.05$). In streams and marshes, *Branchiura* spp. were always the more abundant taxa in all sites except at S1 and M3 where the both taxa were equally abundant.

Seasonal distribution of Naididae

Table 6 shows no significant seasonal variation of the abundance of *Branchiura* spp. and *Limodrilus* spp. within each ecosystem ($p > 0.05$). More than 87% of *Branchiura* spp. specimens and 75% of *Limodrilus* spp. specimens were mature during all seasons.

Density of the populations

With a median density of 8 individuals/m² (Figure 2a), *Branchiura* spp. were significantly more abundant in the mud and sand/clay substrates than in the other ones (herbal, sandy and sand/mud), where the density of these oligochaetes fluctuated between 1 to 3 individuals/m². Similarly, the density of *Limnodrilus* spp. (Figure 2b) was significantly higher in the mud (0-39 individuals/m²) as well as in the sand/clay substrates (0-19 individual/m²). This taxa was not found in the sand while in the sand-mud substrate, it could reach 1 individual/m². In herbarium, the density of this taxa fluctuated between 0 to 4 individuals/m².

Influence of environmental parameters on the dynamics of organisms

The water temperature and the organic pollution index were negatively and often significantly correlated with the abundance of all the maturity stages of both taxa. All the other parameters (electrical conductivity, alkalinity, total dissolved solids, salinity, orthophosphate and water velocity) were positively and often significantly correlated to the abundance of the mature stages of these oligochaetes. Nitrate was positively and only significantly correlated to mature *Branchiura* spp. and negatively but not significantly correlated to mature stage of *Limnodrilus* spp. (Table 7).

Table 2. Central values of physico-chemical parameters at each station.

Ecosystems	Stations	Velocity (m/s)	Temperature (°C)	Turbidity (FTU)	Colour (Pt-Co)	SS (mg/L)	pH (UC)	CO_2 (mg/L)	Alkalinity (mg/L)	TDS (mg/L)
Streams	S1	0.43±0.14^{b}	25.3±1.52^{a}	26.1±38.1^{a}	122.8±133.6^{a}	17.2±19.6^{a}	7.29±0.36^{a}	16.96±8.15^{a}	28.2±11.7^{b}	121.3±16.4^{b}
	S2	0.09±0.03^{c}	25.38±0.85^{a}	37.0±30.9^{a}	141.8±131.1^{a}	26.7±18.0^{a}	7.14±0.83^{a}	15.65±9.69^{a}	27.1±7.4^{b}	134.2±9.1^{b}
	S3	0.34±0.1^{b}	25.18±0.65^{a}	22.6±19.8^{a}	140.9±95.5^{a}	14.9±8.4^{a}	7.59±0.37^{a}	17.77±4.21^{a}	55.01±13.0^{a}	231.6±9.8^{a}
	S4	0.71±0.15^{b}	25.48±0.82^{a}	24.7±19.7^{a}	115.5±48.3^{a}	14.2±10.6^{a}	7.80±0.34^{a}	17.57±9.17^{a}	55.3±14.0^{a}	221.5±26.3^{a}
	S5	1.00±0.26^{a}	25.67±0.75^{a}	27.7±27.1^{a}	109.0±53.9^{a}	16.3±11.0^{a}	7.72±0.28^{a}	17.95±6.20^{a}	50.8±8.1^{a}	199.0±35.7^{a}
	Average values of Rivers	**0.51±0.35**	**25.44±0.95^{c}**	**27.6±27.4^{a}**	**126.0±96.9^{a}**	**17.8±14.5^{a}**	**7.51±0.53^{a}**	**17.18±7.53^{a}**	**43.3±16.9^{a}**	**181.5±50.4^{a}**
Lakes	L1	/	28.57±0.83^{a}	26.3±25.5^{a}	91.5±40.2^{a}	19.5±11.1^{a}	7.83±048^{a}	17.18±11.80^{a}	29.7±12.5^{a}	133.4±38.9^{a}
	L2	/	29.18±1.11^{a}	30.0±25.9^{a}	146.4±95.4^{a}	19.8±11.7^{a}	7.56±0.49^{a}	17.01±8.20^{a}	31.9±12.5^{a}	134.2±15.5^{a}
	L3	/	28.71±0.92^{a}	28.3±36.5^{a}	106.1±78.9^{a}	16.8±15.0^{a}	7.42±0.45^{a}	16.11±7.97^{a}	14.3±4.6^{b}	68.5±47.8^{b}
	Average values of Lakes	/	**28.82±0.97^{a}**	**28.22±28.95^{a}**	**114.7±76.7^{a}**	**18.7±12.4^{a}**	**7.60±0.49^{a}**	**16.77±9.22^{a}**	**25.28±12.99^{c}**	**112.0±47.4^{b}**
Marshes	M1	/	26.35±1.31^{a}	26.4±27.6^{a}	99.3±55.5^{a}	21.4±21.3^{a}	7.55±0.28^{a}	21.50±14.02^{a}	43.3±10.0^{a}	219.9±64.2^{a}
	M2	/	26.48±1.62^{a}	47.5±57.9^{a}	156.3±178.6^{a}	53.8±71.0^{a}	7.49±0.42^{a}	24.22±25.92^{a}	24.5±13.4^{b}	111.8±29.6^{c}
	M3	/	26.74±1.00^{a}	26.4±30.7^{a}	160.1±87.0^{a}	20.9±15.9^{a}	7.48±0.37^{a}	21.47±16.91^{a}	31.8±10.8^{a}	158.4±34.8^{b}
	Average values of Marshes	/	**26.52±1.31^{b}**	**33.4±41.1^{a}**	**138.5±119.0^{a}**	**32.0±45.2^{a}**	**7.51±0.35^{a}**	**22.40±19.09^{a}**	**33.2±13.6^{b}**	**163.4±63.0^{a}**

		Electric conductivity (µS/cm)	Salinity (‰)	PO_4^{3-} (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	NH_4^+ (mg/L)	O_2(%)	OPI
Streams	S1	243.2±32.8^{b}	0.11±0.01^{b}	1.20±1.38^{a}	1.95±3.30^{a}	1.41±0.86^{a}	0.47±0.89^{a}	47.53±24.40^{a}	3.00±0.86^{a}
	S2	271.8±18.6^{b}	0.13±0.01^{b}	3.65±4.48^{a}	1.30±3.17^{a}	2.21±1.20^{a}	0.49±0.65^{a}	47.32±22.19^{a}	2.81±0.67^{a}
	S3	459.5±22.2^{a}	0.29±0.20^{a}	2.40±2.75^{a}	1.52±3.01^{a}	2.59±1.92^{a}	0.93±2.11^{a}	47.78±20.43^{a}	2.64±0.78^{a}
	S4	438.1±55.9^{a}	0.22±0.03^{ab}	2.06±2.73^{a}	1.76±3.27^{a}	1.96±1.40^{a}	0.26±0.32^{a}	46.14±20.73^{a}	2.75±0.67^{a}
	S5	436.3±38.6^{a}	0.21±0.02^{ab}	1.09±1.58^{a}	3.30±6.27^{a}	2.40±1.49^{a}	0.18±0.10^{a}	47.74±19.55^{a}	3.06±0.75^{a}
	Average values of Rivers	**369.7±99.5^{a}**	**0.19±0.11^{a}**	**2.08±2.87^{a}**	**1.97±3.92^{a}**	**2.11±1.42^{b}**	**0.46±1.07^{a}**	**47.30±20.80^{a}**	**2.85±0.74^{a}**
Lakes	L1	295.0±62.1^{a}	0.14±0.03^{a}	0.90±1.35^{a}	2.43±4.83^{a}	3.33±4.14^{a}	0.43±0.90^{a}	47.22±22.74^{a}	2.83±0.69^{a}
	L2	261.0±55.9^{a}	0.11±0.03^{a}	1.69±2.48^{a}	1.48±1.54^{a}	2.83±1.48^{a}	0.19±0.13^{a}	51.80±20.78^{a}	2.78±0.73^{a}
	L3	129.3±47.7^{b}	0.07±0.03^{a}	2.02±2.49^{a}	1.48±1.57^{a}	1.47±0.98^{a}	0.15±0.12^{a}	49.77±20.21^{a}	2.86±0.73^{a}
	Average values of Lakes	**228.4±90.3^{c}**	**0.10±0.04^{b}**	**1.53±2.16^{a}**	**1.80±3.01^{a}**	**2.54±2.65^{b}**	**0.25±0.53^{a}**	**49.59±20.74^{a}**	**2.82±0.70^{a}**
Marshes	M1	444.4±112.3^{a}	0.22±0.05^{a}	1.70±2.16^{a}	1.65±2.04^{a}	4.12±2.87^{a}	0.13±0.07^{a}	55.19±18.04^{a}	2.42±0.38^{a}
	M2	215.3±54.7^{c}	0.18±0.23^{a}	2.40±2.41^{a}	1.97±2.34^{a}	5.30±4.88^{a}	0.47±0.77^{a}	59.37±14.02^{a}	2.53±0.73^{a}
	M3	300.5±39.1^{c}	0.14±0.02^{a}	2.57±3.83^{a}	1.07±1.41^{a}	3.53±3.18^{a}	0.22±0.19^{a}	52.94±17.59^{a}	2.61±0.45^{a}
	Average values of Marshes	**320.1±120.7^{b}**	**0.18±0.14^{a}**	**2.22±2.84^{a}**	**1.56±1.95^{a}**	**4.32±3.72^{a}**	**0.27±0.47^{a}**	**55.83±16.39^{a}**	**2.52±0.53^{a}**

Values in bold = ecosystem averages. Values in simple character = station means. On each column, Means values within each ecosystem with same letter = no significant difference, while those with different letters = significant difference. Between ecosystem types, means values with same letter = no significant difference, while those with different letters = significant difference.

Table 3. Seasonal values of physico-chemical parameters.

Ecosystems	Seasons	Velocity (m/s)	Temperature (°C)	Turbidity (FTU)	Colour (Pt-Co)	SS (mg/L)	pH (UC)	CO_2 (mg/L)	Alkalinity (mg/L)	TDS (mg/L)
Streams	SRS	0.63±0.37^{a}	25.47±1.28^{a}	23.6±25.2^{a}	151±135.6^{a}	16.3±12.8^{a}	7.53±0.42^{a}	19.48±13.14^{a}	45.2±16.8^{a}	180.9±54.1^{a}
	SDS	0.45±0.30^{a}	24.67±0.61^{a}	49.5±29.9^{a}	168.3±147.9^{a}	26.9±16.9^{a}	7.38±0.18^{a}	16.54±5.61^{a}	38.5±14.3^{a}	189.2±50.0^{a}
	LRS	0.63±0.42^{a}	25.41±0.82^{a}	14.5±10.7^{a}	84.2±31.1^{a}	11.2±7.3^{a}	7.38±0.39^{a}	17.76±3.53^{a}	45.7±17.4^{a}	179.3±51.5^{a}
	LDS	0.38±0.26^{a}	25.85±0.67^{a}	29.6±30.9^{a}	117.5±104.5^{a}	19.5±16.5^{a}	7.65±0.76^{a}	15.35±4.08^{a}	42.4±18.3^{a}	179.8±50.6^{a}
Lakes	SRS	/	29.01±1.44^{a}	22.1±25.2^{a}	108.9±113.1^{a}	13.9±10.8^{a}	7.51±0.40^{a}	20.34±15.94^{a}	26.0±11.0^{a}	114.4±47.5^{a}
	SDS	/	28.30±0.40^{a}	55.2±36.4^{a}	176.0±85.7^{a}	26.8±11.8^{a}	7.32±0.15^{a}	15.54±5.41^{a}	23.8±8.0^{a}	106.8±41.8^{a}
	LRS	/	28.83±0.94^{a}	16.9±13,1^{a}	100.1±41.3^{a}	13.7±9.0^{a}	7.46±0.46^{a}	17.80±3.10^{a}	21.3±10.2^{a}	112.0±54.3^{a}
	LDS	/	28.93±0.77^{a}	27.8±30.8^{a}	99.4±48.3^{a}	22.1±14.0^{a}	7.93±0.55^{a}	13.93±6.69^{a}	28.4±17.9^{a}	112.8±50.4^{a}
Marshes	SRS	/	27.41±1.51^{a}	20.7±19.5^{a}	128.1±93.3^{a}	13.3±10.1^{a}	7.74±0.21^{a}	34.61±26.03^{a}	25.9±10.8^{a}	173.2±49.6^{a}
	SDS	/	26.15±1.33^{a}	55.6±42.2^{a}	172.3±105.2^{a}	52.8±43.8^{a}	7.31±0.19^{a}	23.80±5.67^{a}	35.8±14.4^{a}	162.3±48.1^{a}
	LRS	/	26.19±0.79^{a}	52.7±66.6^{a}	185.5±185.1^{a}	51.4±76.8^{a}	7.25±0.33^{a}	17.80±3.46^{a}	32.0±17.9^{a}	146.9±59.4^{a}
	LDS	/	26.30±1.28^{a}	17.43±9.5^{a}	94.2±64.2^{a}	21.1±18.0^{a}	7.63±0.36^{a}	15.99±2.65^{a}	38.3±10.1^{a}	168.8±82.9^{a}

Ecosystems	Seasons	Electric conductivity (µS/cm)	Salinity (‰)	PO_4^{3-} (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	NH_4^+ (mg/L)	O_2(%)	OPI
Streams	SRS	359.9±107.1^{a}	0.22±0.20^{a}	2.22±4,72^{a}	5.86±6.15^{a}	2.60±1.55^{a}	0.19±0.15^{a}	36.83±25.74^{a}	3.33±0.77^{a}
	SDS	378.2±99.5^{a}	0.19±0.07^{a}	1.53±1.41^{a}	0.07±0.13^{a}	2.67±0.99^{a}	0.55±0.44^{a}	54.36±13.52^{a}	2.77±0.50^{b}
	LRS	365.8±102.7^{a}	0.18±0.05^{a}	2.51±2.50^{a}	0.17±0.33^{a}	1.85±1.07^{a}	0.11±0.10^{a}	40.35±23.89^{a}	2.91±0.60^{ab}
	LDS	376.0±98.5^{a}	0.18±0.05^{a}	1.93±1.82^{a}	1.34±1.73^{a}	1.66±1.63^{a}	0.89±1.76^{a}	56.84±10.06^{a}	2.48±0.75^{c}
Lakes	SRS	230.9±95.3^{a}	0.11±0.05^{a}	0.64±1.28^{a}	3.63±4.94^{a}	3.58±4.86^{a}	0.08±0.09^{a}	37.09±28.05^{a}	3.44±0.69^{a}
	SDS	213.6±83.6^{a}	0.01±0.03^{a}	0.72±0.83^{a}	0.04±0.04^{a}	3.05±1,72^{a}	0.32±0.22^{a}	55.38±15.36^{a}	3.17±0.51^{b}
	LRS	209.1±81.0^{a}	0.10±0.04^{a}	1.99±2.30^{a}	0.94±0.99^{a}	2.02±0.96^{a}	0.10±0.04^{a}	48.28±19.55^{a}	2.63±0.42^{c}
	LDS	248.5±102.6^{a}	0.11±0.05^{a}	2.27±2.79^{a}	1.94±2.31^{a}	1.89±1.19^{a}	0.47±0.87^{a}	57.07±14.24^{a}	2.33±0.53^{d}
Marshes	SRS	317.7±90.8^{a}	0.24±0.25^{a}	3.81±4.42^{a}	3.27±2.99^{a}	3.33±3.41^{a}	0.14±0.20^{a}	62.09±17.57^{a}	2.56±0.60^{ab}
	SDS	312± 89.9^{a}	0.17±0.06^{a}	1.37±1.09^{a}	0.13±0.21^{a}	3.85±1.03^{a}	0.23±0.14^{a}	61.47±7.88^{a}	2.78±0.69^{a}
	LRS	297.1±104.7^{a}	0.15±0.08^{a}	2.61±2.64^{a}	0.86±0.94^{a}	6.63±5.46^{a}	0.59±0.85^{a}	49.03±18.83^{a}	2.37±0.56^{b}
	LDS	343.1±166.4^{a}	0.17±0.08^{a}	1.16±1.39^{a}	1.53±1.00^{a}	3.55±2.73^{a}	0.15±0.12^{a}	53.42±5.83^{a}	2.47±0.36^{b}

On each column, values with same letter = no significant difference, values with different letters = significant difference.

Table 4. Values of heavy metals in each station.

Types ecosystems/stations		Heavy metals (µg/L)					
		Cd	Pb	Hg	Zn	Cr	Fe
Standards for crops irrigation (FAO, 2003)		10	5000	1	2000	100	5000
Streams	S1	0.00	0.00	0.00	0.10	0.00	21.60
	S2	0.01	0.13	0.00	2.90	0.18	212.74
	S3	0.26	0.03	0.20	1.20	0.01	125.00
	S4	0.36	0.21	0.05	0.32	0.23	109.20
	S5	1.54	0.08	0.04	0.14	0.05	112.00
	Mean	0.43±0.64	0.09±0.08	0.06±0.08	0.93±1.19	0.09±0.10	116.11±67.85
Lakes	L1	2.74	0.00	0.00	0.87	0.10	11.47
	L2	1.41	0.00	0.45	0.98	0.05	32.40
	L3	2.04	0.47	0.01	0.60	0.01	0.78
	Mean	2.06±0.67	0.16±0.27	0.15±0.26	0.82±0.20	0.06±0.05	14.88±16.08
Marshes	M1	0.23	0.12	0.00	0.00	0.03	321.80
	M2	11.9	2.9	0.16	5.21	1.02	46.5
	M3	16.4	0.04	21.9	0.1	0.04	6.25
	Mean	9.51±8.35	1.02±1.63	7.35±12.60	1.77±2.98	0.37±0.57	124.85±171.75

The canonical redundancy analysis (Figure 3) presents the environmental variables that described the distribution of Naididae tubificids in our sampling sites. This canonical redundancy analysis explains 58.5% of species-environment correlation with a variance of 70.2%. The distribution of species along axis 1 are explained by the electrical conductivity, the total dissolved solids, the salinity, the dissolved carbon dioxide, the alkalinity, the nitrates, the temperature and the Organic Pollution Index. Axis 2 is significantly correlated to suspended solids, orthophosphates, nitrates, salinity, dissolved carbon dioxide and the organic pollution index. Thus, conditions of high electrical conductivity, salinity, total dissolved solids content, alkalinity, nitrates and low temperature values appeared favourable to the development *Branchiura* spp. while *Limnodrilus* spp. prefered environments that were rich in dissolved carbon dioxide and fairly poor in suspended solids, orthophosphates, nitrates and ammonium ions.

DISCUSSION

Oligochetes belonging to the genera of *Branchiura* (Beddard, 1892) and that of *Limnodrilus* (Claparède, 1862) were collected in the different sampling sites during the study period. Among these genera only the first one has already been identified in the surface water in Cameroon, precisely in urban streams of Douala (Tchakonte, 2016). None of these has been identified in poor anthropized streams of the center and the west regions of Cameroon (Nyamsi, 2018; Kengne, 2018). Naididae tubificids are for the most characteristic of well mineralized and hypoxic milieu (Martin and Ait, 2012; Schenková and Helešic, 2006). Species belonging to the genus *Branchiura* have developed gills to cope with these harsh conditions (Martin and Ait, 2012). *Limodrilus hoffmeisteri* also possesses a hemolymph that is rich in erythrocruorine which can address easily low oxygen conditions (Martin and Ait, 2012). Therefore the high abundance of *Branchiura* spp. and *Limodrilus* spp. in our milieu indicates the low oxygenation of these environments. This is justified by the non satisfied values of dissolved

Table 5. Relative abundance (%) of the various species of Oligochaetes collected at each station.

Station	Taxa (n_i; $\overline{X}$; %)		Total (n_i)
	***Branchiura* spp.**	***Limnodrilus* spp.**	
S1	138; 12±4[b]; 47.39±19.09[a]	180; 15±14[a]; 52.61±19.09[a]	318
S2	47; 4±2[b]; 100	/	47
S3	376; 31±7[a]; 83.38±6.22[a]	77; 6±3[a]; 16.62±6.22[b]	453
S4	207; 17±7[b]; 81.85±22.31[a]	71; 6±8[a]; 18.15±22.31[b]	278
S5	104; 9±6[b]; 91.37±7.59[a]	9; 1±1[b]; 8.63±7.59[b]	113
S_T	**872; 15±11[b]; 80.78±28.62[a]**	**337; 6±9[b]; 19.20±28.62[b]**	**1209**
L1	43; 4±2[a]; 58.91±37.30[a]	31; 3±4[a]; 42.76±33.97[a]	74
L2	34; 3±2[a]; 59.19±28.69[a]	23; 2±1[a]; 40.81±20.69[a]	57
L_T	**77; 2±2[c]; 59.05±32.54[a]**	**54; 2±2[c]; 40.95±31.02[a]**	**131**
M1	299; 25±16[b]; 70.20±24.60[a]	130; 11±11[b]; 29.80±24.60[b]	429
M2	542; 45±15[a]; 91.68±6.95[a]	48; 4±4[b]; 8.32±6.95[b]	590
M3	245; 20±21[b]; 43.16±25.77[a]	311; 26±31[a]; 56.84±25.77[a]	556
M_T	**1087; 30±20[a]; 68.35±22.47[a]**	**489; 14±21[a]; 31.65±22.47[b]**	**1576**

S_T = Total streams. L_T = Total lakes. M_T = Total marshes. Mean abundances within each ecosystem with same letter = no significant difference, while those with different letters = significant differences. Relative abundance (per station) of both taxa with same letter = no significant difference, while those with different letters = significant differences.

Table 6. Seasonal values of mean abundances of *Branchiura* spp. and *Limodrilus* spp. in different ecosystems.

Ecosystems	Seasons	Taxa (n_i; $\overline{X}$)		Total (n_i)
		***Branchiura* spp.**	***Limnodrilus* spp.**	
Streams	SRS	253; 17±13[a]	89; 6±15[a]	342
	SDS	140; 14±10[a]	39; 4±5[a]	179
	LRS	187; 12±9[a]	108; 7±6[a]	295
	LDS	292; 15±11[a]	101; 5±6[a]	393
Lakes	SRS	28; 3±3[a]	22; 2±4[a]	50
	SDS	13; 2±2[a]	4; 1±1[a]	17
	LRS	15; 2±2[a]	9; 1±1[a]	24
	LDS	21; 2±3[a]	19; 2±3[a]	40
Marshes	SRS	457; 51±17[a]	204; 23±38[a]	661
	SDS	154; 26±11[a]	59; 10±9[a]	213
	LRS	175; 19±17[a]	100; 11±14[a]	275
	LDS	300; 25±19[a]	126; 11±8[a]	426

On each column, means values with same letter = no significant difference, those with different letters = significant difference.

oxygen in our samples (< 75%, Table 2).

The distribution of tubificids in our study sites is governed by many factors. The significant correlations between the indicators of water organic pollution (electrical conductivity, TDS, Salinity, Nitrates) and oligochaetes abundance (Table 7) indicate that these organisms prefer polluted water. Schenková and Helešic (2006) obtained similar results in a small stream in the Czech Republic, where the abundance of the oligochaetes community was significantly and positively correlated with the electrical conductivity and nitrate. Water temperature was negatively and significantly correlated with the abundance of *Branchiura* spp. and *Limnodrilus* spp. This physical parameter varies between 21.9 and 31°C in this tropical area (Table 2). As the Naididae originate from temperate zones (Timm, 1980), we suggest that the above species are sensitive to some degree of heat. In fact, Timm (2020) demonstrates that the reproductive capacity of Oligochaetes decreases at elevated temperatures (25° to 35°C). In the literature, we also notice that the reproduction rate of *Branchiura sowerbyi,* for example, declines when the water temperature exceeds 25°C (Aston and Miler, 1982; Bonacina et al., 1994).

No specimen of *Limnodrilus* spp. was collected at S2. The lower pH values obtained at this station (sometimes 5UC) could justify this result. Roff and Kwiatkowski (1977) also observed the absence of *L. hoffmeisteri* in lakes with a pH below 6.6. As with

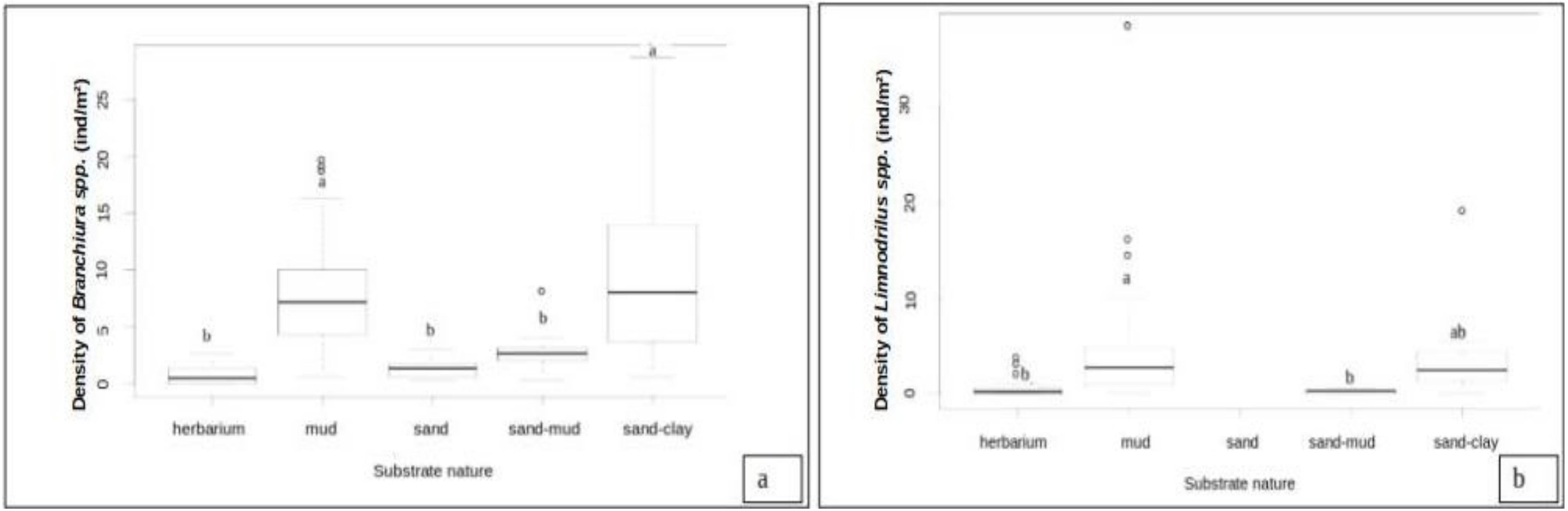

Figure 2. Densities of (a) *Branchiura* spp. and (b) **Limnodriius** spp as a function of substrat.

Table 7. Correlations between physico-chemical parameters and the abundance of Naididae Tubificids.

Species mature stages	Variables								
	Velocity	Temperature	Conductivity	Alkalinity	TDS	PO_4^{3-}	NO_3^-	salinity	IPO
Branchiura spp. mature	0.176*	-0.320**	0.387**	0.309**	0.411**	0.112	0.190*	0.434**	-0.151
Branchiura spp. immature	0.179*	-0.442**	0.365**	0.335**	0.355**	0.175*	0.120	0.446**	-0.200*
Limnodrilus spp. mature	0.019	-0.212*	0.186*	0.225**	0.160	0.111	-0.026	0.185*	-0.174*
Limnodrilus spp. immature	-0.087	-0.078	0.228**	0.152	0.270**	0.011	0.087	0.206*	-0.080

* = significant correlation at 5%, ** = significant correlation at 1%.

Ragonha et al. (2013), the substrate composition played an important role in the oligochaetes community structure and distribution in this study.

In the current study, tubificids preferentially colonised muddy and sand-clay substrates (Figure 2). This result does not agree with those of Ragonha et

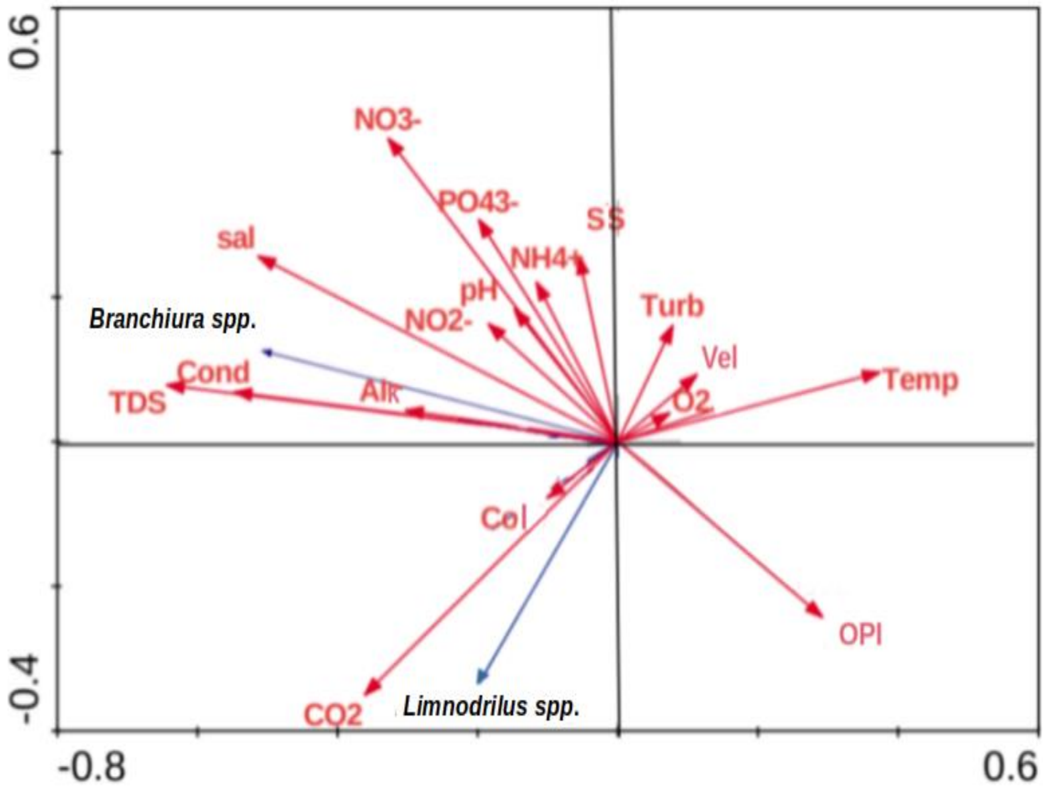

Figure 3. Result of the canonical redundancy analysis performed on the biotic variables measured in the different sampling stations.

al. (2013) who reported the dominance of tubificids in sand rich organic matter. Schenková et al. (2001) also found more tubificids in fine sand that is rich in organic matter than in other substrates.

There was no significant difference between seasonal distribution of Naididae tubificids identified in the present study (Table 6). Conversely, Nijboer et al. (2004) argued that the seasons mostly influence the hydrographic regime of a given site, with consequences on the development of the vegetation, and the grazing groups of oligochaeta such as Naididae-Naidinae, Pristininae. Schenková and Helešic (2006) also associated the seasonal variation of oligochaetes to the development of the vegetation which favours the installation of Naididae-Naidinae. It is worth to also make clear that *Branchiura* spp. and *Limnodrilus* spp. weakly colonised herbarium (Figure 2) Mature individuals of *Branchiura* spp. as well as of *Limnodrilus* spp. were collected throughout the year (Table 6). A year-round maturity period had already been reported for *Tubifex tubifex* and *L. hoffmeisteri* in rivers in Spain (Martinez-Ansemi, 1990). Contrary to the results obtained by Tchakonte (2016) in the polluted waters of the city of Douala, *T. tubifex* was not collected in our study stations. According to Zeybek et al. (2018), this specie is very abundant in polluted environments where it often co-occurs with *Limnodrilus hoffmeisteri,* although *T. tubifex* is a poor competitor in the environment (Nijboer et al., 2004). It only thrives in extreme environmental conditions that limit the development of other benthic macroinvertebrates (Nijboer et al., 2004). Competitive or predatory pressure is a limiting factor for its presence in aquatic environments (Milbrink, 1983; Zeybek et al., 2018). In our study stations, the observation of a shrunken tail in some oligochaetes, which is a sign of regeneration, could precisely reflect a certain predatory pressure in our environment. In this respect, Kaliszewicz (2003) demonstrated the regeneration of the anterior, the posterior and even both parts of the body in some Naididae such as *Stylaria lacustris* following their sectioning by insect larvae. The predation pressure could also explain the low densities of oligochaetes in our study area (Figure 2) where some stations even contained fish. The shrunken tail could also be a result of a decontamination strategy developed by these aquatic worms. Bouché et al. (2000) observed the amputation of the tail of *T. tubifex* following the exposure to concentration of 0.01 to 0.05 mg/l of cadmium. After having accumulated the metal in its tail, this annelid gets rid of it. Since the cadmium concentrations obtained at some stations are at least equal to those reported by Bouché et al. (2000), *Limnodrilus* spp. collected might have had the same response to this stress. The values of cadmium and mercury found in swampy stations (M2 and M3) are above the water quality standards for crops irrigation and may be harmful to human.

The dominance of the abundance of *Branchiura* spp. over that of *Limnodrilus* spp. (Table 5) can on one hand be explained by their better adaptation to pollution. The Canonical Redundancy Analysis (Figure 3) showed a higher link between *Branchiura* spp. and the indicators of organic pollution. It could also be explained by their possible better (a) adaptation to the predation pressure and (b) annual productivity rate. In fact, studies on *Branchiura sowerbyi* showed that it possesses sensorineural specializations that maximize the detection of vibrations in the substrate, water movement and contact which make it more successful in escaping predators (Drewes and Zoran, 1989). Raburu et al. (2002) also demonstrated that *B. sowerbyi* reproduced and developped faster than *L. hoffmeisteri*.

Conclusion

This study enabled us to isolate and identify, to the genus level, the Naididae tubificids present in 8 water bodies of the city of Yaoundé. These are *Branchiura* spp. and *Limnodrilus* spp. The distribution of these organisms in the study sites was governed by the oxygenation of the milieu, its mineralization, the nature of the substrate and the temperature. *Branchiura* spp. and *Limnodrilus* spp. are two polluo-resistant species. Their presence in those water bodies, in addition to showing the high pollution level of the water, also shows the high predation pressure in the milieu studied.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessing and plugging the missing links for effective community participation in the Strategic Environmental Assessment and Land Use Plan of Yala Wetland, Kenya

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Wetlands are one of the world's most important environmental assets but currently face complex challenges. Wetlands' long-term sustainability require participation of the riparian communities in their management, yet this involvement in seeking solutions to wetland's resources use remains a grave challenge. Yala Wetland, Kenya is a very important resource whose challenges revolve around land and water resource use for competing interests and from catchment degradation. Consequently, action research was conducted to assess level of and effectiveness of Yala Wetland Community Participation in Yala Strategic Environmental Assessment and Land Use Planning processes through Yala Project Advisory Committee Framework. The study targeted 410 local communities, thirty-four key informants, and 187 students from learning institutions. The study revealed that utilization of Yala resources has been partly informed by how the wetland communities perceive its formation. Further, they identified key environmental issues, their root causes and corresponding opportunities that Yala Land Use Plan needed to address. The analysis also showed existing gaps in integration of community information and scientific information, disconnect between decision making and requisite scientific and practical evidence; and absence of community sensitive governance structure. The study integrated local communities' vast knowledge and planning information and formed Yala Swamp Management Committee with communities at the centre of conservation. Additionally, there is a secretariat led by a Community Facilitator to coordinate execution of the Conservation Area Management Plan 2019-2029. The final Yala Land Use Plan developed in participatory manner itemized three main land uses namely Conservation areas, Agricultural areas and settlement areas.

Keywords: Yala Wetland, Community Participation, Land Use Planning, Governance.

INTRODUCTION

Wetlands occur where the ground water table is at or near the land surface, or where the land is covered by water (Ramsar Convention Secretariat, 2016), and are one of the world's most important environmental assets which provide homes for large, diverse biota as well as significant economic, social and cultural benefits related to timber, fisheries, hunting, recreational and tourist activities. They constitute an important resource for riparian communities and therefore it is important that communities participate in their management. Community participation in natural resource management has evolved from the realization that people living with natural resources should be responsible for their management and benefit from using the resources (Ostrom, 1990; WWF, 2006; Lockie and Sonnenfeld, 2008; GoK, 2010a). This is central to sustainable natural resource management at all levels. The Aarhus Convention of 1998 states that citizens must not only have access to information but must also be entitled to participate in decision making and have access to justice in environmental matters (DETR, 2000; Stec et al., 2000). However, participation of local communities in seeking solutions to wetlands resources use remains a grave challenge as managers of participation processes engage in low level consultations that do not empower them to co-manage these resources alongside government agencies mandated to do so (GoK, 2010a; Springate-Baginski et al., 2009).

A synthesis of research and policy priorities for papyrus wetlands presented in Wetlands Conference in 2012 concluded that more research on the governance, institutional and socio-economic aspects of papyrus wetlands is needed to assist African governments in dealing with the challenges of conserving wetlands in the face of growing food security needs and climate change (van Dam et al., 2014). The other three priorities were the need for: better estimates of the area covered by papyrus wetlands as limited evidence suggest that the loss of papyrus wetlands is rapid in some areas; for a better understanding and modelling of the regulating services of papyrus wetlands to support trade-off analysis and improve economic valuation; and research on papyrus wetlands should include assessment of all ecosystem services so that trade-offs can be determined as the basis for sustainable management strategies (‘wise use’).

In Africa, wetlands degradation is on the increase as wetland ecosystems are relied upon to lessen industrial, urban and agricultural pollution and supply numerous services and resources (Nasongo et al., 2015; Kansiime et al., 2007). Similarly, lack of recognition of the traditional values of these wetlands, desire for modernisation and failure to appreciate their ecological role aggravate their degradation (Maclean et al*.,* 2003; Panayotou, 1994).

Public participation has been the focus of many Environmental Impact Assessments (EIAs) and Strategic Environmental Assessment (SEA) studies globally (Doelle and Sinclair, 2005; Hartley and Wood, 2005). This article defines public participation as the process of ensuring that those who have an interest or stake in a decision are involved in making that decision. Participation has become a key element in the discussion concerning development particularly in natural resources management (Cooke and Kothari, 2001). Today, the concept is seen as a magic bullet by development agencies who are making participation one, if not the core element of development (Michener, 1998).

According to the International Association of Public Participation (IAP2, 2008), public participation consists of five levels: information (lowest level, where participation does not go beyond information provision), consultation, involvement, collaboration and empowerment (highest level, where the public are given a final say on the project decision).

Okello et al. (2009) study on public participation in SEA in Kenya concludes that it is unsatisfactory. The study noted that Environmental Management and Coordination Act (EMCA) of 1999 and its 2015 amendment and Environmental Impact Assessment Audit Regulations 2003 (EIA AR) did not have provisions detailing consultation with the public during SEA and that knowledge and awareness of the public at all levels of society were found to be poor (GoK, 2015). The undoings of public participation include information inaccessibility in terms of readability and physical access, inadequate awareness of the public on their roles and rights during EIA, incomprehensible language and incomplete regulation for public participation during SEA. These undoings have to be overcome if public participation in Kenya has to be improved and move to higher levels (that is, collaboration-empowerment) of participation on the spectrum of public participation level.

Community participation in Yala Wetland SEA and LUP

Yala Wetland is an important resource shared by Siaya and Busia counties of Kenya. It supports the livelihoods of surrounding communities, including water, papyrus and fisheries, among others, and provides vital ecosystem services such as purification and storage of water. It also acts as a carbon sink, thus regulating global and local climatic conditions and is internationally recognized as a Key Biodiversity Area that hosts globally and nationally threatened bird, fish and mammal species. The Wetland is also an important agricultural asset that has attracted both local farmers and external agricultural interests (EANHS, 2018).

This important resource is facing many challenges that revolve around land and water resource use for competing interests and also from catchment degradation (GoK, 2018, 1987; Odhengo et al., 2018a; Ondere, 2016; Odero, 2015a; Odero, 2015b; Muoria et al., 2015; van Heukelom, 2013; Raburu, 2012; Thenya and Ngecu, 2017; Onywere et al., 2011; GoK, 2010b; Kenya Wetland Forum, 2006; Lihanda et al., 2003; Otieno et al., 2001; GoK, 1987). These challenges pointed to the need for a

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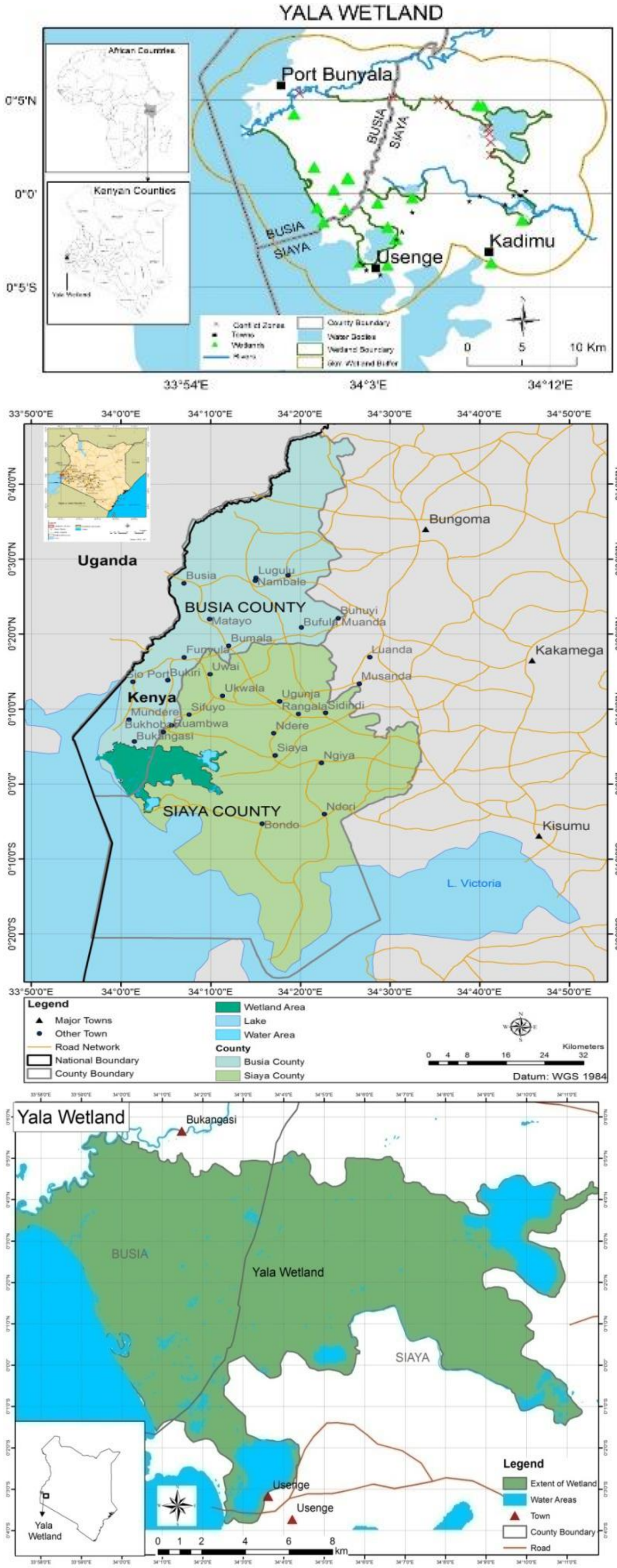


Figure 1. Location of Yala Wetland in Lake Victoria Basin. Source: Simonit and Perrings (2011).

well-considered Land Use Plan (LUP) that would provide a rational and scientific basis for future development and use of the resource. This situation prompted and encouraged County Governments of Siaya and Busia, and Nature Kenya to initiate processes that culminated in the present effort to prepare a LUP that will help resolve these challenges so that Yala Wetland will be able to sustainably support local residents' livelihoods while its ecological integrity and that of its associated ecosystems is protected.

Preliminary processes implemented by Inter-ministerial Technical Committee (IMTC) and a Deltas Management Secretariat prepared a LUP Framework to guide the planning process and was agreed upon by stakeholders. The IMTC's responsibility is coordination, policy and planning processes of major deltas in Kenya. The Framework was as result of a participatory and collaborative process that involved various stakeholders at the local, county and national levels. As required by Kenya Constitution article 69(1) and part VIII section 87-92; and section 115 of County Government Act, 2012 on devolution provisions and part 2 section 6 (1-2) Public Participation Bill, 2020 provided for participation of local communities in the Land Use Planning process through a Yala Project Advisory Committee (YPAC) (GoK, 2010, 2012a; GoK, 2012b; GoK, 2020). The LUP process also benefited from a SEA process that served to assess the environmental implications of the Land Use Plan. The action research reported in this paper sought to: (1) assess the historical and current state of community participation in SEA/LUP of Yala Wetland ecosystem management; (2) identify the local communities' key environmental issues for SEA/LUP of Yala Wetland ecosystem management; (3) incorporate the results in the Yala Wetland SEA/LUP processes.

MATERIALS

The Yala wetland area

Yala Wetland is located on the north eastern shoreline of Lake Victoria between 33° 50' E to 34° 25'E longitudes to 0° 7'S to 0° 10'N latitude (Figure 1), and is situated on the deltaic sediments of the confluence of both Nzoia and Yala Rivers where they enter the north-eastern corner of Lake Victoria. It is highly valued by local communities (NEMA, 2016). Yala Wetland is Kenya's third largest wetland after Lorian Swamp and Tana Delta and has a very delicate ecosystem. It is shared between Siaya and Busia counties of Kenya and covers an area of about 20,756 ha (about 207 km^2) (JICA, 1987; LBDA, 1989; Odhengo et al., 2018b).

Yala Wetland and its environment have a high population density (KNBS, 2010). The Siaya County side had human population density estimated at 393 km^{-2} in 2009 while Busia County had a higher concentration of up to 527 persons/km^2 (KNBS, 2010).

Based on the 2019 National Census Results, the population of Siaya and Busia Counties were 743,946 with a growth rate of 1.7 % and 833,760 with a growth rate of 3.1%, respectively. The population of the planning area (wetland and its buffer of 5 km radius) was estimated at 130,838 in 2014 and was projected to be 171,736 in 2030 and 241,280 in 2050 (KNBS, 2010). The mean household size was 5.05, although population density in the wetland and adjacent areas were not uniform. High population concentrations were found in the Busia County side around the banks of Nzoia River and to the South in Siaya County side around Usenge town and north of Lake Kanyaboli (KNBS, 2010).

Biodiversity

The Yala Wetland, which is the largest papyrus swamp in the Kenyan portion of Lake Victoria, is an exceptionally rich and diverse ecosystem, containing many rare, vulnerable and endangered species of plants and animals (EANHS, 2018). The wetland is almost entirely covered in stands of papyrus.

Over 30 mammal species have been recorded in the wetland. They include the Sitatunga (*Tragecephalus spekeii*), a shy and rare semi-aquatic antelope that is nationally listed as Endangered (Thomas et al., 2016; Wildlife Act, 2013; KWS, 2010; IUCN, 2016). The wetland provides an important refuge for Lake Victoria cichlid fish, many of which have been exterminated in the main lake by the introduction of the non-native predatory fish, Nile Perch (*Lates niloticus*). Recent surveys in Lake Kanyaboli recorded 19 fish species within nine families, which included all the two critically endangered cichlids species: *Oreochromis esculentus* and *Oreochromis variabilis* (IUCN, 2018; KWS, 2010; Ogutu, 1987a, b). The fishes use the swamp as a breeding ground, nursery, and feeding grounds (Aloo, 2003).

The Yala Wetland climate has a variable rainfall pattern that generally increases from the lake shore to the hinterland (Ekirapa and Kinyanjui, 1987; Awange et al., 2008). The mean annual rainfall ranges from 1050 to 1160 mm and is bimodal. The mean annual daily maximum and minimum temperatures are 28.9 and 15.9°C, respectively giving a mean annual temperature of 24.4°C (Luedeling, 2011; Semenov, 2008).

The hydrological conditions within the Yala Wetland is characterized by five main water sources, namely: inflows from the Yala River, seepage from River Nzoia, flooding from both rivers, backflow from Lake Victoria, local rainfall and lakes within Yala Wetland (Okungu and Sangale, 2003). River Yala is the main source of water for the swamp and other satellite lakes. The naturalized mean monthly discharge is 41.1 m^3/s. The lowest flows barely fall under 5 m^3/s in the months of January to March while the highest discharge of 300 m^3/s occur in the months of April/May and August/ September. The minimum suspended silt load of River Yala Water is 543 ppm (BirdLife International, 2018; Sangale et al., 2012; Okungu and Sangale, 2003).

Originally, the Yala River flowed through the eastern swamp (now 'reclaimed') into Lake Kanyaboli, then into the main swamp, and finally into Lake Victoria via a small gulf. The Yala flow is now diverted directly into the main swamp, and a silt-clay dike cuts off Lake Kanyaboli, which receives its water from the surrounding catchment and through back-seepage from the swamp. A culvert across the mouth of the Yala, some metres above the level of Lake Victoria, has cut off the gulf on the lake and, through back-flooding, created Lake Sare (BirdLife International, 2018, Gichuki et al., 2005). This river flows on a very shallow gradient through small wetlands and saturated ground over its last 30 km before entering Lake Victoria through its own delta. The soils in this region have a very high clay content which impedes ground water flow but there is known to be a gradual movement of seepage water into the northern fringes of the Swamp. Flooding occurs annually and the very high discharge rates mean that the river channels are overtopped with floodwater passing into Yala Swamp. Parts of the western swamp lie below the level of Lake Victoria and are constantly filled with backflow in addition to being subjected to flooding from the lake and upper catchment.

Annual rainfall in Lake Victoria Basin (LVB) encompasses a bimodal pattern. The Yala/Nzoia catchment has high precipitation in the Northern highland (1,800-2,000 mm per annum) and low in the South-Western lowlands (800-1,600 mm per annum). Local rainfall contributes to Yala Wetland water. The water balance for Yala Wetland also includes the water retained within the three freshwater lakes found within the swamp: Kanyaboli (10.5 km^2), Sare (5 km^2) and Namboyo (1 km^2). Lake Kanyaboli has a catchment area of 175 km^2 and a mean depth of 3 m. Lake Sare is an average of 5 m deep and Lake Namboyo has a depth of between 10 and 15 m (NEMA, 2016; Owiyo et al., 2014a; Dominion Farms, 2003; Envertek Africa Consult Limited, 2015).

METHODS

This study employed action research methodologies as the appropriate tool that would seek to assist the "actor" in improving and/or refining his or her actions. Action research also seeks transformative change through the simultaneous process of taking action and doing research, which are linked together by critical reflection. Kurt Lewin, then a professor at MIT, first coined the term "action research" in 1944 (Mills, 2000).

Sampling and data collection

The study used non-random purposive and stratified sampling to collect data. A total of 410 respondents from 60 local community groups participated in focus group discussions (FGDs) from the swamp and adjacent buffer zone including: beach management units, women groups, youth groups, smallholder farmer's cooperatives, religious leaders' associations, sand harvesters, and YPAC members. There were 34 key informants interviewed mainly elders and change makers on historical, cultural and indigenous knowledge information. Data was also collected from 187 students who participated through essay writing, debates and artworks. These were drawn from primary (12), secondary (5) and post-secondary polytechnics and colleges (2) in Yala Wetland and its buffer zone. The target organizations and individuals were active in wetland conservation and spatially spread all over Yala Wetland and its buffer zones. Additionally, the researcher kept a journal where he recorded descriptive accounts of his research activities, experiences and critical reflections. Sample size determination for this research was based on judgment with respect to the quality of information desired and the respondents' availability that fit the selection criteria of involvement in conservation activities in the swamp (Sandelowski, 1995). According to Neuman (1997), it is acceptable to use judgment in non-random purposive sampling and reiterates that there is no 'magic number'.

Data analysis

Qualitative data were analyzed in using content analysis methods. Content analysis technique allowed the researcher to categorize and code the collected information based on participants' responses to each question or major themes that emerged from FGDs, in-depth interviews, essays, debates and artworks. Content analysis as Babbie (2015) argues is useful since it captures well the content of communications generated through interviews, essays and FGDs in an inductive manner, where themes were generated based on emerging similarities of expression in the data material. Many of these elements provided quotations in the write- up of research findings and other similar elements were quantified using descriptive statistics to give a sense of the emerging themes and their relative importance according to the respondents.

Respondents also conducted priority ranking of issues to arrive at overall prioritisation of issues that informed LUP content.

The study dealt more with people's perception than with statistically quantifiable outputs. Thus, data analysis to gauge these

Table 1. Grading of responses.

Grade (%)	Rank
1-16	Very poor
17-33	Poor
34-50	Unsatisfactory
51-67	Satisfactory
68-83	Good
84-100	Excellent

perceptions was done by calculating percentage response (Neuman, 1997). The response rates were calculated using the following formula.

Response (%) = x / y × 100

where x: respondents who gave feedback and y total number of respondent groups. To grade the percentage response, a modification of Lee's (2000) EIA study review package was used (Table 1).

The researcher used satellite images from Google Earth which provided detailed photographic evidence of the condition of the wetland and various land use changes in Yala Swamp over years. They were also used to determine the current size of the wetland in line with revised definition of the wetland and various land cover/use changes in the swamp over the years. Satellite images and GIS analysis has been used variously to determine land cover/land use changes (EMCA, 2012; Turner, 1998; Liverman et al., 1998; Chambers, 2006; Ampofo et al., 2015; Lillesand and Kiefer, 1987).

Literature review was conducted on public participation, policies, laws and relevant studies that provided secondary data and a valuable source of additional information for triangulation of data generated by other means during the research and this has also been used by many researchers (Friis-Hansen and Duveskog, 2012; IYSLP, 2017).

Overall, a multidisciplinary research using case study design employed exploratory action research with both qualitative and quantitative methods of data collection and analysis. Appreciative Inquiry (AI) methodology and participatory approaches and secondary data were used in data collection and analysis (Dweck, 2008; Cooperrider et al., 2008). The secondary data include policy and legal frameworks, wetland ecosystem management guidelines and procedures, relevant studies to Yala Wetland and other sensitive ecosystems elsewhere. This qualitative research used was supported by quantitative methods on how contextual factors and processes affected the planning and management of Yala Wetland ecosystem. Strauss and Corbin (1990) noted that quantitative and qualitative methods are tools that complement each other, while Greene (1995) in her doctoral research used and shows the value of journaling as research methodology for in-depth reflection by the researcher and vital in action research designs. Greene (1995) says "learning to write is a matter of learning to shatter the silences, of making meaning, of learning to learn" (p.108).

RESULTS AND DISCUSSION

Community participation in Yala Wetland ecosystem results are presented under formation of the wetland and its value to local communities, and essential indigenous knowledge systems used by communities in managing Yala Wetland ecosystem.

Formation of Yala Wetlands, its value and community involvement in its management

According to the recollection of the local communities, the swamp was a flat ground inhabited by the local people prior to the 1960s, when heavy rains caused its formation. First, before 1960s, the swamp was a water body which later disappeared allowing the local populations to move in for cultivation. They reported that Sare was a small water pool where children played football, and that in their experience, there have been three cycles of water drying or significantly reducing, namely cycle one 1917-1920s; cycle two 1960s-1970s; and cycle three 1980s onwards. Further, they also reported that they had heard from their forefathers that Lake Victoria had also dried completely twice in its history of existence. This has been corroborated by studies on Lake Victoria (Awange and Obiero-Ong'anga, 2001). Second, the swamp partly formed from flooding experienced in 1960 - 1963, which they believed to be a curse from gods. They recalled that in December 1962 and much of 1963 there were heavy rains (*kodh uhuru* meaning the rain at independence) which is equivalent to today's *El Nino* rains, and that the flooding continued into the 1970s, causing malaria and other challenges that forced most people to move to high grounds. Initially, there was a small opening by the lakeside at Goye in Usenge, but with 1960s rains, it widened, A ferry was brought but with increased rains, it was swept to Mageta islands. They then used boats until the two areas were linked by a causeway. The families in Yimbo dispersed over time and some of them moved to other places in Bunyala, Alego, Gem and other far off places. They still retain the names from Yimbo like Nyamonye, Usenge, and Uriri in Alego.

In their perspective, "Lake Kanyaboli is a mystery (*en hono*), when the water dried from Sigulu an elder, Wanjiri Kosiemo, discovered the dried land for the people of West Alego and people moved in to farm. There were a lot of indigenous fish species like *Kamongo* (mudfish) and a lot of food such that there were no thefts from the farms." An elder remembers this and states that *Ikwaloga mana ka onge,* meaning people steal food only when there is lack of it. In 1968, a road was constructed through Yala Swamp, with the Lolwe bus company route passing through the swamp. The communities further explained that Lake Sare is a result of backflow of River Yala from Lake Victoria, and they attributed the expansion of the swamp to the forced diversion of River Yala's course as the waters spread into the swamp without going direct into both the Lakes Kanyaboli and

Victoria as was before. The inhabitants of Mageta were driven away by tsetse fly infestation in 1929 but returned after successful government Tsetse eradication project in the islands in mid-sixties. They noted that the local communities created beliefs out of some experiences and some believed going back to Mageta was not going to be fraught with bad omen. A third community explanation on the formation of wetland was linked to the construction of Owen Falls Dam in Uganda in 1954 which they believed resulted into the beginning of backflow of water.

The Bunyala community provided an additional explanation, linking flooding to River Nzoia channel expansion for construction of Webuye Paper factory. In Musoma where River Nzoia enters Lake Victoria, there is a backflow that is partly responsible for submerging villages in the swamp. There are 10 Yala Swamp islands inhabited by 36 clans spread across 39 villages. Among the indigenous communities living in those 10 swamp islands include: Bulwani, Maduwa, Bukhuma, Siagiri, Iyanga, Khumabwa, Maanga, Bungeni, Runyu, Rukaza, Kholokhongo, Nababusu, Gendero, Mauko, Bubamba, Buongo, Siagwede, Siunga, Bunofu, Busucha, Mugasa, Isumba, Ebukani, Bumudondu, Erugufu, Ebuyundi, and Khamabwa.

Therefore, it can be stated that the utilization of Yala Wetland resources has been partly informed by how the local communities perceive its formation. For those who perceived it as God’s gift for them, they utilize swamp resources as their own and as such take genuine care of the resources therein. For example, they see Lake Kanyaboli and the Yala Swamp as rare fish gene bank. Additionally, it has religious and cultural values for them. The Yala Swamp is a historical site that comprises of important components of the Luo and Luhyia cultural heritage (Got Ramogi) where the Luos first settled in Kenya having come from Uganda before dispersing to other parts of Kenya; Gunda Adimo (historical sites). For the Bunyala communities including 36 villages in the swamp, the wetland is their home from where they derive their entire livelihoods. Besides, their ancestors and recent family members who died have been buried there, bestowing special recognition of the spirits of their family members whom they insist they have obligation to care for. Other community wetland formation postulations do not support sustainable utilization of the swamp resources because they consider it a menace which causes floods and government resources who decides how to use without regard to the local communities; thus requires mindset change if they have to change to support sustainable interventions for the wetland. Therefore, improvements to sustainably manage the wetland ecosystem ought to factor the historical and contextual information and mindset change among wetland communities towards the wetland In final SEA and LUP reports, this historical and contextual information was included as chapter 4 in the SEA report, titled understanding the Yala Swamp, recent history of the Yala Swamp that shaped final LUP plan and its implementation plan and other related ecosystem management plans like the Yala Swamp Indigenous Conservation Area Management (ICCA) for 2019-2029.

The essential indigenous knowledge systems used by communities in managing Yala Wetland ecosystem

The local communities have been managing the wetland ecosystem using various indigenous knowledge systems that promote wise utilization and concern for the other users like the government, wildlife and marine animals. However, not every community member ascribes to these ideals hence conflicts over the wetland resources also occur. For example, the communities have developed positive conservation practices by attaching defined significance to the various wildlife species: some birds are totems therefore cannot be eaten by those communities. Table 2 shows various birds and their associative conservation values as seen by wetland communities as documented from some elders who are custodians of wetland information. This valuable indigenous ecological information has been shared during wetlands and environment days to raise the consciousness the rest of wetland communities to uphold positive attitude towards those birds and conserve them for their utility to the communities.

During the study, two relatively older members of the community (one 89 and one 78 years old) could narrate these historical events but very few young ones (like one 27 years) could. However, there was no documentation of these historical information of how the wetland communities used to manage the wetland. Therefore, there is urgent need to document and preserve this information and disseminate it to fill in the integration need for planning and management purposes of the wetland ecosystem and other land uses in the area.

The indigenous knowledge systems about Yala Wetland are vital for planning and management and hence the urgent need for their preservation. The local communities have managed the swamp using various indigenous knowledge systems that promote wise utilization, concern for the other users like the government, wildlife and wetland animals. However, not every community member ascribes to these ideals hence conflicts over the wetland resources. For example, the traditional totems and taboos system which are positive conservation practices arising from attaching some significance to the various animals and birds and thereby regulating their exploitation is close to the culling practice of sustainable harvesting of wildlife resources practiced in formal wildlife management. Further, the analysis showed the need for integrating local communities’ knowledge and scientific knowledge in the planning and management of the ecosystem.

These indigenous knowledge systems have since been recognized and used in the implementation of LUP and other ecosystem management plans. The key

Table 2. Name of birds in Yala Wetland and communities attached values.

Luo name	English name	Scientific name	Attached values
Ajul	Hamerkop	*Scopus umbretta*	Predict where one can possibly marry from
Akuru	Red dove	*Streptopelia semitorquata*	Symbolizes peaceful marriage
Arum	Shoebill or Whale-Headed stork	*Balaeniceps rex*	A sign of bad omen, symbolizes death of an elderly person in village
Ochwinjo	African piled wag tail	*Motacilla aguimp vidua*	When killed the house rooftop burns (the victim)
Ogonglo	African open billed stork	*Anastomus lamelligerus*	A sign of rainfall
Opija	Bam Swallo	*Hirundo rustica*	A sign of rainfall
Achwall	Black headed gonolek	*Laniarius erythrogaster*	Agent of seed dispersal
Ochongorio	Common bulbul	*Pycnonotus barbatus*	Agent of seed dispersal
Hundhwe	Rupel robin chat	*Cossypha seminara intercedens*	Predict time
Chiega-tho	Red chested cuckoo	*Cuculus solitarius*	Associated with rainfall
Orepa	Long tailed widow bird	*E Piogne delamerei*	Associate with Wetlands
Tula	African wood owl	*Strix woodfordii nigricantor*	Brings bad omen
Odwido	White Browed cuocal	*Centropus superaliosus*	Predicts time
Owuadha	Yellow wag tail	*Motacilla flara*	Associate with cows
Angwayo	White winged turn	*Chlidonias leucopterus*	Indicators of fish in the lake
Obur ngogo	Common house martin	*Delichon urbica*	Water bird
Nyamwenge	Africa Sacana	*Actophilornis africanus*	Shows presence of water lilies
Miree	Quelea	*Quelea quelea aethiopica*	Symbolizes good harvest

Source: Author's Interview Information (2016).

environmental events such as Wetland days, Environmental days are currently being used to disseminate LUP plans have been allocating sessions where elders share this knowledge and in schools, environmental awareness and education sessions in the region are also incorporating these.

Key environmental issues SEA/LUP of Yala Wetland ecosystem planning and management identified by local communities

The Yala Wetland communities identified key environmental issues that should inform SEA and LUP development processes of the wetland management. The main environmental challenges identified in order of priority (from highest to lowest) are: encroachment and reclamation of the wetland by the locals for development projects; burning of papyrus (resulting in the loss of biodiversity, fish breeding grounds, bird habitats and livelihoods); high human population density; resource use and related conflicts (human and wildlife conflicts); conflicts among the local communities on boundary issues and perception of unequitable benefit sharing from Dominion Farm (Alego and Yimbo communities); conflicts between the local community, the investors, government and third parties (Non-Governmental Organisations (NGOs), Community Based Organisations (CBOs), Media); disappointment and apathy due to unfulfilled promises by Dominion Farms (subsidized price of rice; broken promises to pastors fellowship forum); declining water levels in Lake Kanyaboli; flooding and its negative effects; weak framework for local communities participation; incoherent implementation of wetland policies; Nile Treaty constraints on Lake Victoria catchments and River Nile utilization; low agricultural productivity and resultant food insecurity; threats to wetland wildlife species as large chunks of land have been taken by for agriculture; birds poisoning using chemicals around Bunyala irrigation scheme; and pollutants channeled into the wetland; poverty and associated inequalities; and alien invasive species. All these concerns were taken into account in completing SEA and LUP.

Causes of Yala Wetland environmental challenges

The respondents identified some of the root causes of the aforementioned environmental challenges as increasing population and destruction of biodiversity; underground streams flowing back into the wetland causing flooding; high cases of malaria due to breeding zones for mosquitoes created by the wetland during rainy seasons; the drying of Lake Kanyaboli attributed to diversion of water for use by the Dominion Farms; water contamination by effluents discharged from the commercial farms, absence of proper inlet of water into Lake Kanyaboli (Figure 5); reduced rainfall due to climate change over the years; backflow of River Yala causing flooding and displacement of wetland residents; direct flow of Yala River water into Lake Namboyo causing flooding from its back flow; and intrusion into fish breeding zones by the fisher forks.

Yala Wetland environmental challenges by remotely sensed data (satellite images)

Information from the satellite images analysis corroborates some of the aforementioned findings from communities. Detailed photographic evidence of the condition of the wetland was not available prior to 1984, but the extent of changes that have occurred to the wetland in the last 40 years could be seen with reference to historic and current aerial and satellite images provided by Google Earth. The following images (Figure 2a to g) of various dates provide a valuable record of historic land use changes in the area. Figure 2a is an image of the wetland taken on 31 December 1984. The south-eastern plain below Lake Kanyaboli (the area now occupied by Dominion Farms) appears as partially reclaimed and cultivated. However, there is no evidence of the retention dyke which was built during the 1960's separating Lake Kanyaboli and the middle area of wetland and much of the lake itself appears to be covered with either papyrus or floating vegetation.

Figure 2a shows the south-eastern plain below Lake Kanyaboli and the enlarged image (Figure 2b) shows the existence of parts of the retention and cutoff dykes, although these had fallen into disuse by the 1980s. However, the Yala River had been partially diverted at this time and flood water flowed both to Lake Kanyaboli and along the southern canal discharging into the middle swamp at a point close to Bulungo village (Figure 2c).

Detailed examination of the historic evidence (2001) shows that the southern diversion of the River Yala ended at a point to the north of the peninsula on which the village of Bulungo is situated (Figure 2d). The original course of the southern diversion canal can still be seen in Figure 2d with the current canal, realigned and reconstructed after 2003, marking the boundary between traditional farmland around Bulungo village and recent large scale reclamation.

These satellite images show very minimal change in the main characteristics of the Yala Wetland between 1984 and 1994, as revealed by a comparison of Figure 2a to c, however towards the end of this period the image suggests that revegetation has occurred across the lower part of the area now leased to Dominion Farms.

The wetland communities through focus group discussions, key informant interviews, community meetings and students' essays, debates and artwork feedback showed the manifestation of key environmental issues and suggested how SEA and LUP should mitigate them in the final plan. This is shown in Table 3.

Multiple analysis of the historical, current and contextual information about the community participation in Yala Wetland developments to date thus revealed that the wetland ecosystem has varied and critical issues that need to be considered for its sustainable management. This requires management that is sensitive to accommodate local communities' context and cultural belief systems. The historical and contextual understanding of Yala Wetland and environmental issues analyzed in this study were then used to shape the final SEA and LUP reports for the management of the wetland. Further, local communities and students were able to envision the future of Yala Wetland which informed the final LUP outcome.

Envisioning/Communities dream of a future perfect Yala Wetland in 2066

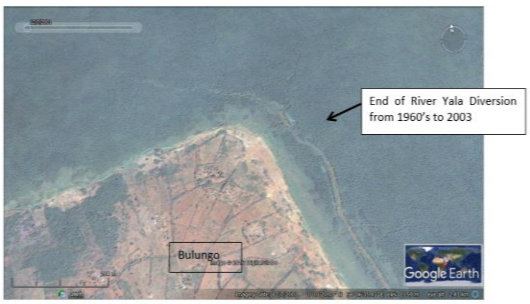
The communities were asked to envision Yala Wetland in 2066 in their focus group discussions and community meetings. The content analysis data of the dreams and aspirations from the communities brought out a clear picture of what they would like the wetland to look like in 50 years' time. The frequencies of emerging themes were: biodiversity conservation (8%); enforceable laws and regulations to protect the wetland (7%); mechanized commercial farming with robust extension system (7%); unique habitat conserved including the one for varieties butterflies (7%); and developed recreational and tourism facilities in harmony with nature (7%). The exhaustive list of the communities aspirations that shows the frequencies of issues mentioned in the FGDs that eventually informed final LUP is as shown in Figure 3.

Envisioning a future perfect Yala Wetland in 2066 by wetland communities

The results from primary and secondary schools, and

(a) Yala Wetland in 1984

(b) Close up of the reclamation area on 31st December, 1984



(c) The River Yala discharge point into the Middle Swamp as it existed between the 1960s and 2003 (Image taken by Google 7th December 2001).

(d) Bulungo Peninsula showing the old and current alignments of the southern canal. (Source: Image taken by Google 2016).

(e) Yala Wetland in 1989

(f) Yala Wetland in 1994

(g) Yala Wetland in 1999

Figure 2. Yala Wetland challenge.

post-secondary institutions on key environmental issues and their ranking for Yala LUP considerations that were analyzed from essays, artworks, and debates are as shown in Figures 4 and 5. Figure 5 is a creative fusion of

Table 3. Key environmental issues in Yala Wetland and mitigation measures for LUP.

Key environmental issue	Manifestation	How LUP should cover/covered this to mitigate its impact based on community contribution to the process
Destruction of important biodiversity areas	Growing pressure on papyrus due to land use change, demand for its products; declining fish stocks and species	Dedicated Institutions (that is, YSSG) to check on swamp changes and promote conservation of important habitats. Environmental programmes in schools and post-secondary institutions in Lake Victoria Basin (updated curriculum of environmental education for upper primary and secondary schools in Lake Victoria Basin needed). Annual schools wetland competitions for raising awareness and undertaking wetland conservation activities by students. Cage Culture Fishing EIA in Lake Victoria Promote rearing Lake Victoria endangered fish species such as cichlid in Lake Kanyaboli and in private ponds. Planting papyrus on degraded areas and strengthening cluster leaders through training, collaborative problems diagnosis and creative problem solving. Upgrade and strengthen community museum in Kombo beach, Lake Kanyaboli set up by an elder and stocked with wetland communities' historical artifacts Document, preserve and disseminate indigenous knowledge on wetland conservation and use it in implementing Ecosystem management plans
Population growth	Expected rise	Job and wealth creation opportunities for the young people
Land use changes	Influx of large-scale investors	Conduct EIAs, SEAs and Environmental Assessment and ensure compliance with recommended mitigation measure
Weak governance systems	Under the devolved system, the governance of the wetland is unclear	LUP specific implementation structure such as Yala Swamp management committee for various LUP zones; Strengthen the capacities of YSSG and local conservation groups to implement ecosystem management plans
Benefit sharing mechanism	-Absence of guidelines for sharing wetlands benefits equitably -Lack of comprehensive information on costs of ecosystem services to guide stakeholders in its management.	Quotable quotes: *Otoyo adak e samba niang to kia mit niang*" A hyena lives in a sugarcane plantation but does not know its sweetness". Inventorying opportunities of Yala wetland and articulate these in the LUP Develop mechanisms for equitable benefit sharing of wetland's resources and consider 70%:30% investor/community and Government and then 60%:40% for wetland community and County governments. Use the community shares to implement their 7- point priorities
Conflicts	Both human- wildlife and human-human conflicts are experienced in the swamp. Examples of conflicts-Gendro community and Dominions	Conflict management capacity enhancement among the wetland's officials Develop an apex a governance structure that caters for the interest of all wetland communities in decision making structures over the Yala wetland Attend to Usonga communities' conflict over the establishment of Lake Kanyaboli game reserve.

Table 3. Contd.

	farms; Usonga communities with KWS over the game reserve gazettement of Yala swamp	
Declining water resources	Diversion of main river course, proposed development of multipurpose dams, expansion of irrigation, water quality is affected by population and siltation	Identification of Gongo multipurpose use dam for future development Conduct catchment conservation activities Regulate and charge water abstraction from the wetland by large scale and medium scale farming enterprises
Climate change	Changes in precipitation affects livelihoods as well as biodiversity	Ecosystem management plans that are climate change and variability sensitive Intensify agroforestry practices among the communities in agricultural zone of the final LUP.

various artworks submitted by students into one mosaic that captures their aspirations artistically. On these, the communities aspirations significantly informed the vision and mission and planning statements in the final Yala Wetland LUP.

Some of the students creatively envisioned Yala Wetland using artworks and these were further collapsed into the following mosaic (Figure 5).

The Yala Wetland communities used transformational learning methodologies to reflect and act upon their world in order to change it to future aspiration. This changed world view became the basis for their inputs in the Yala Swamp LUP. The Community Facilitator (CF) inducted the wetland communities on the application of opportunity-based view/lenses through appreciative inquiry methodology and empathy walk which they quickly adopted and used to generate their inputs into the plan. The broader wetland community representation through community facilitator intervention enabled local communities to envision, dream, and articulate their aspirations of the future Yala Wetland using possibility-based mindset and eventually provided for wider ownership for the sustainable Yala Wetland. All their perspectives were incorporated in the final SEA and LUP reports and depicted in the final Yala Land Use Plan (Figure 6).

Final Yala Delta land use plan

The planning process took over two years (2016-2018) and with enhanced community participation provided by the action research interventions as discussed, finally recommended three main land uses namely: conservation, agricultural and settlement areas as shown in Figure 6.

Governance framework for Yala Wetland ecosystems management

The local communities have participated in the management of the Yala Wetland in various ways alongside other actors. They have done this through their community-based organizations, through chiefs' meetings/open public gatherings, religious groups/networks, schools and cooperative societies. The attendance of some of these meetings has been determined by the relationship between individuals and organizers of those meetings. Political players which included local members of parliament and civic leaders were found to dominate key decision making on the wetland as evidenced in the decision to lease part of the wetland to the Dominion Farms Limited, which was made solely by the political class through the then local authorities (county council and district development committees), without any reference to the local communities. Likewise, communities have been consulted without substantial stake in the management of Yala Wetland through existing community formations (CBOs), and religious groups.

This analysis reveals that there has been no Yala Wetland wide institutional framework where communities' wetland ecosystem issues are discussed and channeled for decision making in the management of the wetland ecosystem.

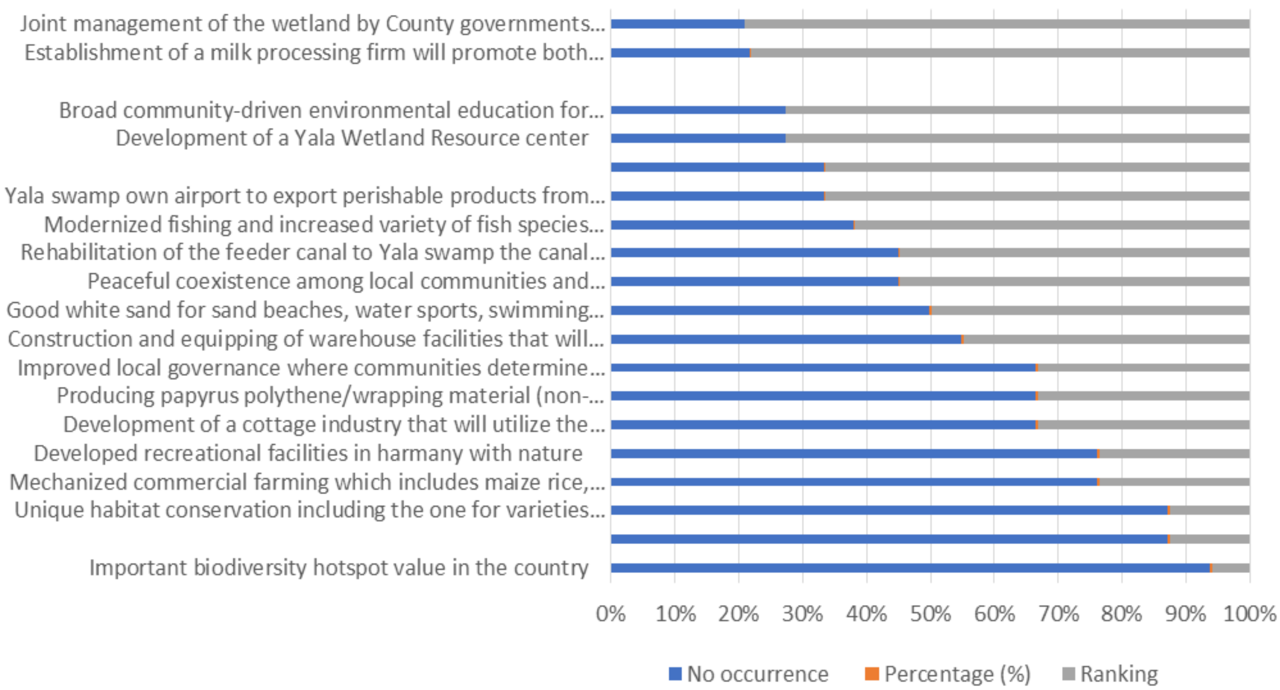


Figure 3. The qualitative analysis of the dreams and aspirations from the communities themes from school essays, debates, artworks and sermons.

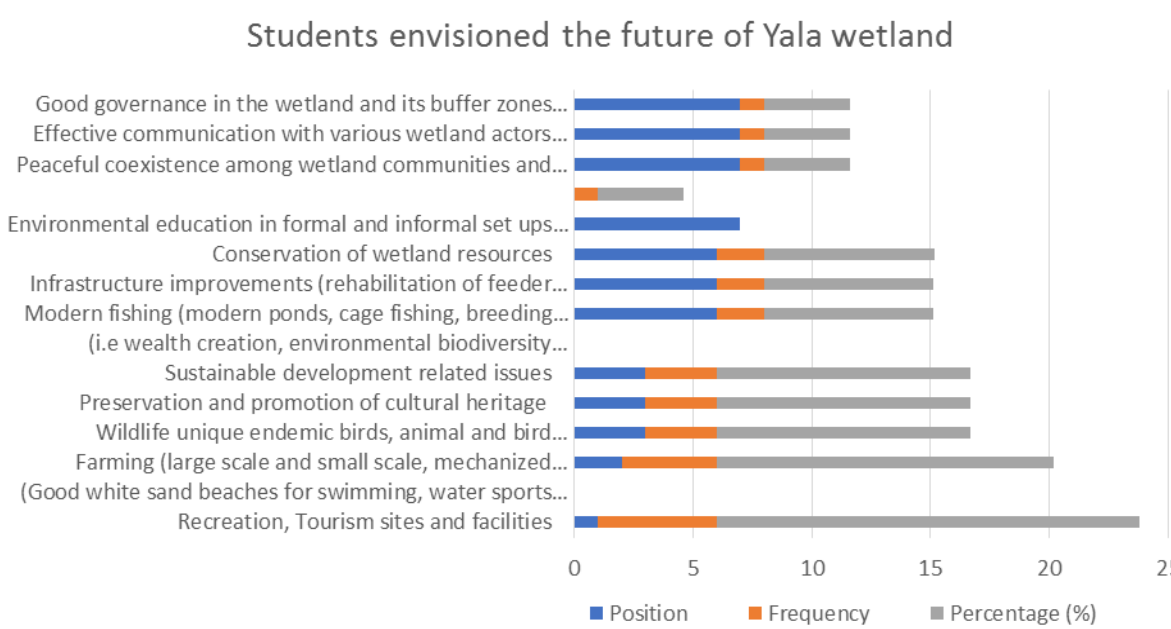


Figure 4. Key themes from learning institutions submission.

Rather, small group community formations such as CBOs, sector specific groups that lack the larger wetland clout to influence key environmental decisions have been the norm. Instead, political players have dominated key decision making on the wetland ecosystem issues and decision done solely by the political class. This gap for community participation in the management of Yala Wetland ecosystem affairs has continued over time

Figure 5. Mosaic about the future Yala Wetland from institutions' artwork.

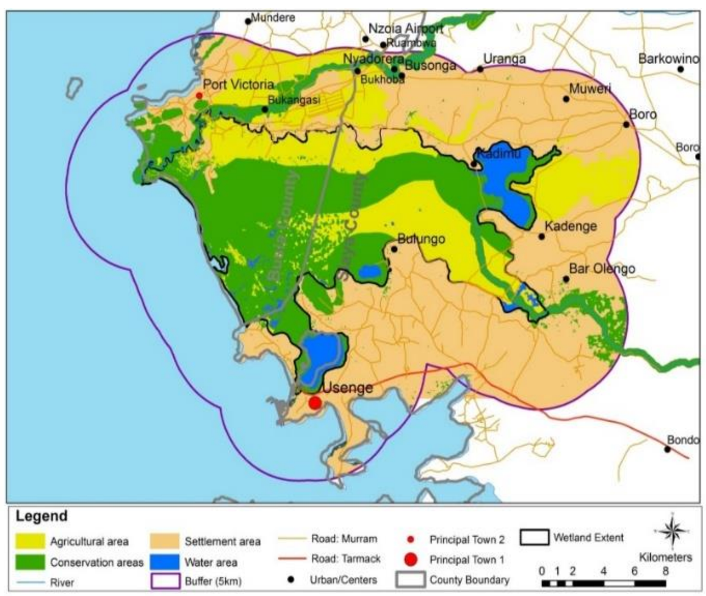


Figure 6. Zonation of Yala Delta.
Source: Odhengo et al. (2018b).

despite significant increase in wetland challenges. In order to remedy this, the wetland communities proposed a governance system that has wetland-wide representation, and provides a structure for communities' participation at conservation areas zone of the wetland. It is named Yala Swamp Management Committee. This governance structure has been validated by the community representatives at the development of Yala Indigenous Community Conservation Areas Management Plan 2019-2029 in March 2020 (Figure 7). The 43 membership shown in Table 4 has been derived from various community groups representing different interests, namely County Village Natural Resource Land Use Committees (VNRLUCs), Inter-County ICCA steering committee, Yala Ecosystem Site Support Group members (YESSG), and Civil Society organizations (CSOs) guided by fair ecosystem and equity-based representation between Busia and Siaya counties and

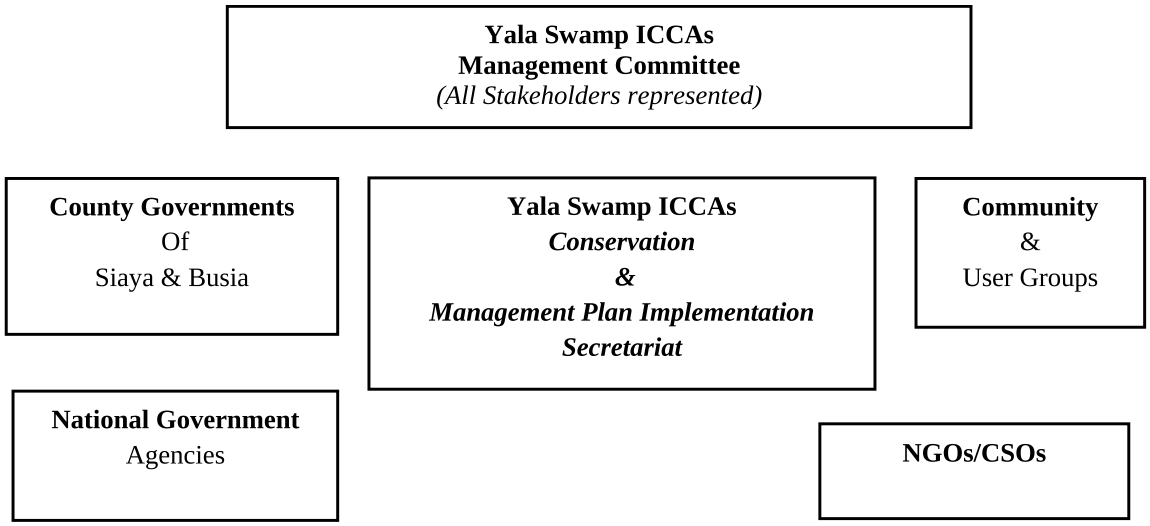


Figure 7. Governance structure of managing Yala Wetland ecosystem conservation areas.

Table 4. Yala Swamp ICCAs management committee membership.

Position	Number
Representatives from each of the 5 CCA cluster sites i.e Kanyaboli-2, R. Yala corridor-1, Lake Namboyo-1, Lake Sare-1, Bunyala Central-1, Bunyala South-2, Islands-2	10
Beach Management Unit-Alego Usonga BMU Network-1, Bondo BMU Network-1, Bunyala-1	3
Farmers (small holdler and commercial farmer)	4
Water Resources Users Association-MUWERI-1, Lower Nyandera-1, BUCAWRUA-1	3
Community Forest Association (Got Ramogi)	1
County Wildlife Conservation and Compensation Committee-Siaya-1, Busia-1	2
Sand Harvesters Association-Usenge 1, Osieko 1	2
Community warden/scouts	2
Community tour guides association	2
Handicrafts (papyrus, palm leaves weavers)	2
Medicinal gatherers/herbalists	2
Cultural/Religious groups	2
Traditional conservationists (formerly hunters)	2
Representatives from the County Environment Committee	2
Civil Society Organization/Network	2
Private sector/network	2
Total	43

provides for 3 members co-option to bring some unique value addition to ICCA such as fundraising leverage. In addition, technical staff from the various county and national government sectors and other agencies (e.g. Agriculture, Fisheries, Tourism, Wildlife, etc.) will be co-opted in the committee as the need arises. The ICCA Management Committee shall provide strategic leadership, mobilize resources, and provide oversight on conservation areas' programs implementation.

This governance structure has put wetland Communities at the core for managing conservation areas of Yala Wetland ecosystem as identified in the final LUP.

Proposed community committee member where the 43 positions will be shared based on fair representation and equity between Busia and Siaya counties

The Yala Swamp Management Committee members are drawn from the conservation area zone of the Yala Land

Use plan initially, but other zones (that is, Settlement and Agricultural), would join too. The 10-point committee's roles and responsibilities have been spelt out and are adequate to deliver their Yala Wetland conservation management plan 2019-2029 (in draft August 2020) when finally adopted. This proposed structure seeks to put the wetland communities at the core of conservation area zone management of the Yala Wetland, and is in line with relevant legislation (Wildlife Conservation and Management Act, 2013).

CONCLUSION AND RECOMMENDATIONS

From the foregoing, the utilization of Yala Wetland resources has been partly informed by how the local communities perceive its formation. Consequently, improvements to sustainably manage the wetland ecosystem ought to factor the historical and contextual information. The Yala Wetland communities identified key environmental issues, their root causes and corresponding opportunities that LUP needed to address to ultimately manage Yala Wetland sustainably. The analysis also revealed existing gaps in the integration of community information and scientific information, disconnect between decision making and requisite scientific and practical evidence required to guide wetland management decision making, absence of community sensitive Yala Wetland wide institutional framework in planning and managing Yala ecosystem.

The study succeeded in integrating local communities' vast knowledge and planning science information and proposed a governance structure and membership for the management committee that put communities at the centre of conservation in Yala Wetland, starting with community conservation areas. To overcome the implementation challenge, there is a secretariat led by a Community Facilitator to undertake day to day activities of implementing the conservation area management plan of the Yala Wetland. Also, there is the need for a strong, passionate and transformational leadership at the community level on wetland issues. All these have since been incorporated in the LUP processes and reflected in the final Yala Wetland land use plan. The study recommends the urgent need for systematic documentation and preservation of Yala Wetland local communities' knowledge systems and subsequent use of it to manage Yala Wetland ecosystem.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Application of renewable technology for mitigating environmental hazards of palm oil industry: Strategy for climate change and adaptation

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Improper disposal and burning of agricultural residues are commonly practiced in some developing countries in which harmful gaseous products released into the atmosphere and some are depleted and reacted with the soil causing environmental pollution. Renewable technology can therefore be introduced for the utilization of the residues and ensure proper storage medium of the residues. An investigation was carried out on the pollution potential of oil palm residues on surface and underground water resources at the processing centre. Oil palm residues and water samples from the stream and well located near the oil processing site were used for the experiment. Water samples were collected during the raining and dry season to determine the level of pollution caused by the residues. Physical, chemical and bacteriological parameters of the water samples were determined. The chemical compounds of the palm residues were investigated. Results showed that aromatics compounds are mainly dominant of the palm fruit fiber which was characterized for bio-fuel production. It is revealed that effect of pollution on water bodies is significant at $p<0.05$. Hence, results showed that some parameters like colour, total solids, pH, amine contents, *Escherichia coli* exceeded World Health Organization (WHO) levels for drinking water. The amine content with (0.35 mg/L) of the samples was higher than the level recommended (0.1 mg/L) for drinking. For colour, the least value of 15.5 mg/l of the total samples was higher than the recommended value (15.0 mg/L). Also, the values of *E. coli* which ranged between 0.03-0.15 were far above zero count/100ml of World Health Organization (WHO) maximum permissible level for drinking water. Therefore, oil palm waste should be properly disposed and ensure improved storage of the residues for further processing. Conversion of the residues to useful products through renewable technology will alleviate environmental pollution.

Key words: Residues, climate change, pollution effect, renewable technology.

INTRODUCTION

Climate change refers to as a change of climate which is directly or indirectly attributed to human activity that affects the composition of the global atmosphere, while climate change includes global warming and everything else that will be affected by increasing greenhouse gas (GHG) levels (UNFCCC, 1994). The level of these GHGs has increased beyond natural level Awosika et al., 1992). There is a scientific consensus that the gradual increase in the average temperature of earth's average temperature of Earth has risen between 0.4 and 0.8°C in the last 100 years (IPCC, 2005). The increased volume of carbon dioxide and other GHGs released from the burning warming is caused by increase in the emission of GHGs of fossil fuels, deforestation, agriculture and other human activities are sources of global warming that have occurred in the last 50 years (IPCC, 2005).

GHGs are good absorbers of heat radiation coming from Earth's surface acting like a blanket over its atmosphere, keeping it warmer than it should be. Enhanced GHGs effect however, is not natural as it acts to destabilize the Earth's radiation balance due to anthropogenic accumulation in Earth's atmosphere of radioactive GHGs especially anthropogenic ozone (Awosika et al., 1992). It has been suggested that if the current trend of anthropogenic GHG emissions continues through 2030, Earth is likely to experience an average rise in temperature ranging from 1.5 to 4.5°C (Idowu et al*.,* 2011). The global issues of increasing energy prices, dwindling reserves of fossil fuels and impacts of climate change have led to intense global support for bioenergy and chemicals from agricultural crops and residues (Schroeder, 2009). Nigeria has numerous agricultural resources and generates large quantities of wastes daily. Unfortunately, these residues are unutilized properly as they are left to decompose at the dump site (Jekayinfa and Scholz, 2007) and a large percentage is used as land fill while some are burnt. This has environmental implications as stated by Jekayinfa and Omisakin (2005) that pollution rate will be increasing if the residues are not utilized.

Pollution from the activities of oil multinational mostly has to do with air, land and water. Air pollution affects humans and other living organisms. Land pollution affects the land soil and destroys plants and living organisms in the soil while water pollution affects aquatic life (Onifade et al*.,* 2017). Air, water and land pollution can be caused by oil spillage, gas flaring, above or below ground oil pipe line leakage and oil waste dumping (Elum et al*.,* 2017). Agricultural wastes have a high chemical content that is injurious to health (US-EPA, 1992). Any waste that contains 20% of more solid or with a moisture content up to 50% (wet basis) is considered to be solid waste while those with less than 5% solid are regarded as liquid waste (Lawrence and Henry, 1991). Pollution of adjacent surface and underground water systems depends on the composition of the waste, distance apart and the medium or layer through which the discharge travels. The atmospheric condition of the immediate environment is altered by the presence of pollution elements like carbon and nitrogen making the environment un-conducive for man and his activities.

Climate can be affected with a slight change in temperature from human activities (Onifade et al*.,* 2017) and at the right moment can cause outbreaks of epidemic diseases or insect pests, which can destroy entire landscapes, forest or farmlands nevertheless everything in nature is related, changes in one area may trigger changes in other areas (Osagie, 2002; Adejuwon and Odekunle, 2006). For example, the immediate survival of many coastal areas, population, forests and wildlife may now depend on our ability to study, understand and share the small changes that are observed in the environments and ecosystems around man. The aspect of weather variability has been correlated with the activities of man which have in turn generated micro weather variation, pollution of environment by forest fuels burnt daily from industries and automobiles all of which generate heat, thereby altering the heat balance (Osagie, 2002; Adejuwon and Odekunle, 2006).

Many countries have plenty biomass that can be processed as an energy resource. Various categories of biomass are widely available from agriculture residues, wood residues, and dedicated energy crops to municipal solid waste (Jekayinfa and Omisakin, 2005). Among the categories, agricultural residues represent significant potential for developing the bio-energy industry (Elum et al*.,* 2017). The main advantage of using agricultural residues is that they have little or no market value and ready for production in large quantities. These residues generated through direct harvest of crops at the growing site (field residues), or as a by-product of processing at a processing facility USEPA (2006). Several researchers have explored the potency of agriculture residues for energy, and the results are encouraging (Elum et al*.,* 2017).

This work focuses on alleviating and coping with the negative effects that emanate from fossil fuel-based energy sources. Proper utilization of renewable energy plays a vital role in meeting current and future energy and chemical demands. It can be observed that abundant agricultural residues are dumped on the farm and processing site in most developing countries, as this is commonly practiced in South-western Nigeria. It is observed at different processing sites visited in the author's community, that the selected agricultural residues (palm fruit fiber and physic nut shell) used in this work are improperly disposed due to lack of storage facilities while some are burnt and eroded by rain as a result of poor orientation about renewable technology that is climate-friendly.

Consequently, the residues dump over a long period have caused land pollution as shown in Figure 1 and may also cause water pollution if residues are eroded into water bodies (rivers, streams and dams) by runoff water

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Figure 1. Burning of residue causes air pollution.

during heavy rain. This may lead to blockage of drainage, canals and water ways which might cause flood and other natural disasters. Sometimes, the residues are burnt which causes air pollution as shown in Figure 2; consequently, the burning activities might release some greenhouse gases from residues into the atmosphere which can attribute to the problem of climate change and global warming. The burning exercise might also kill living organisms in the soil needed for plant growth. Figure 3 shows the effect of improper disposal of wastes on environment, as a result of non-utilization of wastes which leads to natural disaster like flood and water pollution. This study investigates the effect of residues disposal on surface and underground water and employed renewable technology for the purpose of converting waste to energy and greatly contribute to global climate change mitigation. The detrimental effects of climate change require that alternative forms of energy such as biogas to avoid environmental catastrophes. The renewable technology activities can improve social development and economy identity and strength of the villages and cities and it also has beneficial and better environmental implications on the nation.

Renewable technology

Renewable technology is defined as the technology available for the conversion of cellulose in agricultural residues into fuel and chemical feedstock. The possible technologies include incineration, combustion in controlled atmosphere, hydro carbonization, anaerobic digestion and pyrolysis (Ren et al*.,* 2013; Faisal et al*.,* 2007; Bello et al., 2009). Of these renewable technologies, pyrolysis offers the most visible root for the generation of fuel and chemical feedstock. This process implies decomposition of cellulose by heating in the absence of oxygen to produce gases, liquid and char; which has been the source of many basic organic chemicals such as acetone and methanol (Faisal et al*.,* 2007). Pyrolytic products can be used as fuels, with or without prior upgrading, or they can be utilized as feedstock for chemical or material industries.

Pyrolysis is a process of the thermo-chemical conversion of biomass to char, bio-oil and gas, in the absence of oxygen and other reactants (Balat et al*.,* 2009). It is a non-equilibrium process where the biomass undergoes multistage decomposition resulting in large changes in specific volume. In this conversion process, combustion and gasification occur where complete or partial oxidation is allowed to proceed. The reaction rate, order and product yields depend on parameters such as temperature, heating rate, pre-treatment, catalytic effects, particle size etc (Bridgewater and Peacookie, 2000) and these parameters influence the optimum value in a fast pyrolysis process (Faisal et al*.,* 2018). Also, Tsai et al*.*

Figure 2. Improper disposal of residue causes land pollution.

Figure 3. Improper disposal of waste causes flood and water pollution.

(2006) reported that fast pyrolysis is the most suitable process route to maximize the yield of liquid product. It is on this note that the paper emphasizes the importance of pyrolysis on the extract lignocellulosic content of two agricultural residues to simultaneously respond to bioenergy and chemical production.

The root cause of energy situation is that in the recent years, while there has been no limit on growth in energy demand, the production of energy from the existing sources has come under increasing mounting pressure. It seems probably therefore, that the shortage of fuel (energy) supplies is an actual fact of life and the fossil fuel supplies in our planet may not last forever (Bello et al*.,* 2009). There is energy crisis in our hand, henceforth source of energy supply is far below energy consumption. There is environmental pollution on the release of green gas house emission from fossil fuel burning which is causing health hazard. This has led to an increase in research on development of renewable energy and technology which plays vital roles for future energy and chemical supply. However, there are various renewable energy sources which could reduce the demand on fossils fuels. The renewable technology saves time and it is usually more environmentally friendly, especially on air emissions (Schroeder, 2009). There is great potential in the utilization of renewable biomass for energy and chemicals production to develop human life prosperity to address the crisis of energy security and sustainable economics in the world (Schroeder, 2009; Ren et al*.,* 2013).

Agricultural materials can be converted to liquid by thermal, biological and physical methods. Thermal conversion methods used are combustion, gasification, liquefaction, pyrolysis and carbonization. Pyrolysis is the most popular technique of biomass because it can produce liquid yield up to 75% wt on a dry-feed (Guillain et al., 2009; Bridgwater, 2006).

METHODOLOGY

This section describes the sample preparation, renewable technology and proximate analysis of the residue. The palm fruit fiber is a waste product of palm kernel fruits and after oil processing. The samples were collected from rural area (Iranyin village) near Ogbomoso town (8°07' N, 4°16'E), South western, Nigeria. The samples used for the study were sun dried and ground into fine particle size. The samples were then screened to give various fractions using different wire mesh sizes. The diameter of the particle size of palm fruit fiber used ranged from 0.250 to 0.550 mm in form of 0.250, 300, 0.425 and 0.550 mm. Each sample was mixed with Sodium Anhydrous in order to make it dried and remove totally the moisture in it. Extraction of oil from the samples (residues) and characterization of bio-oil were carried out at the laboratory of the Department of Chemistry, University of Nairobi, Kenya.

Also, the water samples were collected from surface and underground source near the oil processing centre. The water samples used were collected from the point of discharge, 1 m distance away from discharge centre and from a nearby stream and well. 2 litres of each sample were collected with clean plastic bottles. The samples were taken twice during the raining season between August and September 2017 and dry season in December (2017). The experiment was replicated and the average values were recorded. The samples were analyzed for physical properties such as colour, turbidity, odour, taste, total solid, dissolve solid and suspended solid. The chemical examination of water is performed to detect the quantity of chemical substances in water which could affect its portability. Such chemical properties carried out were Ammonia, Carbodioxide and Calcium, Copper, Chlorine, Lead, Iron, Manganese, Nitrate, Sulphate, pH, phenolphthalein, Alkalinity, Melthy Orange and total hardness. Bacteriological Tests (temperature, cyaninde, bacteria count) were carried out immediately on the sample collected on getting to the laboratory.

Characterization of bio-oil

The bio oil obtained from lignocellulose of palm fiber was used for characterization. Litmus papers blue and red were used to check its acidity and alkalinity. A microprocessor pH meter (HANNA pH 211) was used to measure the pH of the oil. Analysis was done at room temperature; the meter was calibrated by measuring pH of buffer solution to be 7.03 at 23.6°C. The density of oil was conducted at room temperature of 23.6°C. The density is defined as sample mass divided by a fixed empty volume of pycnometer. Then a 2 ml pycnometer was used to determine the density; the bio-oil was filled into the flask and weighed the mass. Viscosity of bio-oil was measured using Ostwald Viscometer (a U shape glass viscometer). All experiments were carried out three times and average readings were recorded.

A separate constituent of the pyrolysis mixture together with helium carrier gas goes to the flame ionization detector. It was at this zone that the separated organic compounds ionized at a high temperature in contact with hydrogen or air flame. A polarized electric grid captures the resultant ions which generate a current that will be recorded as a chromatogram. Peak areas of individual gases were measured and the abundance was determined from the prepared calibration. The calibration which is an external standardization has a technique involving essentially, the injection of known amounts of pure compounds as reference substance at the same conditions with that of the sample (pyrolytic products). The sample peak was compared with that of the standard. Also, individual compound was identified by matching their elution times along the base line with that of the standard. So, different components in the liquid solvent and their retention time are displayed on the screen of the GC-MS monitor.

RESULTS AND DISCUSSION

Physical characterization of bio-oil

The liquid extracts were acidic in nature because it turned blue litmus paper to red. This indicated that the samples had been burnt under inert condition. The pH values of oil, which ranged from 4.64 to 6.43, increased with increase in temperatures. This means that oil obtained at high temperature are slightly acidic while oil obtained at low pyrolitic temperatures indicate low pH readings which is more acidic. The density of the oil is 0.8319 g/ml (831.99 kg/m^3) at 23.6°C. It was observed that all density values at different temperatures and particle sizes gave similar readings. The density and viscosity are related to phenomenon of liquid floatation which can have

Table 1. Chemical compounds in the bio-oil of palm residues analyzed by GC-MS.

Chemical compounds	Molecular formula	Molecular weight (g/mol)	Peak probability %
3-methyl Pentadecanoic acid	$C_{16} H_{32}O_2$	256	1.47-2.85
2,16-methyl Hexadecanoic acid	$C_{18} H_{34}O_2$	284	1.30-10.15
Methyl Hexadecanoic acid	$C_{17} H_{34}O_2$	270	81.3
14-methylPentadecanoic acid	$C_{17} H_{34}O_2$	270	9.92-28.7
Tridecanoic acid	$C_{17} H_{34}O_2$	270	2.58
Ethyl Pentadecanoic acid	$C_{17} H_{34}O_2$	270	6.53
EthylEicosanoic acid	$C_{22} H_{44}O_2$	340	3.53-11.3
Ethyl Hexadecanoic acid	$C_{19} H_{38}O_2$	298	2.84
Ethyl Tridecanoate	$C_{15} H_{30}O_2$	242	1.46
MethylOctadecanoic	$C_{19} H_{38}O_2$	298	4.04-66.6
16-methyl heptadecanoate	$C_{19} H_{38}O_2$	298	10.5
Ethyl Octadecanoic acid	$C_{20} H_{40}O_2$	312	60.7
Nonadecanoic aci d	$C_{21} H_{42}O_2$	326	0.93
Cyclopropanepentanoic	$C_{20} H_{38}O_2$	310	3.73
Tetradecanoic	$C_{16} H_{32}O_2$	256	2.7- 4.63
Ethyl Heptadecanoic	$C_{19} H_{38}O_2$	298	5.48
2-2-hydroxyethoxy	$C_{22} H_{44}O_4$	372	2.71-12.3
Hexadecanoic acid	$C_{18} H_{36}O_2$	284	49.4
Isopropyl palmitate	$C_{19}H_{38}O_2$	298	7.31-41.0
Ascorbic 2,6-dihexadecanoic	$C_{38} H_{68}O_8$	652	7.1-14.3
Ascorbic acid, 6-octadecanoate	$C_{24} H_{42}O_7$	442	2.8

significant effect on fluid atomizers. The bio-oil produced in this study gave viscosity of 0.695 cPa at room temperature; this value was less than that of water used as standard. This indicated that the viscous period of bio-oil is less than that of water. Hence, this could be due to low value of water content (5.93%) which caused it to be less viscous. The presence of water content in bio-oil shows the presence of lignin in the raw material which is 60.36%.The calorific value of the bio-oil is 22.33 kJ/g, as shown in Table 4. This shows the amount of energy produced by the complete combustion of 0.291 g of the oil. The calorific value is an important factor to determine the energy content of the fuel. Compared to other common fuel, gasoline (47 kJ/g), Diesel (45 kJ/g), Ethanol (29.7 kJ/g), wood (15 kJ/g) coal (15 kJ/g) and natural gas (54 kJ/g) (NIST), this indicates that bio-oil from palm fruit fiber is a potential source of energy and can be upgraded first before using it as fuel.

Chemical characterization of bio-oil

Table 1 presents the results of the spectra obtained from GC-MS which was used to characterize the bio-oil produced from palm fruit fiber. The O-H stretching vibrations between 3200 and 3400 cm^{-1}, show the presence of phenols and alcohols. The C-H stretching vibrations between 2800 and 3000 cm^{-1} and C-H deformation vibrations between 1350 and 1450 cm^{-1} show the presence of alkane groups. The C=O stretching vibrations between 1680 and 1750 $cm^{-1}$are compatible with the presence of ketones, quinones, aldehyde groups. The peaks between 1500 and 1645 cm^{-1} represent C=C stretching vibrations, indicating the presence of alkenes. Besides, mono and polycyclic and substituted aromatic groups can be identified by the absorption peaks between 690-900 and 1350-1450 cm^{-1}. Then, Ethers can be identified by a strong C-O stretching band near 1100 cm^{-1} due to the C-O-C linkage in the compound. Aromatic ethers show a strong band near 1250 cm^{-1}, while cyclic ethers show a C-O stretching band in the range of 1250-900 cm^{-1}. A broad N-H wagging band appears at 750-650 cm^{-1} representing secondary amides.

GC-MS was used to analyze and identify the chemical components in the liquid. The most abundant products and highest peak area achieved by hexadecanoic (81.3%). Other prominent products are pentadecanoic acid (1.47-14.5%), octadecanoic (2.6-70.1%), eicosanoic (3.5-11.3%), 2-2-hydroxyethoxy (2.71-12.3%), Ascorbic 2,6-dihexadecanoic (7.1-14.3) and Isopropyl palmitate (7.31-41.0). It was observed that different values were obtained at various temperature and particle sizes. This shows effect of experimental parameters (temperature and particles sizes) on the chemical compounds produced from palm fruit fiber. For instance, highest peak of methyl-hexadecanoic, 81.3% was obtained at 158.8°C, 0.42 mm, methyl-pentadecanoic acid was high, 14.5%, at

Table 2. Analysis of underground water samples during rainy season.

	Sample A	Sample ^{B}	Sample C
TH (mg/L)	9.05^{a}	25.00^{b}	50.50^{c}
$^{C}a^{2+}$ (mg/L)	7.20^{a}	18.80^{b}	38.80^{c}
Mg^{2+} (mg/L)	1.80^{a}	6.20^{b}	12.20^{c}
^{C}hloride (mg/L)	8.60^{a}	10.40^{b}	12.70^{c}
Mn (mg/l)	0.80^{a}	0.50^{b}	1.90^{c}
SO_4^{2-} (mg/L)	16.45^{a}	18.60^{b}	21.30^{c}
pH	6.39^{a}	4.22^{b}	4.40^{c}
^{C}olour	15.50^{a}	17.50^{b}	18.00^{c}
BOD (mg/L)	5.50^{a}	5.40^{a}	5.20^{a}
E.^{C}oli	0.08^{a}	0.03^{b}	0.06^{a}
Turbidity	5.20^{a}	$5.50^{a,b}$	5.80^{b}
DS (mg/L)	350^{a}	480.50^{b}	540^{c}
SS (mg/L)	690^{a}	700.50^{b}	860^{c}
TS (mg/L)	1041.5^{a}	1179^{b}	1400^{c}

Values in the same row and sub-table not sharing the same subscript are significantly different at p< 0.05 in the two-sided test of equality for column means. Sample A: A nearby well (unlined); Sample B: Point of discharge Sample C: 1 m distance away from discharge point

441.42°C, 0.42 mm, eicosanoic had value of 11.3% at 300°C, 0.25 mm. Heptadecanoic has highest peak at 200°C, 0.55 mm. Only 300°C, 0.25 mm and 400°C, 0.25 mm contained Ascorbic 2,6-dihexadecanoic.There are a great number of other compounds but their peak areas are low, so this study did not examine them further. Every compound in Table 5 is classified as aromatic oxygenated and hydrocarbon compounds which are dominant compounds in the palm fruit fiber oil. Oxygenated content is favorable to be used for fuels while other compounds can be useful for chemical productions. The results obtained in this study are different and values are higher than those obtained from palm kernel shell by Faisal et al. (2018).

Pollution effect of the residues on underground water

The results of the physical, chemical and bacteriological analyses carried out on water samples are shown in Tables 2 to 5. The results of the analysis were compared with that of World Health Organization (WHO, 2015)'s standard. This shows the rate of pollution and contamination from palm residues on underground (well) water sources located near the palm oil processing site.

The physical properties considered were turbidity and colour. The value of 5.6 mg/L for turbidity was recorded for the water samples collected from a nearby well. This was because of higher production capacity and direct discharge of waste effluent around the well. This value was far above World Health Organization (WHO, 2015)'s permissible level (5 mg/L). The colour of water samples was not so attractive; the sample that was taken from the point of discharge was yellowish while the sample collected at 1m distance from the discharge point was orange. The value of the colour 15.8 mg/l was recorded for well water samples. This value was not corresponding to the level by WHO (2004)'s standards of 15 mg/L. The difference in the colour was due to the distance of the water sources from the point of discharge. This implies that the water is not potable, but can be treated by some processes like screening, filtration and sedimentation.

The results of some chemical parameters like methyl orange alkalinity, the total hardness, Calcium hardness, magnesium hardness, sulphate hardness and manganese ions are shown in Tables 2 to 5. High values of ions were recorded during dry season because there was higher concentration of chemical parameters than in the raining season with diluted solution. The values of Manganese ions recorded during the dry season and raining season were 1.1 and 0.9 mg/L respectively. The values of total hardness of water were 9.0 and 9.5 mg/L during the raining season and dry season respectively. The treatment processes like aeration can remove the ions while coagulation process will reduce the hardness. The pH value of 6.40 mg/L was recorded for water samples collected from well. This indicated that the water samples were acidic and needed to be neutralized. The values of total solid with 1200, 1080 and 1040 mg/L were recorded for water samples collected at the processing site. The values are not in conformity with WHO recommended value (1000 mg/L) this is because of high production at site per day.

The values of coliform count were above the zero count/100 ml of WHO recommended level for drinking water. The values ranged between 0.03-0.15 as shown in

Table 3. Correlation analysis of underground water samples during rainy season.

	Cn	TH	Ca^{2+}	Mg^{2+}	Cl	Mn	SO_4	pH	Colour	BOD	E.Coli	Turbidity	DS	SS	TS
TH	0.389	1													
Ca^{2+}	0.373	0.999**	1												
Mg^{2+}	0.433	0.998**	0.998**	1											
Cl	0.445	0.993**	0.993**	0.995**	1										
Mn	-0.184	0.818**	0.830**	0.795**	0.785**	1									
SO_4	0.445	0.995**	0.993**	0.994**	0.997**	0.777**	1								
pH	-0.898**	-0.746**	-0.731**	-0.771**	-0.778**	-00.24	-0.785**	1							
Colour	0.745**	0.888**	0.876**	0.900**	0.910**	00.478	0.919**	-0.960**	1						
BOD	-0.169	-0.675*	-0.657*	-0.633*	-0.665*	-00.557	-0.703*	00.494	-0.665*	1					
E.Coli	-0.858**	-0.252	-0.227	-0.269	-0.315	0.283	-0.335	.766**	-0.656*	0.438	1				
Turbidity	0.477	0.848**	0.859**	0.879**	0.854**	0.644*	0.829**	-0.697*	0.746**	-0.187	-0.103	1			
DS	0.677*	0.940**	0.934**	0.954**	0.959**	0.583*	0.960**	-0.924**	0.984**	-0.609*	-0.528	0.845**	1		
SS	0.068	0.942**	0.950**	0.928**	0.918**	0.954**	0.915**	-0.482	0.685*	-0.614*	0.064	0.787**	0.776**	1	
TS	0.383	0.998**	0.996**	0.992**	0.991**	0.818**	0.995**	-0.745**	0.893**	-0.718**	-0.273	0.815**	0.937**	0.938**	1

**. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

Tables 2 to 5. The well was not properly lined though covered. The bacteriological pollution occurs as a result of residues disposal found around the site. The bacteriological characteristics of the water are as a result of food waste, faeces and urine around. This shows the presence of *E. coli* and pathogens in the water samples. The value of BOD indicates the amount of micro-organism present in the water samples. In the case, the treatment process self-purification should be adopted by locating wells at about 500 m away from any processing site.

Table 3 presents correlation analysis of water samples collected in a well near oil palm processing site. Most of the parameters apart from BOD and *E. coli* showed significant difference ($p < 0.05$) across the sampling points. The pH was negatively correlated ($p < 0.01$) with most of the parameters, the most significant being colour ($r = 0.96$). BOD also showed negative correlation ($p < 0.05$) with total hardness (TH), $Ca^{2+,}$ Mg^{2+}, chloride, sulphate (SO_4^{2-}), colour, dissolved solid (DS), suspended solid (SS) and total solid (TS) which was the most significant ($p < 0.05$). Table 5 shows the correlation analysis of water samples collected from a well at the processing site. Most of the parameters across the sampling points were significantly different ($p < 0.05$). The pH and BOD from the sampling point within the stream were significantly different ($p < 0.05$) from the sampling points at the exit area (sample B and C). This could be attributed to the significant correlation ($r = 0.873$) between them. Similar trend was observed for the soluble solid (SS) which also correlated with pH and BOD. Conversely, in terms of the dissolved solid (DS), the sampling point within the stream was significantly different ($p < 0.05$) from the sampling points at the exit area. This could be attributed to its negative correlation with BOD and pH. There was no significant difference ($p < 0.05$) in turbidity across the sampling points.

Conclusions

This study explores the potential of renewable energy as remedy to environmental hazard. The research explores the nexus between climate change impacts, energy and pollution potentials of agricultural residues on the environment. The renewable technology of palm fruit fiber was experimented and hence examined the current and potential adverse effects of residue burning on climate change. It is observed and concluded from the results that the pollution potential of the palm oil processing site located near water source

Table 4. Analysis of underground water samples at during the dry season.

	Sample A	Sample B	Sample C
Cn (mg/L)	3.25[a]	2.70[b]	1.40[c]
TH (mg/L)	9.50[a]	25.20[b]	51.20[c]
Ca^{2+} (mg/L)	7.50[a]	19.20[b]	39.00[c]
Mg^{2+} (mg/L)	2.00[a]	6.10[b]	12.20[c]
Cl (mg/L)	9.05[a]	10.00[b]	13.00[c]
Mn (mg/L)	1.00[a]	0.60[b]	2.20[c]
SO_4^{2-} (mg/L)	19.35[a]	21.00[b]	23.45[c]
pH	6.40[a]	4.20[b]	4.33[b]
Colour	15.80[a]	18.00[b]	20.00[b]
BOD	5.80[a]	5.00[b]	5.10[b]
E.Coli	0.19[a]	0.80[b]	0.80[b]
Turbidity	5.40[a]	5.80[a]	6.00[a]
DS (mg/L)	47.00[a]	50.00[a]	630.00[b]
SS (mg/L)	675.00[a]	780.00[b]	790.00[b]
TS (mg/L)	1141.50[a]	1280.00[b]	1420.00[c]

Note: Values in the same row and sub-table not sharing the same subscript are significantly different at p< 0.05 in the two-sided test of equality for column means. Sample A: Nearby well; Sample B: Point of discharge; Sample C: 1 m distance away from discharge point

Table 5. Correlation analysis of underground water samples during the dry season.

	Cn	TH	Ca^{2+}	Mg^{2+}	Cl	Mn	SO_4^{2-}	pH	Colour	BOD	*E. coli*	Turbidity	DS	SS	TS
Cn	1														
TH	-0.968**	1													
Ca^{2+}	-0.970**	0.999**	1												
Mg^{2+}	-0.970**	0.999**	0.999**	1											
Cl	-0.958**	0.983**	0.987**	0.978**	1										
Mn	-0.850**	0.796**	0.804**	0.781**	0.878**	1									
SO_4^{2-}	-0.900**	0.945**	0.947**	0.940**	0.949**	0.774**	1								
pH	0.640*	-0.741**	-0.735**	-0.759**	-0.628*	-00.19	-0.674*	1							
Colour	-0.837**	0.924**	0.910**	0.919**	0.870**	0.607*	0.892**	-0.790**	1						
BOD	0.511	-0.640*	-0.646*	-0.653*	-0.579*	-0.17	-0.721**	0.873**	-0.663*	1					
E.Coli	-0.642*	0.721**	0.725**	0.733**	0.660*	0.307	0.825**	-0.845**	0.740**	-0.954**	1				
Turbidity	-0.413	0.334	0.361	0.345	0.381	0.378	0.529	-0.186	0.137	-0.486	0.613*	1			

Table 5. Contd.

DS	-0.923**	0.928**	0.928**	0.916**	0.965**	0.942**	0.862**	-0.455	0.815**	-0.355	0.452	0.228	1		
SS	-0.785**	0.821**	0.817**	0.839**	0.719**	0.36	0.788**	-0.942**	0.835**	-0.823**	0.894**	0.386	0.559	1	
TS	-0.935**	0.985**	0.982**	0.986**	0.951**	0.710**	0.963**	-0.807**	0.955**	-0.732**	0.816**	0.368	0.865**	0.884**	1

**. Correlation is significant at the 0.01 level (2-tailed). *.Correlation is significant at the 0.05 level (2-tailed).

at Iranyin village is high which affects the water potability.

In this framework, climate stewardship becomes a partnership between the public, higher educationist and the government. To implement the findings, it is important that strong enforcements of environmental protection laws are needed to ensure the stoppage of palm residues burning and discharge of effluent improper. Finally, this study encourages the practice of renewable technology to alleviate the emission of greenhouse gas and global warming, hence the use of bio-energy will enhance Nigeria's economy diversification, reduce dependence on crude oil and create a strong synergy between the agriculture and energy sectors.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Analysis of the influence of precipitation patterns on wetland sizes in South-Eastern Zimbabwe

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In this paper, the hypothesis that rainfall variability has an impact on wetland loss is tested. There is limited research in Zimbabwe that recognises the influence of rainfall variability on wetland loss. The purpose of this research is to determine the influence of rainfall variability on wetland size over time. Topographical maps, for the period 1972 to 2008, provided data on wetland locations and their changes in size with time. Rainfall data for Masvingo province for the 1980 to 2015 period was obtained from the Meteorological Services Department (MSD) of Zimbabwe. Statistical analysis shows that there is no relationship between rainfall variability and wetland loss. It can be concluded that there is no relationship between rainfall variability and wetland loss therefore. The research findings show that the rates of change in wetland size differ from one wetland to another. The implications on wetland management are that interventions should largely address human causal factors of wetland loss than rainfall variability. Therefore, it is vital to devise a wetland rehabilitation plan that enables management of water from the rivers and wetlands that the communities depend on.

Key words: Climate change, rainfall variability, standard precipitation index (SPI), wetland rehabilitation, Zimbabwe.

INTRODUCTION

Climate plays a critical role in influencing water, vegetation and even soil components of wetlands (Habibullah et al., 2019; Dzvimbo et al., 2017; Erwin, 2009). It is regrettable that wetlands are being converted to agricultural land worldwide as a mitigation strategy to cope with challenges associated with climate change and poverty (Dzvimbo et al., 2017; Li, 2008; Dube and Chimbari, 2009; Erwin, 2009). There is a need to test the relationship between rainfall variability and wetland loss in an attempt to establish wetland rehabilitation intervention strategies.

Due to increasing aridity in Zimbabwe, rainfall variability maybe a key variable in determining wetland loss. This has triggered an accelerated conversion of wetlands for agriculture purposes. This practice poses challenges for reconciling wetland productivity and preservation because wetland conversion for cultivation purposes ensures household food security. It is against such observation that the researcher notes that besides notable influence of climate change on wetland health, fragmentation of wetlands can result from mismanagement (Chikodzi, 2018). Hayal et al. (2012)

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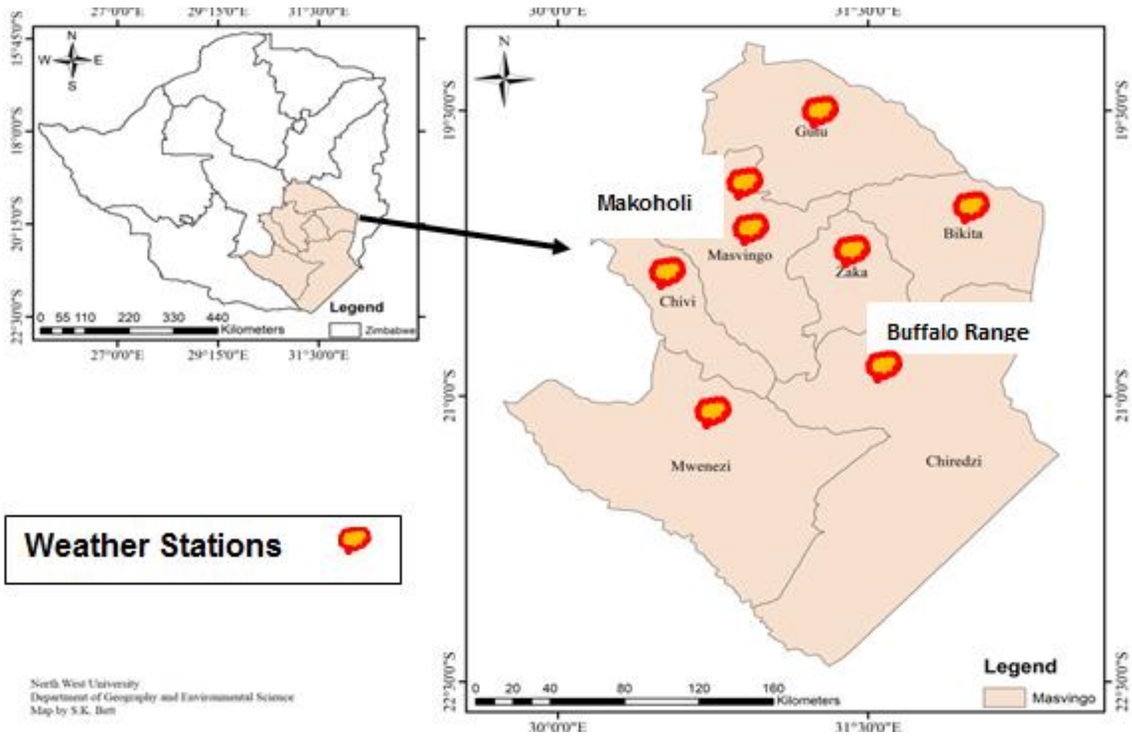

Figure 1. The study area and location of weather stations.
Source: Author.

conclude that wetlands are among the ecosystems most vulnerable to anthropogenic activities, a condition aggravated by climate change.

Rainfall variability alone does not necessarily influence wetland size and loss. Limited understanding of the hydro-geomorphic and climatic influences on wetlands can result in inappropriate implementation of wetland rehabilitation measures (Riddell et al., 2012). There is limited literature focusing on the influence of climate change on spatio-temporal wetland loss. Wetland production in an effort to alleviate poverty, impacts negatively on provision of ecosystem goods and services (Howe et al., 2013). Zimbabwe has undertaken some research (Gadzirayi et al., 2006; Manzungu and Mtali, 2012; Mudombi, 2020) focusing on the agricultural use of wetlands. In other countries, notable studies such as that of Erwin (2009), Hayal et al. (2012), Ogato (2013) and Ndiwa and Muthama (2020), propose that wetland rehabilitation projects should be implemented in the face of climate change. However, in Zimbabwe, there is very limited literature that recognises the influence of rainfall variability on wetland loss. The purpose of this study is to trace and explain changes in rainfall patterns and wetland size in South Eastern Zimbabwe.

In South Eastern Zimbabwe, climatic conditions explain the small size of wetlands characterizing the study area. Climate variability has led to the shrinking and drying up of most wetlands in Zimbabwe (Ndiweni and Gwate, 2014). The majority of the people survive on less than $1(USD) per day. Such widespread poverty and food and water insecurity are socio-economic conditions that drive people to use wetlands. According to the World Bank (2019), there is a marked gap between income levels in Botswana and South Africa on one hand, and Zimbabwe on the other. Per capita GDP in Zimbabwe has generally hovered in the $US 1000-2000 in the last decade, roughly 1/3 or less of per capita production in Botswana or South Africa. Therefore, natural geological, hydrological, climatic and anthropogenic conditions exert a greater influence on wetland size. The rest of this paper is organized as follows. We first examine the characteristics of the study area. This is followed by a discussion on materials and methods used in the study, a discussion of research findings, and lastly the recommendations and a conclusion.

Study area

This study was conducted in Masvingo province, located South Eastern Zimbabwe (Figure 1). Masvingo refers to the name of one of the ten provinces in Zimbabwe. Again one of the districts in the same province is also apparently called Masvingo district. It lies between latitudes 20° and 22°S and longitudes 30° and 32°E in the Masvingo province. The area is characterised by

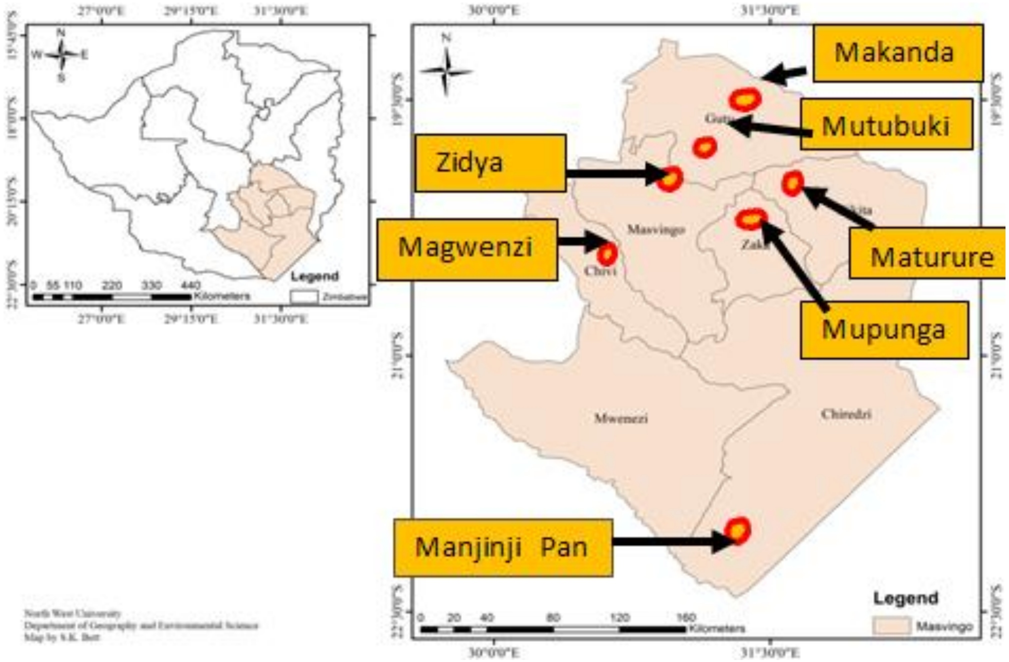

Figure 2. Distribution of sampled wetland patches.

granitic geological structures and valley depressions hydro-geomorphic conditions that have an influence on occurrence of wetland conditions in Riverine valleys. The average annual rainfall is about 550 to 650 mm and average temperature is 26°C.

MATERIALS AND METHODS

Sampling weather stations and wetland patches

Masvingo provincial annual rainfall data for the period 1980-2015 was obtained from the Meteorological Services Department (MSD) of Zimbabwe. The period 1980-2015 was selected because the data reflects relatively current rainfall trends which are crucial in determining the extent to which temporal change in wetland size, as well as wetland loss are influenced by climate. In this study, a rainfall season is defined with reference to a year, for example the 1984/85 season will be denoted as 1985; 1989/1990 will be denoted as 1990 and so on. This was done because rainfall seasons normally start in October of the preceding year and ends in April of the succeeding year. The years that were included in the analysis include 1980, 1985, 1990, 1995, 2000, 2005 and 2010. The Meteorological Services Department (MSD) has 8 weather stations in the Masvingo province, as shown in Figure 1. The data sets obtained are for weather stations within a radius of 70 km to each of the seven wetlands (Figure 2). The change in wetland size was measured using topographical and orthophoto maps over time. Rainfall figures were used to compute the Standardised Precipitation Index (SPI) to establish peaks of wet, dry, and drought episodes.

The meteorological stations that were included in the study are those that had complete records, for the period of interest, 1980-2015. The 8 weather stations whose rainfall data were included in the analysis are located at Bikita, Buffalo Range, Chivi, Gutu, Makoholi, Masvingo, Mwenezi and Zaka. These weather stations are also considered as the official sources of meteorological data in South Eastern Zimbabwe. Table 1 shows the raw rainfall data for the 8 districts in South Eastern Zimbabwe.

The number of wetland patches for each district was determined by reference to aerial photographs and topographical maps. A wetland patch is defined as a distinct delineated piece of wetland occurring within the landscape or catchment. The province has a total of 163 wetland patches (EMA, 2009). In this study, using stratified random sampling, 7 wetlands were selected using random number tables. This was based on the fact that wetlands sampled were supposed to be one of those close to rainfall gauging stations. A sample size of at least 4% of the wetland patches was used to measure changes in wetland size over time. A sample size of 4% gives reliable and credible results on influence of precipitation on wetland sizes over time. Using stratified random sampling, one wetland each was selected from each district, with the exception of Gutu district where three wetlands were sampled. From Gutu district, 3 wetlands were selected because proportionally it has more wetlands than the other districts. As a result, 7 wetland patches were selected. The sample wetland patches are shown in Figure 2.

Topographical maps obtained from the Surveyor-General's office, provided data on wetland location, their sizes and change in size over time. The identified sections of the maps that show wetlands were digitised from aerial photographs of the years, 1972, 1984, 1995 and 2008 to trace spatial-temporal changes in wetland size. Aerial photographs are taken once in a year in Zimbabwe. However, due to socio-economic and political circumstances, the period 2008-2016 has no aerial photographs taken in Zimbabwe, although survey maps are available.

One of the key objectives of the research was to measure changes in the size of wetlands patches. The following formula, after Mtisi (2014) was used to determine spatial changes in wetland areas per patch:

$$[(X - Y) / X] \times 100 \quad (1)$$

where X is previous wetland area and Y is recent wetland area.

Table 1. Annual rainfall totals for districts in the Masvingo Province Zimbabwe.

Year	Rainfall							
	Bikita	Chiredzi	Chivi	Gutu	Makoholi	Masvingo	Mwenezi	Zaka
1980	1033.5	706.1	924.6	667.2	615.1	632.8	681.6	596.3
1981	1607.9	718.5	867	1086.6	916.3	773.6	762.3	1030.4
1982	628.3	449.5	435	439.9	384.4	341.1	339.2	329.2
1983	924.8	309.7	456	476.2	239.6	241.7	258.4	362.2
1984	1148.9	653.3	534	576.1	604.4	588.8	463.7	872.9
1985	1273.9	672.0	1067.4	976.5	746.0	838.3	652.6	936.5
1986	1009.9	657.0	687	713.6	632.6	515.6	582.0	690.7
1987	807.0	427.4	460	555.2	490.9	591.2	309.9	629.9
1988	982.6	403.0	480.0	784.5	609.5	586.7	433.8	489.1
1989	878.2	425.2	433.4	674.0	457.7	600.3	307.2	573.5
1990	857.5	431.0	828	723.6	748.1	680.8	471.8	531.7
1991	672.8	354.4	231.4	373.0	315.0	219.7	304.1	412.3
1992	460.6	371.6	374.2	583.8	507.0	513.7	291.9	436.4
1993	1200.0	922.4	493.8	988.2	579.7	630.9	429.0	559.1
1994	886.1	287.8	398.5	559.9	499.4	348.0	239.5	433.6
1995	919.8	478.9	433.7	343.4	479.7	592.8	393.1	519.9
1996	872.3	705.0	730.9	422.2	839.7	797.0	754.0	883.8
1997	921.3	531.0	604.8	662.2	1092.9	667.8	443.2	914.8
1998	1228.7	561.6	664.0	753.4	662.0	635.6	680.0	665.1
1999	1129.3	661.7	609.5	547.7	591.8	698.3	342.5	1022.9
2000	1820.2	1176.6	1077.8	986.6	1041.6	1134.8	1024.6	1474.4
2001	1490.0	673.4	800.4	983.3	736.9	1022.2	725.8	1342.4
2002	594.1	314.4	217.6	641.9	368.5	421.2	410.0	331.2
2003	1424.7	714.7	516.0	804.2	958.3	1013.4	427.5	1036.1
2004	1342.7	578.7	491.8	258.5	790.0	836.3	585.0	520.9
2005	848.5	285.9	508.0	772.5	674.7	515.3	272.2	420.9
2006	951.0	471.7	348.5	564.3	841.4	719.8	569.2	580.2
2007	1538.2	749.2	435.7	615.0	1005.9	729.3	617.2	1025.6
2008	806.6	315.1	528.9	376.0	366.4	474.2	396.0	515.0
2009	932.2	633.7	472.8	649.0	759.0	644.4	383.7	425.2
2010	857.7	498.3	828.0	619.5	741.2	673.3	424.0	647.4
2011	1005.4	591.8	417.3	751.9	675.1	768.8	539.9	787.2
2012	575.8	306.6	241.9	338.1	381.5	308.2	248.2	344.8
2013	1233.8	574.0	369.1	230.8	756.5	488.5	436.5	752.5
2014	1306.8	713.3	554.6	648.2	889.8	839.4	506.6	1096.0
2015	726.6	330.6	367.7	377.6	349.9	347.3	356.9	360.0

Source: Meteorological Services Department of Zimbabwe.

All the seven wetland patches, selected from the study area showed a decline in wetland size between 1972 and 2008. Digitised aerial photographs were used to measure the change in the size of wetlands. Subsequently, the changes in rainfall patterns between 1980 and 2012 are discussed.

RESULTS AND DISCUSSION

Rainfall patterns in the area from 1980-2015

Table 1 shows that rainfall has generally been on the increase in the Chivi district from 1980 which recorded 924.6 mm and rose to 1067.4 mm in 1985. Between 1990 and 1995, there was a decrease in the amount of rainfall received (from 828.4 to 433.7 mm). Extreme rainfall variability creates uncertainties in decision making and rainfall variability poses challenges for wetland rehabilitation. These include deciding on alternative sources of livelihood, especially when alternative options to wetland utilisation and cultivation are not readily acceptable to affected communities.

There is a general decrease in rainfall in the area from

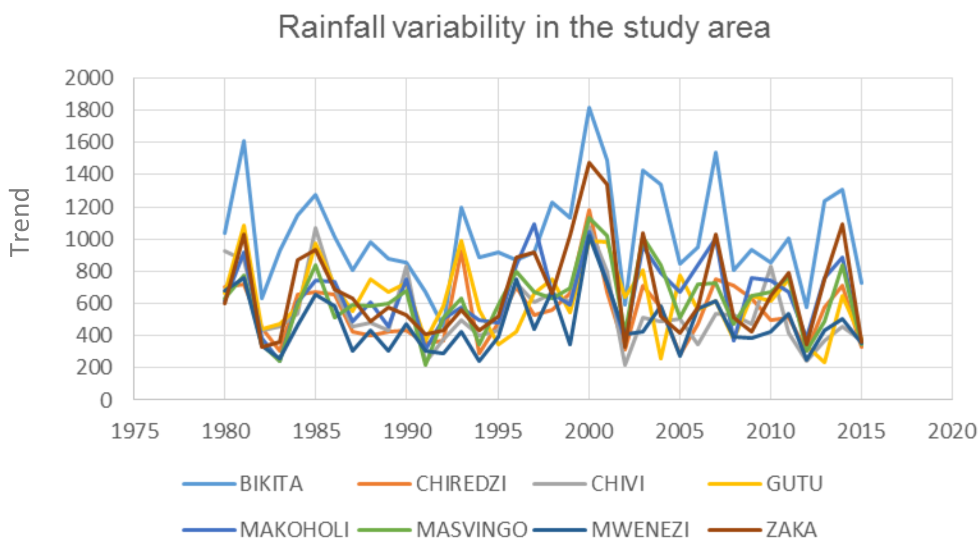

Figure 3. Rainfall trends in Masvingo districts 1980-2010.
Source: Author.

1980 to 2015 and variations from year to year. However, this variation is not significant. The rainfall amount recorded at Bikita was 1 033.5 mm in 1980 and it rose to 1 273.9 mm in 1985. This amount dropped by 416.4 to 857.5 mm in the 1990 rain season. Wetland utilisation increases during such dry episodes. Crop failure occurs in 3 out of every 5 years mainly due to poor distribution of rainfall within a wet season (Hamandawana et al., 2005; Mudombi, 2020). Again in most cases, there are some indications of possible relaxation of wetland cultivation restrictive policies in Zimbabwe (Taruvinga, 2009). The rainfall fluctuations in Figure 3, therefore, illustrate the changes in precipitation patterns over time.

The rainfall statistics for the Gutu district reveal quite a lot. The district recorded 667.2 mm in 1980 and 976.5 mm in 1985, which declined to 723.6 mm in 1990, with a further drop further to 343.4 mm in the 1995 season. The frequency and magnitude of drought occurrence has increased through time. The low rainfall during dry episodes leads to the conversion of wetlands to agricultural use which halts its recovery from previous wetter episodes. Nevertheless, one can observe from these trends that precipitation is on the decline in the Gutu district. Erratic and unreliable rainfall in the Gutu district explain the overexploitation of wetlands with water demand crops such as sugar cane and bananas, at the Chibvongodze and Mutubuki wetlands. Climate change and rainfall variability have affected and continue to affect individuals, populations, species and ecosystem composition and functions (Gitay, 2014).

The Buffalo range rainfall gauge station is representative of the Chiredzi district. The Samson and Manjinji pan are located in the Chiredzi district and close to Buffalo range weather station. The pan had 706.1 mm in 1980 which declines to 672 mm in 1985. This drops further to 431 mm in 1990. The general observation is that there is rainfall variability from one year to another. Thus, rainfall variability and continued land transformation will result in an increase in both human pressure on wetlands and human influence over the drivers that affect wetland functioning (Kotze, 2013; Abell et al., 2017).

The Makoholi research station recorded 615.1 mm in the 1980 rainfall season, which increased to 746 mm during the 1985 season. In 1990, it recorded 748.1 mm which declined to 479.7 mm in 1995. However, the *Cyclone Eline* episode of 2000 resulted in a record rainfall of 1 041.6 mm before it declined to 674.7 mm. These variations point to the influence on people to opt for wetland cultivation (Mapanda and Mavengahama, 2011).

The Zaka District's rainfall gauging station recorded 596.3 mm in 1980, which increased to 935.5 mm in 1985. Quite often, rainfall comes in thunderstorms, particularly in the early phases of the rainy season. The rains therefore are particularly violent during the early part of the season, the very time when the land would be cracked and practically bare and devoid of vegetation cover (Makwara and Gamira, 2012). The year 2000 rainfall record shot up, due to *Cyclone Eline*, to 1474.4 mm and then declined to 420.9 mm in 2005. Nevertheless, the 2000 heavy rainfall was responsible for gully incision and desiccation of the Mupunga wetland. Furthermore, rainfall increases to 647.4 mm in 2010. It is clear that the Zaka district, a semi-arid, mountainous area with erratic rainfall averaging 600 to 800 mm/year (Makwara and Gamira, 2012), contributes greatly to the exposure of wetlands to all year round cultivation.

Table 2. SPI values for the districts between 1980 and 2010.

District/Year	1980	1985	1990	1995	2000	2005	2010
GUTU	-0.29	1.22	-0.17	-1.87	1.27	0.22	-0.52
BIKITA	-0.16	0.56	-0.70	-0.51	2.22	-0.72	0.70
ZAKA	-0.4	0.60	-0.59	-0.63	2.20	-0.92	-0.25
CHIVI	0.49	1.10	0.08	-1.60	1.14	-1.28	0.08
MASVINGO	-0.48	0.60	-0.23	-0.69	2.15	-1.09	-0.27
BUFFALO RANGE	0.37	0.24	-0.66	-0.48	2.13	-1.20	-0.41
MWENEZI	0.53	0.40	-0.38	-0.72	2.00	-1.24	-0.59
MAKOHOLI	-0.67	0.16	0.17	-1.52	2.02	-0.29	0.13

Table 1 shows that Masvingo weather station records 632.8 mm in 1980, which increases to 838.3 mm in 1985. Kamanga et al. (2003) observe that, Masvingo receives annual rainfall of between 450 and 650 mm and at the same time experiences dryness during the summer seasons and recurrent droughts. Agricultural drought is one that affects mainly crops whilst meteorological drought denotes a year that receives rainfall amounts far below the expected average. Trends in wetland utilisation increase when low rainfall, such as 208, 272.6, 293.1 and 109.7 mm received in 1983, 1987, 1991 and 1992, respectively occur.

Annual rainfall figures tend to blur precipitation deficits during the course of the year which impacts on wetland wetness. For example Table 1 illustrates that in 1985, Masvingo district records 838.3 mm of rainfall, however most of the rainfall fell in November and January, that is, 133.1 and 365.3 mm, respectively. The other months recorded less than 10 mm which denotes very dry phases even with an overall relatively wet season. The need for dry season based agriculture in Zimbabwe drives farmers to opt for wetland cultivation which explains wetland loss in the study area evident at Zidya (Table 4). These trends occur especially in rural areas where uplands are predominantly defined as regions of low agricultural potential due to poor soils and low unpredictable rainfall (Ellis-Jones and Mudhara, 1995).

The standard precipitation indices (SPI) are calculated for the districts to help analyse the changes in rainfall patterns and the implications there-of on wetland loss (Table 2). The observed precipitation deviates from the long-term mean for a normally distributed random variable is calculated using the following equation:

$$SPI=\left(x-\bar{x}\right)/\sigma \qquad (2)$$

where x is the long term precipitation, $\bar{x}$ is the mean precipitation for a specified period of time and σ is the standard deviation.

SPI is a commonly used meteorological drought indicator as it is solely based on precipitation. The index ranges between +3 and -3, and the condition is near normal if the SPI is between +0.99 and -0.99 (Tirivarombo and Hughes, 2011). SPI that are ≥1.5 show extremely wet spells and ≤-1.5 denoting extremely dry spells (Tirivarombo and Hughes, 2011).

In some years this SPI is <-1.0, as noted in the 1995 cases of Gutu, Chivi and Makoholi. However, in the year 2000, a positive SPI values of >+1 and +2 in the majority of the rainfall stations is recorded. Wetland remediation measures need to factor in possible impacts of double exposure. The concept of double exposure refers to the fact that ecosystems and social groups will be confronted both by the impacts of rainfall variability and other factors that are not climate-related. The aforementioned rainfall data can help to inform wetland remediation options for affected communities. The standardised precipitation index time series for each of the 8 weather stations in the Masvingo district shows the degree of variation from the norm (Figure 4). A normal rain season has value between +0.1 and -0.1 while >+1 and <-1 denote extreme rainfall events. Values >+1 mean very wet years and values <-1 mean extremely dry year. SPI values that are outside this range indicate anomalies in rainfall (Figure 4).

Based on the anomalies in Figure 4, Chiredzi, Zaka, Makoholi and Gutu experienced extremely dry seasons in 1995 which could have resulted in short to medium term decline in wetland size. Furthermore, in 2005, Bikita, Zaka, Chiredzi, and Makoholi experienced very dry conditions and possible losses in wetland sizes. These results point to the fact that rainfall variability should, to some extent, be factored into wetland rehabilitation techniques. Although other causes such as anthropogenic factors may contribute much to wetland shrinkage, the influence of rainfall variability cannot be ignored.

According to Frenken and Mharapara (2002), it was discovered that 10 years ago, the water table was on average 15 m from the surface. But due to mismanagement of wetlands, the water table dropped to a depth of 30 m on average suggesting future scarcity of water in Zimbabwe.

The SPI values in Figure 4 for 1995 and 2005 indicate

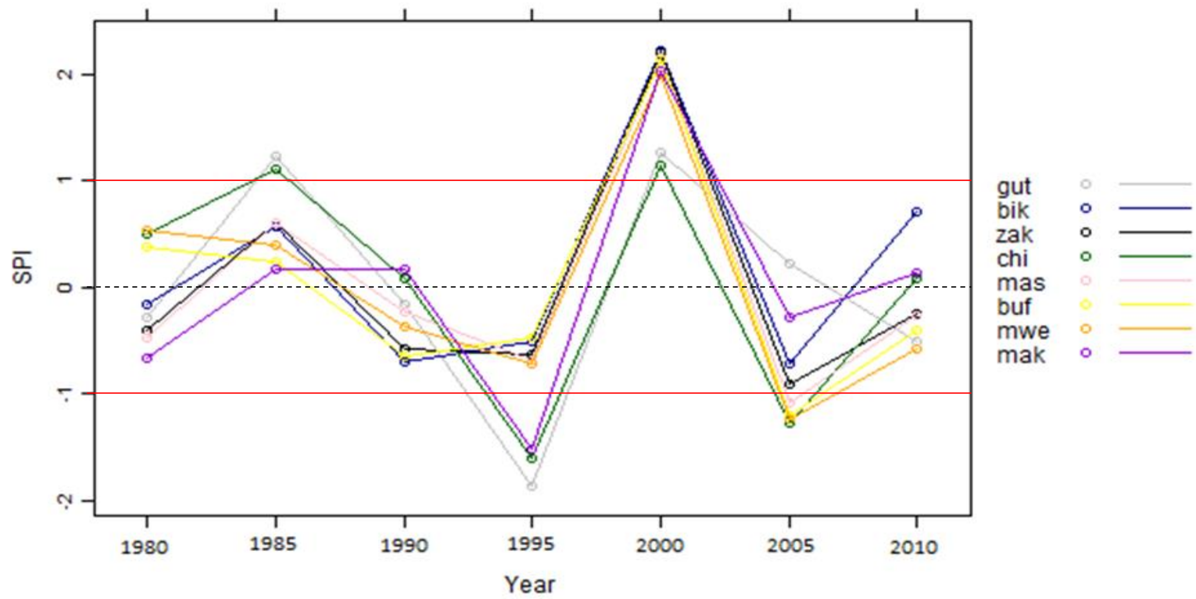

Figure 4. SPI values for the districts.

Table 3. Analysis of wetness and dryness using SPI (1980-2010).

SPI value occurrence	% occurrence	Nominal SPI class
>1.645	10.7	Extremely wet
1.644 to 1.282	1.7	Severely wet
0.842 to 1.281	5.3	Moderately wet
0.524 to 0.841	10.7	Slightly wet
-0.523 to 0.523	46.4	Normal
-0.841 to -0.524	3.5	Slight drought
-1.281 to -0.842	10.7	Moderate drought
-1.644 to -1.282	8.9	Severe drought
<-1.645	1.7	Extreme drought

very dry years whilst 1985 and 2000 were generally wet years. Although after a flood it takes some time for a wetland to retain to its base level, floods have a positive effect on wetland recovery. The amplitudes of SPI time series for 1985 and 2000 illustrate extreme wet weather events which have a strong bearing on wetland health. Farai et al. (2012) found an increase in the number of seasons recording below normal rainfall since 2002.

An analysis of SPI values in Table 3 enables the tabulation of the percentage of occurrence and their meaning as shown in Table 4.

It should be noted first that, reliable SPI data values need at least 30 years of continuous precipitation records (Jayanthi et al., 2013). Table 3, however shows SPI values occurrence over a period of 31 years, with over 5 year intervals, which is credible enough to analyze impacts of rainfall variability not only on wetland ecology but rehabilitation successes as well. Table 4 illustrates nominal SPI classes that interpret the meaning of SPI values in qualitative terms. From the nominal SPI classes, it can be observed that severe and extreme droughts have a combined occurrence of 10.6%. Slight and moderate droughts have a combined occurrence total of 14.2%. Extreme drought worsens wetland shrinkage such as Magwenzi that shrunk by 4.1% between 1984 and 1995.

Changes in size of wetland patches 1980-2012

The results showing the change in wetland size over a time period are presented in Table 4. The varying changes are attributed to differences in biophysical factors, such as topography, pedology, rainfall amounts in the catchment area and human influences. Although these factors were not part of the research, they exert

Table 4. Changes in wetland size over time in South-Eastern Zimbabwe.

Wetland name/years	Area (m^2)	Interval % change in wetland area
Makanda		
1972	20163	Baseline
1984	19865	-1.5
1995	19456	-2.1
2008	19000	-2.4
Mupunga		
1972	74941	Baseline
1984	73543	-1.9
1995	71890	-2.3
2008	70000	-2.7
Magwenzi		
1972	91099	Baseline
1984	88360	-3.1
1995	84880	-4.1
2008	80000	-6.1
Mutubuki		
1972	70845	Baseline
1984	67600	-4.8
1995	64320	-5.1
2008	60000	-7.2
Zidya		
1972	1083142	Baseline
1984	1060864	-2.1
1995	1036000	-2.4
2008	1000000	-3.6
Maturure		
1972	56442	Baseline
1984	56161	-0.5
1995	55715	-0.8
2008	55 000	-1.3
Manjinji		
1972	15886	Baseline
1984	15698	-1.2
1995	15420	-1.8
2008	15000	-2.8

Source: Author

some influence on wetland size, structure and functions.

The Makanda wetland measured 20 163 m^2 in 1972, which declined to 19 865 m^2 (1.5%) in 1984. By 1995 the size had dropped further to 19 456 m^2. Over a 13 year interval the wetland shrank in size by -2.4% to almost 19 000 m^2. The trends indicate that unless effective and sustainable wetland rehabilitation measures are taken to reverse the situation, some wetlands can dry up. Hove and Chapungu (2013) state that the drying up of wetlands can be explained by excessive water abstraction and climatic changes. The decline of the wetlands over the time period is shown in Figure 5.

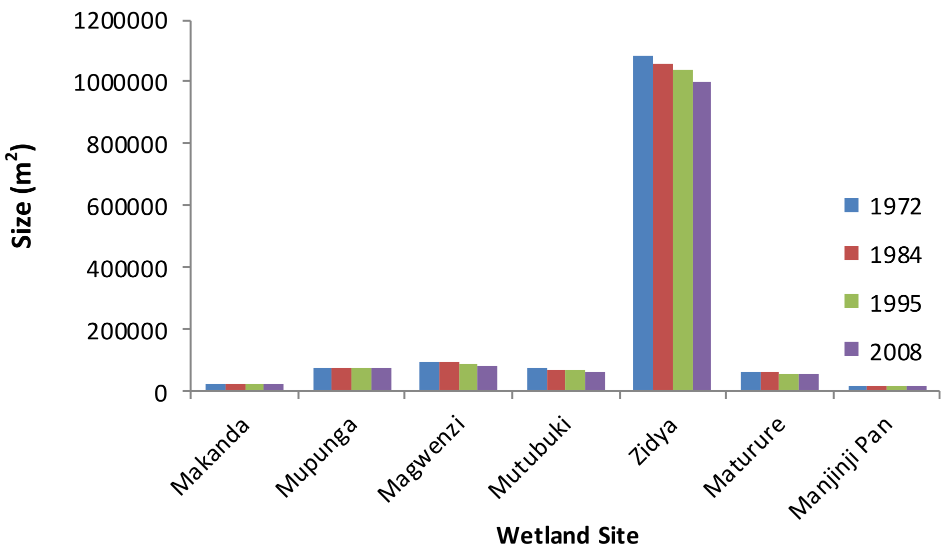

Figure 5. Change in wetland size from 1972-2008.

The Mupunga wetland experienced a slight decline in its size between 1972 and 1984, as it declined from 74 941 to 73 543 m^2 amounting to a -1.9% decline. Further spatial decreases were noted between 1984 and 1995 (-2.3%) and 1995 and 2008 (-2.7%). The wetland changes are caused by factors such as rainfall amount in the catchment area, relief, rock type and slope steepness.

One of the wetlands that experienced a significant decrease in size is the Magwenzi wetland. The Magwenzi wetland, in the Chivi district, measured 91099 m^2 in 1972 and the figure dropped to 88 360 m^2 in 1984, which is a decline of -3.1%. In 1995, the wetland size declined to 84880 m^2, a drop of -4.1%, the measurements for 2008 showing that the wetland had decreased to 80000 m^2, which is a -6.1% loss of the wetland size. The extreme drought conditions experienced in the Chivi district in 1995 and 2005, shown by SPI value -1.60 and -1.20, respectively, explain the encroachment and cultivation of the observed crops in the Magwenzi wetland.

The Mutubuki wetland also experienced decline in size between 1972 and 2008. The wetland measured 70845 m^2 in 1972 and had a -4.8% decline to 67 600 m^2 in 1984. The wetland decreased by -5.1% to 64320 m^2 by 1995, and shrank further in size from 64320 m^2 in 1995 to 60000 m^2 by 2008. This period experienced the greatest reduction in wetland size amounting to about -7.2%. The Zidya wetland measured 1083142 m^2 in 1972 and declined slightly by -2.1% to 1060864 m^2. In 1995 it dropped further to 1036000 m^2. Finally by 2008, the Zidya wetland had lost -3.6% of its 1995 size to 1000000 m^2. Wetlands in Zimbabwe are generally small in size; however, the Zidya wetland is the biggest, as shown in Figure 5 of the sampled wetland patches.

The Maturure wetland experienced the least decline in wetland size in the study area. The change was from 56442 m^2 in 1972 to 56161 m^2 in 1984. This is a decline of about -0.5%. The same wetland decreased by -0.8% from 56161 m^2 to 55 715 m^2 over an eleven year period from 1984 to 1995. Maturure also lost -1.3% of its size when it declined from 55715 m^2 in 1995 to 55000m^2 in 2008. The gorge like topography of the Maturure wetland and mountainous nature of its catchment could explain the slight decrease of wetland size. Maturure wetland occurs in a trough like valley encircled by mountains and hilly terrain from which recharge seepage lines ensure continuous supply of underground water.

The Manjinji pan measured 15886 m^2 in 1972 and dropped to 15698 m^2 by 1984, which is a -1.2% decline. The size of the wetland fell from 15698 m^2 in 1984 to 15420 m^2 by 1995, which is a -1.8% decline. The pan shrank in size by -2.8% after decreasing from 15420 to 15000 m^2 as at 2008. Although accounting for the decline of wetland size is rather complex, poverty-driven wetland cultivation practices are key drivers of the shrinkage.

Statistically, the research findings illustrate that there is no significant relationship between changes in rainfall patterns and wetland loss (Table 5). From the regression analysis, the p value = 0.611 ($p>0.05$) and therefore the hypothesis that rainfall variability has no significant impact on wetland rehabilitation and recovery should be accepted. This suggests that other factors account for the observed decline in wetland size. These factors might be over-cultivation and overgrazing. The coefficient of determination is 0.010; therefore, only about 1.00% of the variation in the wetland loss is explained by mean annual rainfall variability. Hence, although wetland shrinkage is an on-going phenomenon, it cannot be attributed to rainfall variability alone.

Correlation analysis, [with the results shown in Table 6] was used to prove the validity of the statement that there

Table 5. Analysis of variance (ANOVA).

Model		Sum of squares	Df	Mean square	F	Sig.
1	Regression	34316333752.606	1	34316333752.606	65	0.611[b]
	Residual	3363293092110.071	26	129357426619.618		
	Total	3397609425862.678	27			

[a]Dependent Variable: wetland loss. [b]Predictors: (Constant), mean annual rainfall.

Table 6. Correlation between wetland loss and annual rainfall.

Correlation		Wetland loss	Mean annual rainfall
Pearson Correlation	Wetland loss	1.000	-0.100
	Mean annual rainfall	-0.100	1.000
Sig. (1-tailed)	Wetland loss	.	0.305
	Mean annual rainfall	0.305	.
N	Wetland loss	28	28
	Mean annual rainfall	28	28

Source: Research findings

is a relationship between changes in rainfall variability and the amount of wetland loss. The results from an analysis of variance (ANOVA) proved that there was no relationship, over the time period, between changes in rainfall patterns and wetland loss. Marambanyika and Beckhedal (2016) and Maviza and Ahmed (2020) cited that wetland mismanagement was identified as a main factor on wetland degradation and loss in Zimbabwe. The Pearson correlation analysis results reveal that there is no significant correlation between wetland loss and changes in rainfall patterns Table 6. The correlation coefficient for wetland loss and mean annual rainfall is -0.1. This value of r suggests a weak negative linear correlation. According to Dixon and Carrie (2016), direct and indirect human activity has considerably altered the rate of change of wetlands. The loss of wetlands was probably due to direct and indirect human activities in wetland ecosystems.

Wetland patches were also subjected to a T-test analysis to determine the relationship between rainfall patterns and wetland size as part of the data triangulation process. The T-tests results reveal that there is no statistically significant relationship between rainfall patterns and change in wetland size. All the seven wetlands have a critical value of 4.303. The rejection criterion was; reject H_0: if $|T| > T\alpha/_2$. The fact that the critical value 4.303 is greater than all T values means that there is no relationship between wetland loss and rainfall changes for the Makanda, Mupunga, Magwenzi, Mutubuki, Maturure and Zidya wetlands together with the Manjinji pan. Therefore, there is no direct relationship between changes in mean annual rainfall and the amount of wetland loss and the findings point to the dominant role of other factors other than rainfall variability.

It cannot for certain be proved that there is a direct linear link between rainfall variability and wetland loss. The rates of wetland loss (y) are directly dependent on rainfall variability (x). In terms of statistics, rainfall variability is a measure of deviation between the normally expected outcome and what in fact occurs. In this study the rate of wetland loss is related to rainfall variability to a lesser extent, to a greater extent the two variables are not related. Wetland loss depends on rainfall variability in the short term but over long term adaptation and wetland resilience has shaped wetlands to condition themselves to prevailing rainfall patterns. The correlation analysis shows that there is no relationship between wetland loss and rainfall variability.

This study used SPI as a measure of rainfall variability. Comparison of SPI values and wetlands loss does not always necessarily show a simple linear relationship, that is, a huge negative SPI of -2.5 does not translate to a huge loss in wetland size. Rather it seems other non-climatic factors contribute to wetland loss. Results of studies by Ziti (2020), show that the seasonal average rainfall decrease from 1972 to 2010 was not statistically significant (p=0.635, α=0.05), but the decline bears a significant environmental impact. This is a perspective that needs further investigation. Research by Maguranyanga et al. (2021) shows that the effects of climate change will likely continue to be heightened variability in rainfall, with drought shocks combining with wider political and economic drivers in particular ways to create shifts in land use, rather than seeing a simple, uni-directional change over time. A study by Fakarayi et al. (2015) showed that wetlands regressively declined in size from 3.503 ha in 1995 to a paltry 1.938 ha in 2010. At the same time the area under cultivation has progressively increased from 89 ha in 1995 to 4244 ha in 2010. This implies that there is a correlation between wetland loss and drivers of change triggered by human activities, such as cultivation.

Conclusion

It can be concluded that since there is no relationship between rainfall variability and wetland loss therefore, this might suggest that causal factors of wetland loss overlap physical and human influences. The introduction of alien species such as gum trees may have a greater role in wetland loss than rainfall variability. Therefore, the monitoring of rainfall data should be undertaken not as an end in itself but within the broader context of reconciling wetland production and adoption of an adaptive wetland rehabilitation model. It is vital to devise a wetland rehabilitation plan that enables management of water from the rivers and wetlands that the communities depend on. This allows for drought preparedness and subsequent prevention of wetland loss. All the seven wetland patches, consisting of one selected from each district in South Eastern Zimbabwe, showed a decline in wetland between 1972 and 2008. The research findings, however, show that the rates of change in wetland size differ from one wetland to another.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessment of heavy metal concentrations in Mango fruits grown in Kasese district, Uganda

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Fruits are a good source of carbohydrates, sugars, dietary fiber, fat, proteins, vitamins and minerals. In this study, mango fruits grown in Kasese as well as the soil and irrigation water used in fruit growing were analysed for heavy metals cadmium (Cd), chromium (Cr) and lead (Pb). The mango fruits and soil samples were obtained from three sites; Mubuku Irrigation Scheme, Mpondwe-Lhubiriha Town Council (MLTC) and Nyakiyumbu Sub-County in Kasese district. The concentration of Cd was below detection levels in all samples of soil, irrigation water and mango fruits. The mean concentrations of Pb and Cr in the mango fruits was 0.32 ±0.08 and 0.4±0.07 mg/kg dry weight while in soil were 69.98 ± 4.24 mg/kg and 13.403±2.03 mg/kg respectively and that in irrigation water were 0.1127± 0.014 mg/L and 0.0171 ± 0.003 mg/L respectively. The concentration of Pb in mango fruits and in irrigation water was above the maximum permissible limits (MPL) while Pb in soil and Cr in all study matrices were within the MPL by WHO and Dutch standards. These findings suggest that in general, mango fruits grown in Kasese as well as irrigation water have high concentration of Pb and may be a health risk to consumers.

Key words: Heavy metals, Mango fruits, soil, irrigation water, Kasese, Uganda.

INTRODUCTION

Heavy metal pollution is widely spread globally due to the rapid pace of urbanization, land use changes, and industrialization, especially in developing countries with extremely high populations (UN-HABITAT, 2004). This has caused emerging issues of food security because of the increasing risk of contamination of food by pesticides, heavy metals, and/or toxins (Clarke and Smith, 2011; Säumel et al., 2012). Consequently there has been increased interest in food safety and this has encouraged research on possible contamination of foods by heavy metals, pesticides and other contaminants in the recent years (Thompson and Darwish, 2019).

Heavy metal accumulation in soils is of concern in agricultural production due to the adverse effects on food quality and crop growth (Nagajyoti et al., 2010). It has been known for long that plants take up metals by absorbing them from contaminated soil and waters (especially irrigation with contaminated water) as well as

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from deposits on different parts of the plants exposed to the air from polluted surroundings (Chojnacka et al., 2005). As a result, nearly half of the mean ingestion of heavy metals (e.g., lead, cadmium and mercury etc.) through food is due to plant origin (fruit, vegetables and cereals). Unfortunately, chronic low-level intakes of heavy metals have damaging effects on human beings and other animals, since there is no good mechanism for their elimination (ul Islam et al., 2007). For instance lead contamination in a long term adversely affects mental growth, causing neurological and cardiovascular diseases in humans, especially children (Zhou et al., 2016; Al-Saleh et al., 2017). Lead (Pb) and cadmium (Cd) have carcinogenic effects (Krueger and Wade, 2016; Al-Saleh et al., 2017; Ju et al., 2017) and can also lead to bone fractures and malformation, cardiovascular complications, kidney dysfunction, hypertension, and other serious diseases of the liver, lung, nervous system, and immune system (Zhou et al., 2016; El-Kady and Abdel-Wahhab, 2018). Chromium(Cr) in its hexavalent form is considered among the 14 most harmful environmental pollutants and can cause non-carcinogenic human health hazards such as neurologic complications, headaches, and liver disease, it could also be a carcinogen associated with lung, nasal and sinus cancers (US-EPA, 2000; Xin et al., 2015; Mishra and Bharagava, 2016).

The effect of heavy metal contamination of fruit cannot be underestimated as fruits contain carbohydrates, sugars, dietary fiber, fat, proteins, vitamins and minerals which are important for human health when eaten and most of these nutrients especially protein, vitamins, iron and calcium are in short supply (Slavin and Lloyd, 2012). Fruits also contain anti-oxidants and other biologically active ingredients hence effective in treatment of numerous diseases (Kay et al., 2006; Habauzit and Horcajada, 2008). The fact that fruits are an important component of the human diet, the effect of heavy metal contamination in them cannot be ignored. Metals from both natural and pollutant sources however, have the potential for being assimilated by plants through foliar or root absorption processes (Smedley and Kinniburgh, 2002). This may result therefore, in a difference in heavy metal composition of fruits like mangoes grown in different geographical places. This study was done to find out the levels of heavy metals in Mango fruits grown in Kasese and also in soils where the mango fruits are grown as well as in the water used for irrigation.

MATERIALS AND METHODS

Study area

Kasese District is in western Uganda and is home to Kasese Airport. The city is near the Rwenzori Mountains and Queen Elizabeth National Park. Kasese is approximately 345 km, by road, west of Kampala, Uganda's capital and largest city. Kasese is also about 61 km by road, north-east of Mpondwe Lhubiriha Town council (MLTC), the border town at the international border between Uganda and the Democratic Republic of the Congo (DRC). The coordinates of Kasese are 0°11'12.0"N, 30°05'17.0"E (Latitude:0.186667; Longitude:30.088050). River Sebwe and Mubuku lie on the main Kasese-Fort portal Highway, which continues on to Mpondwe at the International border with the Democratic Republic of the Congo. The town sits on the eastern bank of Mubuku River, Mubuku is also about 14km from the nearest small town called Hima. River Sebwe is the main source of water for Mubuku irrigation scheme. Nyakiyumbu subcounty Borders Bwera Subcounty.

Sampling procedure and sample size

A total of 30 composite samples of mango fruits were obtained from farms around Mubuku irrigation scheme, Mpondwe – Lhubiriha Town council and Nyakiyumbu subcounty in Kasese district. The sampling was done four times from each of the study areas. The fruits samples were collected in the same orchard in Mubuku irrigation scheme but from Nyakiyumbu and Mpondwe Lhubiriha they were collected from three different orchards randomly selected from each of the subcounties. The fruits were picked by hand from the mango trees during the day and in the dry season. Only the edible part of the fruit was analysed for the heavy metals and the rotten parts were removed first. Also, ten composite soil samples from two farms in Mpondwe- Lhubiriha Town council, one Mubuku Irrigation scheme and two in Nyakiyumbu sub county were obtained around the mango trees at a depth of 0-20 cm using soil auger and bulked together to form a composite sample as has been done in other studies (Bian et al., 2015; Wang et al., 2015; Kacholi and Sahu, 2018). The ten water samples from River Sebwe (whose water is used in Mubuku irrigation scheme) were obtained. These samples were always obtained during the morning. No water samples were obtained from Mpondwe- Lhubiriha and Nyakiyumbu since there is no irrigation in those areas. The collected soil and vegetable samples were put into zip lock bags and labelled, while water samples were put in previously rinsed and dried bottles. The samples were always collected on the same days.

Sample preparation and treatment

Mango fruit samples (each of 0.5 kg) were taken at random from the composite sample and processed for analysis by dry ashing method. The samples were oven dried at 105°C for 24 h first, the dried samples were then powdered manually in a grinder. Powdered samples (50.46 g for sample from Nyakiyumbu, 50.04 g for that from Mpondwe-Lhubiriha Town council and 50.07 g for sample from Mubuku) with three replicates were taken from each of the ten samples, accurately weighed and then placed in a silica crucible. A few drops of concentrated nitric acid were added to the solid as an aid to ashing a process that was done in a muffle furnace by stepwise increase of temperature up to 550°C. The samples were left to ash at this temperature for 6 h. The ash was kept in desiccators and then rinsed with 3 M hydrochloric acid after which the ash suspension was filtered into a 50 ml volumetric flask through filter paper and the volume made to the mark with 3 M hydrochloric acid.

Soil samples were air dried first. From each sample, 1.250 g were transferred to the destruction tube, 50 ml of water and three boiling chips were added. 50 ml of HCl/HNO_3 3:1 was also added. The resultant solution was then mixed and a funnel placed on top of the destruction tube. The tube was then heated to 100°C and

Table 1. Mean concentrations of selected heavy metals detected in soil samples.

Heavy metal	Mean concentration(mg/kg) ± SD			MPL (mg/kg)	
	Nyakiyumbu	MLTC	Mubuku	WHO (2017)	P-values
Cd	-	-	-	0.1	-
Cr	64.356±3.78	78.256±4.48	67.323±4.47	100	0.00
Pb	13.404±2.1	12.572±1.79	14.232±2.2	600	0.00

SD-standard deviation; *Values significantly below the permissible limits following one sample T-test (P< 0.05).

maintained for 1 h, increased to 125°C and maintained for 15 min, increased to 150°C and maintained for 15 min, increased to 175°C and maintained for 15 min, increased to 200°C and maintained for 15 min. The contents were concentrated to 5 ml and then cooled. 1 ml of 30% Hydrogen peroxide was added to the contents and then destructed for 10 min. 10 ml of water and 5 ml were added to the contents, mixed and heated until boiling and then cooled. The whole sample was transferred to a 50 ml volumetric flask which was then filled up to the mark, mixed and allowed to settle for 1 h. Finally, the absorbance of the clear supernatant was measured.

The water sample was prepared by filtration, followed by acidification. 50 ml of the acidified sample were transferred into a 50 ml volumetric flask. The absorbance of the sample was then measured.

Heavy metal analysis by atomic absorption spectrophotometer

Standard solutions of heavy metals (lead, chromium and cadmium) were prepared from the individual 1000 mg/L standards supplied in 0.1 M Nitric Acid. Reagent blanks of the different heavy metals were prepared by diluting 10ml of concentrated Nitric Acid to 100 ml in a volumetric flask. A series of working standards were prepared from the standard stock solutions to obtain heavy metal solutions of concentrations 0.1, 0.2, 0.3 and 0.4 M. The standards were fed into the flame atomic absorption spectrophotometer (AA 6300 shimadzu) and their absorbencies obtained which were used to obtain calibration curves. The samples were also fed into the atomic absorption spectrometer; their absorbencies obtained and then used to get their concentrations from the calibration curves. The detection limits were 0.0005, 0.001, and 0.004 mg L^{-1} for Cd, Cr, and Pb, respectively. The results were subjected to analysis using SPSS ver. 20 statistics program (IBM Corp. Armonk, NY: Released 2011) to determine if there were any significant differences among the means. Significant differences between means were determined at 5% level of significance.

RESULTS AND DISCUSSION

Levels of heavy metals in soil

The study reports on the heavy metal concentration of Cd, Cr and Pb determined in soil samples collected from the selected mango fruit production areas in Kasese district. The observed concentrations of Cd, Cr and Pb in the soil were compared with Maximal Permissible limits by WHO (Cd=0.1 mg/kg, Cr=100 mg/kg and Pb=600 mg/kg). One sample T-test analysis was carried out and Cr in the soil sample results were found to be significantly lower than WHO permissible limits (Cr=100 mg/kg). Likewise, a one sample T-test was conducted for Pb soil sample results and it was significantly lower than the permissible limits (Cr=600 mg/kg). The mean concentration of heavy metals found in the soil samples are summarized in Table 1.

Heavy metal concentrations of soils determined was based on sample dry weight. Levels of Cd were not detected, Cr was lowest at Nyakiyumbu (64.356 mg/kg) and highest at Mpondwe Lhubiriha Town council (78.256 mg/kg) and Pb was lowest at Mpondwe Lhubiriha Town council (12.572 mg/kg) and highest at Mubuku irrigation scheme (14.232 mg/kg). Mean concentrations of Cr and Pb in soil were 69.98 ± 4.24 mg/kg and 13.403 ±2.03 mg/kg respectively. The concentrations of Cr, Pb and Cd detected in the soil samples from all study sites were very much below the Maximum allowable concentrations by Dutch standard (Pb, 85 mg/kg and Cr 100 mg/kg). The mean concentration of Cr and Pb obtained in this study was higher than that obtained by Wang et al. (2012) in soil from a waste water irrigated area in China and that reported by Bahmanyar (2008) from soils under long term irrigation with waste water in Iran. The concentration levels of Pb and Cr was also higher than obtained by Hussain et al. (2017) in Pakistan. The concentration level of Pb was below while that of Cr was above that reported by Fosu-Mensah et al. (2017) in Accra Ghana. Cr was also below but Pb was above the concentrations reported by Hu et al. (2017) in the soil around Yangtze River Delta in China. The results show that Pb and Cr levels in the analysed soils though high are still below the Maximum permissible levels by WHO. The soils in the study area are therefore have heavy metals levels within permissible limits.

Levels of selected heavy metals in water

The heavy metals concentrations of Cd, Cr and Pb was determined in water samples collected from River Sebwe from which water used in Mubuku irrigation scheme and for drinking is obtained. The heavy metals levels in water were highest for Pb followed by Cr and Cd was below detectable levels. The mean concentrations of Cr and Pb

Table 2. Mean concentrations of heavy metals detected in fresh mango fruits.

Heavy metal	Mean concentration(mg/kg) ±SD			WHO (2017) MPL (mg/kg)	P-values
	Nyakiyumbu	Mubuku	MLTC		
Cd	-			0.2	-
Cr*	0.3789±0.06	0.4025±0.10	0.4265±0.06	2.3	0
Pb	0.2907±0.07	0.3139±0.07	0.3627±0.09	0.3	0.137

SD-Standard deviation. *Values significantly below the permissible limits following one sample T-test (P< 0.05).

were 0.0171±0.003 mg/L and 0.1127± 0.014 mg/L respectively Cr concentration in the water from River Sebwe was significantly lower than the MPL while Pb concentrations was significantly higher than the permissible WHO limits. Basing on the MPL for Pb and Cr in water of 0.01 and 0.05 mg/L respectively (WHO, 2017), only Pb concentration was above the MPL.

The concentration levels obtained for Pb were lower than those obtained by Kacholi and Sahu (2018) in water in Dar es Salaam Tanzania and those reported by Bigdeli and Seilsepour (2008) of 0.06 mg/L in a local river for irrigation in Shahre Rey, Iran. The high concentration of lead obtained in this study is of concern because, in addition to effects on the nervous system, exposure to lead has effects both at low and high levels and at short and long term. Prolonged low level exposure, may lead to diminished intellectual ability while long term exposure may lead to kidney damage (Järup, 2003). The Lead (Pb) could be coming from lead acid batteries and paints (Kushwaha et al., 2018) since River Sebwe is not very far from Kasese town and Hima. It could also be from motor vehicle fuels as river Sebwe is near the main tarmac road from Kasese to Fort portal. The concentration of chromium was higher than that obtained by Mousavi et al. (2013) in Mashhad, Iran but lower than that obtained by Bambara et al. (2015) in Burkina Faso. The water obtained from River Sebwe was therefore safe from any side effects of higher chromium concentration.

Levels of heavy metals in fruits

Heavy metal concentration of Cd, Cr and Pb was determined in mango fruits collected from production sites in selected areas in Kasese district. The mean concentrations of heavy metals found in fresh fruits are summarized in Table 2.

Heavy metal concentrations determined were based on sample dry weight. The results showed that the levels of Cd were not detected, Cr levels ranged from 0.3789 to 0.4265 mg/kg. Pb levels were lowest in Nyakiyumbu (0.2907±0.07 mg/kg) and highest in Mpondwe Lhubiriha Town council (0.3627 ± 0.09 mg/kg). One sample T-test analysis for Cr in mango fruits indicated that the results were significantly lower than the WHO Permissible limits. Pb concentrations in mangoes were not significantly different from the WHO Permissible limits. Fruits from Mpondwe-Lhubiriha Town council had the highest levels of both Cr and Pb whereas Nyakiyumbu Sub-County fruits had the lowest levels of the metals followed by those from Mubuku Irrigation scheme. The concentration of Pb in Nyakiyumbu is within the recommended levels of Pb in Mango fruits. This could be due to the fact that of all the three study sites, Nyakiyumbu is the most rural and has less influence from vehicle traffic, garages and other potential sources of lead. Several studies show that heavy metal contamination of garden soils is rampart in urban areas due to industrial activity and the use of fossil fuels (Ahmed and Ishiga, 2006; Wong, 2010; Sterrett et al., 1996; Chronopoulos and Haidouti, 1997; Wong, 2010)

Basing on the MPL for Cd, Cr and Pb in fruits (0.2, 2.3 and 0.3 mg/kg respectively) (FAO and WHO, 2017), the levels of Cr in fruits from all the three study areas are lower than the MPL whereas levels of Pb are higher than the MPL except for those from Nyakiyumbu. The mean concentrations of Lead obtained in mango fruits in this study are lower than those obtained in Misurata-Libya, Bangladesh and Bangalore city, India (Elbagermi et al., 2012; Shaheen et al., 2016) in Mahdavian and Somashekar (2008). The concentrations of Pb and Cr was higher in the mango fruits and this could be because plants absorb the heavy metals when they are deposited on their leaves through the tissues (Kachenko and Singh, 2006) in addition to what they absorb from the water and soils. One of the important dietary sources of metals to plants is through irrigation with contaminated water (Banerjee et al., 2010). The main sources of heavy metals to mango fruits and other plants are their growth media (soil, air, nutrient solutions) from which these are taken up by the roots or foliage (Lokeshwari, 2006). The higher concentration of Pb from fruits obtained from Mpondwe Lhubiriha Town council could probably be due to the fact that the area is more semi urban and has many activities and vehicle traffic as well as garages that could be sources of lead acid batteries.

Conclusion

Generally, the concentration of Pb in Mango fruits was higher than the MPL by WHO except for the fruits obtained from Nyakiyumbu. concentration of chromium in fruits was within the MPL by WHO. The concentration of Cr, Pb and Cd were all within the MPL in soil. Meaning that soils are not yet contaminated by these heavy metals in all the study sites and hence still good for farming. The concentration of Pb in the waters of River Sebwe was higher than the MPL while that of Cr was within the limits. Cd was below detection levels therefore, the water may be a risk to human health due to the high concentration of Pb. These findings suggest that in general the presence of high concentration of lead in the fruits could probably be from the water being used for irrigation but also from other sources in the environment.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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