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African Journal of Environmental Science and Technology

Full Length Research Paper

Effect of a modified lifetime model on e-waste generation in Nigeria under defined reuse options

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Reliable data on e-waste generation is important for environmentally sound management systems. This study models e-waste generation from existing data on electrical electronics imports, consumption and e-waste generation from Nigerian households. Structured questionnaires were used to obtain information on Electrical Electronic Equipment (EEE) use, reuse, and disposal from households in Nigeria households. Data from placed on the market (POM) were obtained from United Nations University (UNU) for five EEE types (TV, DVD player, refrigerator, desktop and laptop) in Nigeria between 1995 and 2019 using the apparent consumption method. A forecast up to 2020 and backcasts to 1980 were made based on these data. The lifetime profile for these five EEEs was modeled using the Weibull distribution function characterized by a time-varying shape parameter and a scale parameter. The POM data from 1980 to 2020 and the lifetime of the selected EEE from households were analyzed and fit into the Weibull lifetime distribution functions. The differences between reuse and non-reuse options show that around 54 million units of DVD players; 106 million units of CRT TV; 22 million units of the refrigerator; 11 million units of laptops and 24 million units of desktop computers would have been delayed from transiting into e-waste stream between 1981 and 2020 through reuse options.

Key words: Electronic waste, electrical electronic equipment, lifetime distribution, re-use repair, recycling, Nigeria.

INTRODUCTION

Waste electrical and electronic equipment (WEEE), or e-waste includes a wide range of products which comprises of any household or business item with circuitry or electrical components with power or battery supply (Balde et al., 2017) which have been discarded by the owner as waste without the intention of re-use (StEP, 2014). Global e-waste generation grew by about 9.2 million metric tonnes (Mt) from 2014 to 2019 which makes total e-waste generated worldwide in 2019 to be estimated at around 53.6 million tons (Mt), an equivalent of 7.3 kilograms per inhabitant (kg/inh). E-waste generated globally per annum is expected to exceed

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74.7 Mt by 2030 (Forti et al., 2020), and up to 111 million tons per annum by 2050 (Parajuly et al., 2019). The growth in e-waste can be linked to high consumption rates of electrical electronic equipment (EEE) with short lifetime cycles, and very low repair rate and reuse options. Many previous research works have been reported in recent times focusing on the e-waste management system (Iqbal et al., 2015; Pathak and Srivastava, 2017; Imran et al., 2017; Sajid et al., 2019). Several of the previous work focused on policy and legislative efforts, financing and awareness schemes as part of the solution to e-waste management. The reduction of e-waste volumes and substantive repair and reuse of EEE have been limited so far in the literature. There has been a significant quest to understand e-waste generation and collection/treatment using Environmentally Sound Management (ESM) by stakeholders. The sustainable collection and management of information are sometimes difficult to achieve especially in developing countries because of the lack of e-waste inventory and often uncoordinated system boundaries. Previous studies have attempted to fill this gap, for instance, Wang et al. (2013) applied an input-out analysis linking sales, stock, and lifespan data approach. Similarly, the US Environmental Protection Agency (EPA) updated two earlier studies and estimated e-waste generated quantities using a deterministic sales obsolescence method (USEPA, 2011). The United Nations University (UNU) developed an interactive map of e-waste generation to develop a global e-waste monitor which used trade data to estimate sales and inferred lifespan from stocks and apparent sales data (Balde et al., 2017). Previous works have used different parameters and approaches to estimate the volume of e-waste generation (Araujo et al., 2012; Huisman et al., 2012). However, none has presented a detailed prognosis of the effect of repair options for End of Life (EoL) devices for reuse on the lifetime estimation and how this further affects the volume of e-waste generated. “Life-time” for this study comprises the active use time of an EEE including the extended reuse time after repairs by owners/households.

This study is a follow-up on the Person in Port (PiP) project (Odeyingbo et al., 2017) which was carried out under the United Nations University (UNU) framework (in collaboration with the U.S. Environmental Protection Agency (EPA), the Basel Convention Coordination Centre for Africa (BCCC) in Nigeria, and Gesellschaft fur Internationale Zusammenarbeit, (GIZ) to assess the quantity and quality of used electrical electronic equipment (UEEE) and e-waste import into Nigeria. The PiP provided reliable data by developing an assessment approach that combines inspection of incoming containers of UEEE and evaluation of import-related documentation. The PiP observed the importation of about 60,000-71,000 tons of UEEE with about 19% non-functional. With a very active repair network, some of the non-functional UEEE are cannibalized to fix other UEEE products. This study aims to investigate the role of the ‘repair and reuse’ tradition in Nigeria in reducing the amount of e-waste generated. This will improve the existing data and knowledge by providing a better prognosis of the e-waste sector of Nigeria and to further refining and complement existing e-waste flow assessment. This study, therefore, quantified benefits from EEE reuse and especially the savings in the e-waste generation in Nigeria. This study fills the gap created by a lack of knowledge of the effect of reuse on lifetime calculation and improves e-waste generation estimates. Effective and continuous capture of data on electrical electronic equipment flow is essential for achieving effective management plans and projections. The availability of data will improve the measurement in the collection rate of WEEE and refine the management plans for the proper treatment of e-waste.

MATERIALS AND METHODS

A household survey approach was applied in this study to develop a lifetime model under the specific repair and reuse traditions in Nigeria. This study used a combination of put on the market (POM) data obtained from UNU data set in and lifetime distributions information obtained from a household survey. When EEE are placed on the market, it stays in households and businesses which represent the active use stage. For this study, the use phase includes the repair and reuse effect on the lifetime which varies from product to product (Baldé et al., 2020). Reuse through repair is a way of extending a product’s first life beyond the point where it has been discarded by its first user. The lifetime includes the time the equipment is used after repair and reuse.

The approach employed for this study involved a general calculation approach using household data as a first step in the development of a lifetime model with consideration for the effect of repair and reuse options which extends the use lifetime in the system boundary Nigeria. The EEE lifetime is a fundamental variable in calculating e-waste generation which is a key objective of this study. Household data obtained through a survey were used to express lifetime distribution function using Weibull distribution (Magalini et al., 2014; Baldé et al., 2015; Wang, 2014; Xianlai et al., 2016).

The household data set focused on the lifetime distributions of five EEE consumers and IT electronics. The lifetime distribution for reuse and non-reuse of the selected EEE were determined from the household survey through the administration of structured questionnaires in 400 randomly selected households in the selected localities. The questionnaire focused on (i) the usage time by consumers before major defects (ii) after repair (iii) how long the EEE was used before final disposal. The survey focused on five EEE types which include desktop computers, TVs, DVD players, laptops and refrigerators.

A system boundary is drawn to clearly define the lifetime to include the repair and reuse options. The inflow and the outflow of EEE in the studied system are presented in Figure 1. The total quantity of EEE in use by the consumer is regarded as the active stock; the age of the products in stock is called the active-stock age. These data were obtained through a consumer survey. The survey results are then used to construct the disposal- after repair and after usage composition and the active-stock age composition. The household assessment was carried out in a preliminary part of this study. The result on lifetime distribution is presented in Table.1 is used to estimate the volume of e-waste with reuse option and

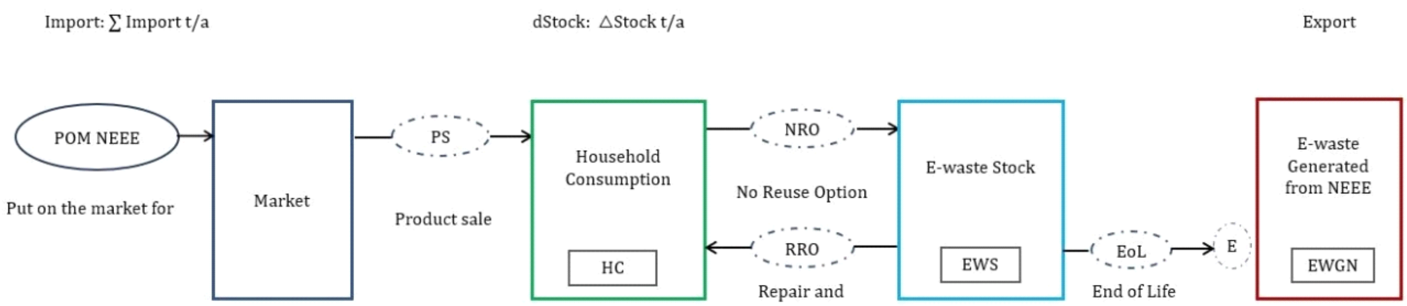


Figure 1. Assessment approach of flow for e-waste generation from new electrical electronic equipment (NEEE).

Table 1. Lifetime of NEEE with reuse and non-reuse option among Nigerian households.

UNU KEY	EEE type	Condition	Lifetime*	Shape (α)	Scale (β)
0303	Laptop	No reuse	3	6.23	3.85
		Reuse	10	2.11	11.70
0108	Refrigerator	No reuse	4	5.85	4.18
		Reuse	13	1.79	14.47
0404	DVD player	No reuse	3	4.26	3.15
		Reuse	12	3.05	13.66
0308	TV CRT	No reuse	4	6.23	3.85
		Reuse	15	5.10	17.09
0302	Desktop computer	No reuse	3	3.78	3.51
		Reuse	12	2.59	14.22

Analysis of household survey showing; *Total average number of years.

non-reuse option. Data on new EEE put on the market (POM) sales data from 1980 to 2020 came from the United Nations University data. The data were calculated by using the “apparent consumption method” which came from internal data based on trade statistics from the United Nations University (Forti et al., 2020). The statistics on sales from the National e-waste registry which forms the POM data does not include data on UEEE import.

Lifetime Model

The lifetime profiles of the selected EEE were modelled using several probability functions. Data from the household survey were used to determine the effect of repair and reuse on lifetime distribution using Weibull distribution (Magalini et al., 2014; Baldé et al., 2015) for the selected EEE products. The Weibull distribution function is considered suitable to relate the ‘discard behavior’ for the EEEs because it exhibits a better data fit characteristic (Wang, 2014; Xianlai et al., 2016) applied similar application in previous scientific literature. The Weibull distribution function is expressed by the time-varying shape parameter α(t) and the scale parameter β(t). The lifetime is categorized into: <1 year, 2 years, 3-4 years, 5-10 years, and > 10 years; while the time repair and re-use added to lifetime were separated into the lifetimes of: < 1 year, 2-3 years, 4-5 years, and > 5 years. These steps were taken to refine the specificity and plausibility of the objective in determining the effect of repair and reuse on lifetime distribution which represents part of the steps in calculating the effect of repair and reuse on e-waste generation.

The lifetime distribution analysis for the collected data from the questionnaires was carried out using STATA software.

Stset (STATA function was used to specify the time-to-failure variable); streg, $(t)=e^{-\lambda t p}$ distribution (Weibull time) was used to model each variable using the Weibull distribution.

Steps 1 and 2 estimate the shape and scale parameters in the model.

Step 1 to 3 was carried out for each of the variables for all the EEE.

The average score for each of the variables for all the EEE was computed in order to check the descriptive features of the variables. St Curve, survive code was input in STATA function to generate the time-to-failure graph using the Weibull distribution calculation of the actual number of years used by the EEE.

Responses to the questions on the duration of use of EEE was on a scale code of 1 to 5 where: code 1 = <1 year; code 2 = 2-4 years; code 3 = 4-6 years; code 4 = 6-10 years; code 5 = 10+ years.

To get the average number of years, let f be the frequency for each duration of the EEE on a scale of 1 to 5, where 1= <1 year and 5 =10+ years.

Let m be the mid-point for each of the durations.Let N be the total number of respondents to the question on the duration of EEE. Then, the average number of years for each EEE before failure is

$$\mu = \frac{\sum mf}{N}$$

Weibull distribution function on Excel® was used to determine the average usage times for the five categories of electronics (NEEE), and average extended life with repair/refurbish and re-use. The analysis of household assessment was the first step in the calculation of lifetime. From the household assessment the following details were retrieved:

The lifetime of a NEEE before repair;
The lifetime extension of the equipment in the above scenarios after repair/ refurbishment;
The total lifetime extension with re-use after repair/refurbishment.
The various stock data were fit into the Weibull lifetime distribution functions for determining the lifetime profiles of selected electronic devices for this study.

A Weibull function is presented in the Excel® work package to show the cumulative distribution function (CDF) and probability density function (PDF) values. Weibull (X, alpha, beta, true) provides the cumulative distribution function, CDF, at the value of X. Weibull (x, alpha, beta, false) provides the probability density function, PDF, at the value for X.

Where Weibull CDF is, $CDF = 1 - exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right)$ and Weibull PDF is, $PDF = \left(\frac{\alpha}{\beta^{\alpha}}\right)x^{(\alpha-1)}exp\left(-\frac{x}{\beta}\right)^{\alpha}$; Weibull reliability,, $R = 1 - CDF$; Instantaneous failure, $R = 1 - CDF; H(t) = \left(\frac{\alpha}{\beta}\right)\left(\frac{x}{\beta}\right)^{\alpha-1}$

Data input

The put-on-market data (POM) of new EEE obtained from UNU calculations and lifetime information from households in Nigeria were used to calculate the volume of e-waste predicted to be generated in a given year. The approach adopted in the assessment of EEE flows is presented in Figure 1. This shows a graphical flow of source (import), stock considering the multidirectional flow between household stock and e-waste stock through the effect of repair that encourages reuse of electronics, and how reuse affects the volume and rate of e-waste generation. The calculation for UEEE import is not included in the analysis.
E-waste generation calculations are based on a time series of POM data in the unit and the average lifetime calculation from Nigerian households using the reuse and non-reuse estimate. Stock and lifetime models, combined with time-series stock data with lifetime distributions of products were used to estimate e-waste generation (Binder et al., 2001; Müller et al., 2009; Walk, 2009). The quantity of e-waste produced (in units) from NEEE was calculated from the time-series of POM data and the UNU e-waste data set for Nigeria for the period 1980-2020 (Supplementary Table S2-S3), considering the various rates of obsolescence in the evaluation year n. However, due to scanty reliable import data of UEEE import beforethe year 2015, further calculation of waste generation from imported UEEE was not included in this analysis. The only reliable data for UEEE import into Nigeria were reported by Odeyingbo et al. (2017) who reported that 60,000 - 71,000 tonne/annum of household UEEE such as refrigerator, laptop, desktop computer, CRT TV, DVD player etc. were imported for the year 2015 and 2016 and 2017. See for details of imported UEEE in Odeyingbo et al. (2017).

$$Ewaste\ generated\,(n) = \sum_{t=t_0}^{n} POM\ (t) \times L^{(p)}(t,n) \quad (1)$$

where e-waste generated (n) is the quantity of e-waste generated in evolution year n, POM (t) is the product sales (Put on Market) in all historical years (t) before year n; t_0 is the initial year that a product was sold; L((p) (t, n) is the discard-based lifetime profile for the batch of products sold in the historical year t. The approach makes use of quantity (in numbers) of POM of EEE in the year 1980 to 2020 (Supplementary Table S1 using the "apparent consumption method" (equation 2). The POM in a historical year t equals the sum of imports of EEE in the year t minus the EEE exported in the same year (Wang, 2014; Forti et al., 2018). Generally, there is little or no domestic production of EEE in Nigeria.

POM (t) = Imports (t) – Exports (t) (2)

The discarded-based lifetime profile for a product was modelled using the Weibull distribution function i.e. a time-varying shape parameter α(t) and β(t), a scale parameter as

$$L^{(p)}(n) = \frac{\alpha}{\beta^{\alpha}}(n-t)^{\alpha-1}e^{-[n-t/\beta]^{\alpha}} \quad (3)$$

$$L^{(p)}(t,n) = \frac{\alpha}{\beta^{\alpha}}(n-t)^{\alpha-1}e^{-[n-t/\beta]^{\alpha}}L^{(p)}(t,n) \quad (4)$$

The lifetime, $L^{(p)}$ (t, n), represents the lifetime profile of the EEE product sold in a historical year. This reflects the probable obsolescence rate in evaluation year n. Weibull distribution function was used to describe discard behaviour for the EEE product (Wang, 2014). The data were analysed using the Graphpad Prism® version 6 software package and the area under the curve of the variation in the comparative analysis were obtained (Figure 2). The differences in the quantity of e-waste reduction were used to determine the volume, rate in percentage of transition, and mass of e-waste reduction.

To further compare the e-waste generated data for this study, the mean number of EEE products in the household study was used to calculate the total household stock in Nigeria from 2013 to 2018. This was calculated by multiplying the average number of EEE devices per household and the total number of households in Nigeria reported in the literature (Euromonitor, 2018). Furthermore, sensitivity analysis was carried out with an average margin of error of ±30% based on the uncertainty of the POM forecast and variation in lifespan results.

RESULTS AND DISCUSSION

Lifetime calculation

This study observed that repair and activities have a significant positive influence on the lifetime of a new TV. Most of the respondents in this study (approximately 74%) indicated that faulty electronic equipment could be repaired and reused at least twice before disposal. Hence an increase in the total lifetime was observed for the studies EEE before disposal. The household analysis for

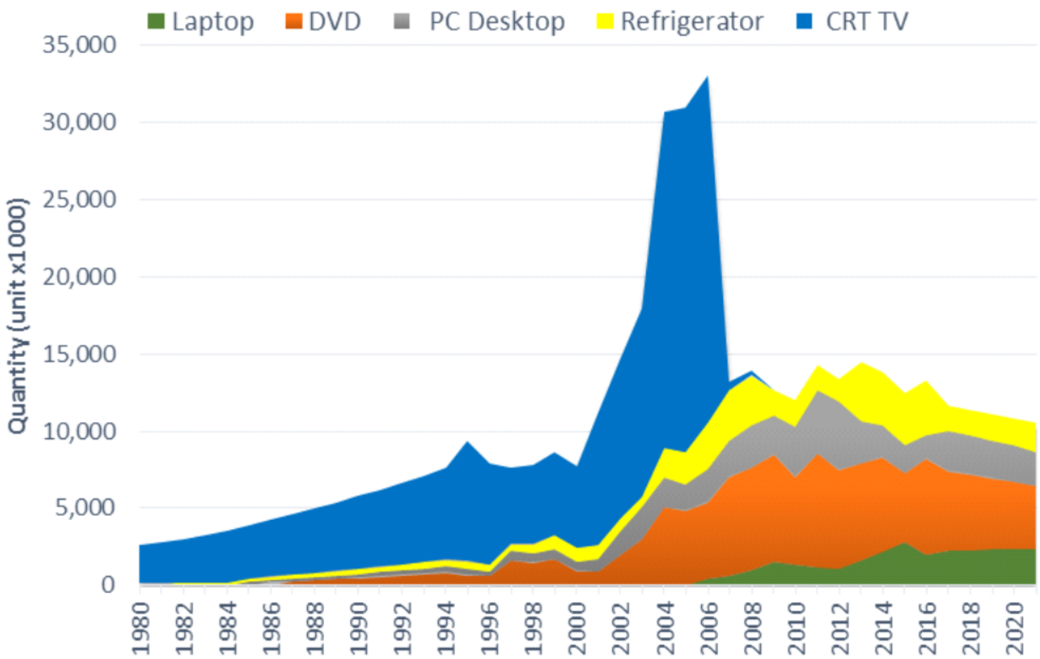


Figure 2. EEE placed in the market annually in (units) for 1980-2020 (UNU data) and mostly new items).

the determination of lifetime distribution for EEE without reuse and reuse options show that repair of EEE significantly contributed to improvement in their usage time. For instance, it improves the lifetime of TV from 4 years to about 15 years, desktop PC from 3 to 12, a refrigerator from 4 to 13, DVD players has an average usage time of 3.9 years before requiring any repair, and repair activity extend the lifetime to 13 years. Traditionally, faulty EEE are not quickly discarded in Nigeria because of reuse tradition which is stimulated by cheaper repair cost. Repair and refurbishing activities extend the lifetime of used, damaged or outdated electronics products through the replacement of defective components. Repair activities in Nigeria involve the restoration of the performance and functionality of EEE products through fixing technical faults and restoring them to functional status. Table 1 shows the non-reuse lifetime and total lifetime after reuse profiles for new EEE in Nigeria households; the total average number of years (lifetime) and Weibull lifetime distribution.

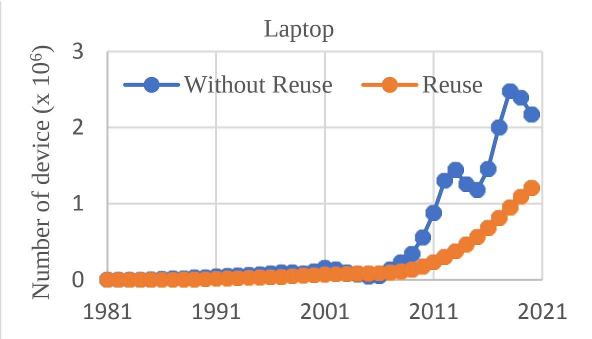
The authors' results showed that repair activity reduces the transformation of EEE to e-waste. Repair and refurbishing activities ensure EEE reach the possible optimal lifetime, while also contributing to sustainable development because of its potential to minimize further emission throughout the lifecycle of EEE and improved the product longevity (Evans and Cooper, 2010). Cooper (2010) also noted that repairing, refurbishing and reusing extend the lifetime of products as the best option in terms of environmental benefits. The higher lifetime of EEE in Nigeria further reflect the real dynamics of repair and reuse in the EEE sector (Table 1).

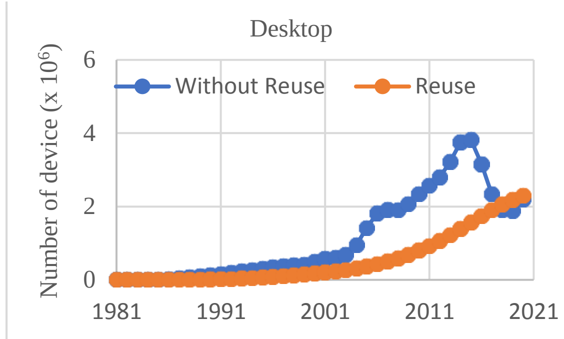
E-waste generation

Area under curve (AUC) analysis estimates and compares the concentration or quantity of more than one parameter (that is, electronics with or without reuse) in a given period. It measures the total area below the plotted curve of each parameter for the sake of comparison. Therefore, parameters with high AUC have a large total area below their plotted curves.

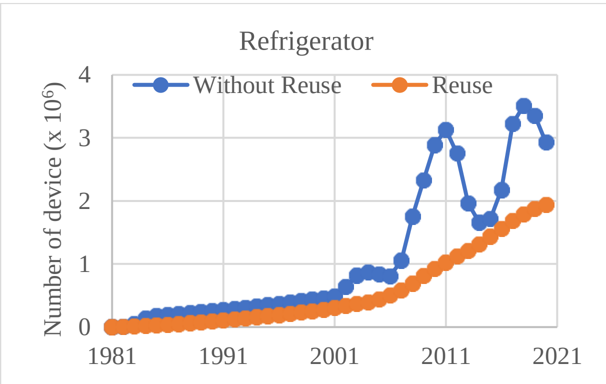
Consequently, a large total area below the plotted curves of the parameters indicates a large quantitative value of such parameters within the given period. In the present study, AUCs of each electronic device (non-reuse and reuse) between 1981 and 2020 were compared.

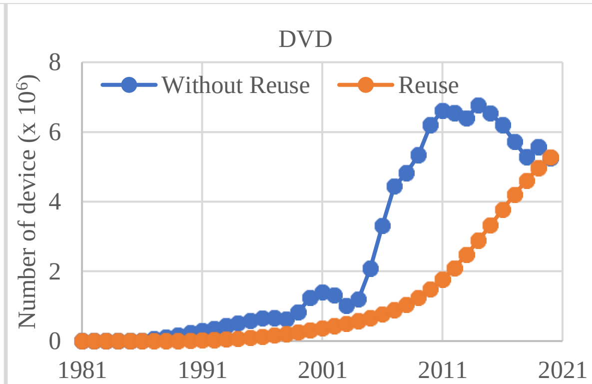
For laptops, the AUC of non-reuse (18248) was higher than that of reuse (7504) (Figure 3A), which indicates a larger quantity of non-reuse laptops than reuse laptops between 1981 and 2020. A similar trend was seen for DVD player (reuse: 20425; non-reuse: 44293), TV (reuse: 103261; non-reuse: 147238), refrigerator (reuse: 21633; non-reuse: 42597), and desktop (reuse: 20425; non-reuse: 44293) (Figures 3B-E). This implies that all electronics under non-reuse were larger in quantity than those under reuse. The difference between the quantity under reuse and non-reuse was calculated for each electronic and the AUC of this difference was compared





A. AUC Reuse-7504, AUC Non-reuse -18248 **B**. AUC Reuse-20425, AUC Non-reuse-44293





C.AUC Reuse-21633, AUC Non-reuse-42597 **D**. AUC Reuse-42061, AUC Non-reuse-96158

E. AUC Reuse-143401, AUC Non-reuse-147238

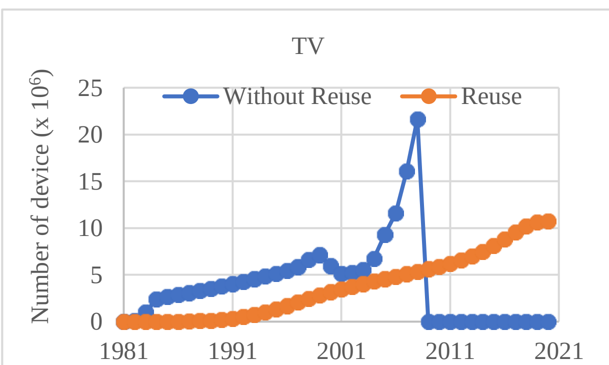


Figure 3: Comparison of Reuse and Non-reuse (A-E).

for each electronic. The AUC of the difference between reuse and non-reuse for each electronics is in the following order: television (106087) > DVD player (54098) > desktop (24778) > refrigerator (20965) > laptop (10914). This indicates that television had the largest difference, while laptop had the least difference.

With the explanation on AUC provided above, it is clear from Figure 3E that the total area covered by non-reuse TV was much higher, considering the sharp rise between 1981 and 2011. The total area below this region was much higher than that of the reuse. The reuse only had a higher area coverage than non-reuse from 2011 to 2021, which is a shorter range compared to 1981 to 2011. Therefore, when these ranges were compared, the authors found that the non-reuse had more coverage regardless of its low coverage between 2011 and 2021. The electronic wastes generated between 1981 and 2020 under reuse had an AUC in order of television (143401)>DVD player (42061)>refrigerator (21633)>desktop (20425)>laptop (70504). On the other hand, e-wastes generated under non-reuse is in the order of television (147238)>DVD player (96022)>desktop (44293)>refrigerator (42597)>laptop (18249). From the above, television and laptop were the highest and lowest e-wastes generated from 1981-2020, respectively, both under reuse and non-reuse.

Table 2. Total e-waste generation prevention rate in percentage and mass in tons.

UNU key	EEE type	Average weight (kg)*	Devices prevented from transiting to waste			Kg/Inh
			Unit	Quantity (t)	%	
0407	CRT	33.20	106,088,917	3,522,333	67	17
0404	DVD player	3.51	54,085,044	189,838	55	1
0108	Refrigerator	16.71	21,455,594	358,523	49	1.7
0303	Laptop	8.76	11,227,945	98,357	58	0.5
0302	Desktop	10.33	23,814,665	246,005	52	1.2

Forti et al. (2018)*.

Effect of reuse and non-reuse function on e-waste generation

A comparative analysis between e-waste generation using repair and non-repair effects are presented in Figure 3A to 3E. The quantity in the unit of e-waste generated between the e-waste calculations with the reuse option was subtracted from the e-waste generated calculation without the reuse option. The differences show that around 54 million units of DVD players; 106 million units of CRT TV; 22 million units of the refrigerator; 11 million units of laptops and 24 million units of desktop computers would have been delayed from transiting to the e-waste stream between 1981 to 2020 through reuse options. The data and calculation presented in Figure 3A-3E.indicated that the extension of EEE product life through, repair and reuse have revealed its effectiveness in reducing the generation of WEEE, hence it has tremendous environmental and resource benefits. The advantages of repair and reuse provide alternative means to hold on to electronics devices for longer use time, often for the low-income households, it reduces waste generation, protects the environment and supports household income through employment. In the study area, repair options often reinstate a faulty EEE product to a serviceable /functional condition.

The result obtained in this study corroborates one of the principles of circular economy of keeping products and materials in use by extending the productive life of resources (Blomsma and Brennan, 2017), and retaining resource value (Reike et al., 2018), which arguably has a positive net effect on the environment. It is the opposite of linear economies which are often used and disposed of. The result from this study support restoration of damage EEE leads to a reduction in the transition of EEE to e-waste by deviating from a linear to a circular economy through repair and reuse. The calculation of lifetime and e-waste generation obtained in this study has refined and complemented existing e-waste flow assessment works by integrating lifetime data of EEE with the effect of repair and reuse in Nigerian households. Further calculation presented in Table 2 shows that massive 3,522,333 (t) of CRT TV, 189,838 (t) of DVD player, 358,523 (t) of refrigerator, 98,357 (t) of laptop, and 246,005 (t) of desktop PCs were prevented from transition to e-waste.

Data from 400 randomly selected households in the selected study area shows that an average of 1.6 and 1.7 units of TV and DVD respectively is calculated per household, while 0.7 of desktop, 0.1 of laptop and 0.7 units of refrigerator per household was further calculated. To further assess the quantity of e-waste generated based on the calculation from Nigerian households, the mean EEE possession in the household was used to calculate the total stock of the researched appliances in Nigeria household by multiplying the average EEE possession with the total number of households in Nigeria from 2013 to 2018. The dataset published by Euromonitor International (2018) was used as a reference for the total household in Nigeria. The calculated data was further used in estimating the total household stock of the selected EEE devices (Table 3). The numbers of households for the periods under consideration are 36.07 M in 2013; 37.17 M in 2014, 38.29 M in 2015, 39.42 in 2016, 40.56 in 2017 and 41.73 M for 2018 using the EEE data possession from the household survey and the total number of households in Nigeria (Table 3).

There is a significant disparity in the calculated household stock data and the calculated stock in pieces using the POM data (Table 4). This further show that UEEE imports are not included in the national statistic hence they cannot be accounted for or traced. This finding shows that calculating the average quantity of appliances per household with the number of EEE in stock from the household survey in Nigeria can be a practical approach to further support the approach which uses calculations based on POM data and lifetimes model. The data reflect that EEE use and e-waste generation is increasing. The transition, however, is proportional to the lifetime of the selected equipment. The comparative analysis of the POM calculation approach and household approach in calculating stocks in the system has given more plausible data on the stock of EEE in Nigeria. It has further improved the lifetime model for developing country under the specific repair, refurbishing and reuse tradition on e-waste to active practical estimates that reflects the real-time situation in Nigeria.

Table 3. Estimated EEE possession in Nigeria per household, based on household data.

EEE type	Possession per household	Total quantity in pieces (x1000)					
		2013	2014	2015	2016	2017	2018
Desktop	0.7	27,416	28,253	29,098	29,958	30,829	31,711
TV	1.6	57,718	59,480	61,260	63,070	64,904	66,762
DVD player	1.7	61,325	63,197	65,089	67,012	68,960	70,934
Notebook	0.1	3,607	3,717	3,828	3,941	4,056	4,172
Refrigerator	0.7	24,891	25,650	26,418	27,199	27,989	28,791

Table 4. Comparison of total household stock using modeled POM-lifetime data and household data in Nigeria ((X1000) in unit.

Year	PCs*	PCs**	TV *	TV**	DVDplayer*	DVDplayer**	Laptop*	Laptop **	Refrigerator*	Refrigerator**
2013	27,416	29,423	57,718	110,607	61,325	60,554	3,609	8,478	24,891	22,857
2014	28,253	30,051	59,480	103,111	63,197	63,799	3,717	10,221	25,650	25,026
2015	29,098	30,262	61,260	95,001	65,089	64,959	3,828	12,453	26,418	26,967
2016	29,958	30,053	63,070	86,191	67,102	67,409	3,941	13,765	27,199	28,922
2017	30,829	30,726	64,904	76,654	68,960	68,340	4,056	15,240	27,989	28,873
2018	31,711	31,175	66,762	66,461	70,934	68,617	4,172	16,605	28,791	28,770

*Household survey stock (HSS), **POM lifetime Modeling data (PLM).

To further validate the amount of e-waste generated a comparative analysis of calculated stock age from POM data presented was compared to the calculated household stock from Nigeria households. Table 4 shows the comparison between the stock data calculated from Nigerian households and the stock data calculated using the POM data. The result for CRT reflects the decline in the production and subsequent importation of CRT TV between the years 2005-2007. This fact has a significant effect on the quantity of e-waste generation. The result further shows that the availability of CRT in households is sustained by the continuous repair, refurbishing and reuse activities which significantly affect the lifetime and high retention in households. For Laptops, the disparity in the household and POM calculation could be connected to the fact that most laptops are used and retained in businesses and offices hence it might not have been captured in the household calculations.

Analysis of the data presented in Table 4 using the Wilcoxon signed ranks test, negative ranks and positive ranks show that there is no significant difference between a desktop computer, DVD player and refrigerator.

The extension of lifetime through repair and reuse is based on the concept of Circular Economy (CE). The circular economy concept in the electronic sector can slow down the rate of EEE consumption by circulating them within the system for the longest possible time and minimizing e-waste generation through smarter product design and business model Parajuly et al. (2017) which integrates repair and reuse possibilities. This can only be achieved through joint efforts across the upstream, midstream and downstream players of the value chain who extend lifetime through maintenance operations (that is, restoration, repair, refurbishment and replacement of defective components to the original as-new condition). Numerous benefits exist in the circular economy approach which includes the creation of employment opportunities, well designed, long-living products through increased maintenance, repaired and refurbishing activities (Ranasinghe and Athapattu, 2020). The result from this study clearly shows that low material circularity in the e-waste sector enhances e-waste generation. A transition towards a circular economy can limit e-waste generation improve resource efficiency, reduce environmental impacts and promote a healthy environment for workers and local communities.

Data uncertainty

Sensitivity analysis (adopting ±30% projections) for each of the electronic devices under the reuse and non-reuse AUCs are presented in the supplementary tables. Data on TV under reuse from 1981 to 2020 was sensitive to ±30% projections (-30%, 140378; normal, 143401; +30%, 146475), whereas television under non-reuse did not fit well for projections (-30%, 193364; normal, 147238; +30%, 194211). In other words, data on television under reuse are well-fitted to make future projections in contrast to those of under non-reuse (Supplementary Figure 1A). For a data model to be well-fitted for future projections, the AUC of the lower boundary must be below the normal value, while that of the upper boundary must be above the normal value. Data on DVD player under Reuse (-30%, 40793; normal, 42061; +30%, 43366) and Non-reuse (-30%, 94601; normal, 96022; +30%, 97663), laptop under reuse (-30%, 7292; normal, 7504; +30%; 7753) and non-reuse (-30%, 17578; normal, 18249; +30%, 18522), refrigerator under reuse (-30%, 21540; normal, 21633; +30%, 22355) and non-reuse (-30%, 41758; normal, 42565; +30%, 43423) (Supplementary Figure. 1A-B); and desktop under reuse (-30%, 20371; normal, 20425; +30%, 20479) and non-reuse (-30%, 43733; normal, 44293, +30%, 44881) were all sensitive to ±30% projections, thus indicating their fitness for future projections.

The authors study has several limitations. The lack of consistent data on UEEE import data to Nigeria limited our calculation for the e-waste generated from UEEE import.

Conclusions

The lifetime model indicated that repair activities encourage reuse and prevent the generation of e-waste by 67% for cathode-ray television, 55% for DVD players, 49% for refrigerators, 58% for laptops and 52% for desktops on yearly basis. The observation from this study reveals that UEEE import is not declared or undeclared in the import statistics. The lack of consistent data on the importation of UEEE has made the calculation of UEEE transition to e-waste difficult. The availability of reliable data on e-waste generation is a prerequisite to an effective e-waste management system. An effective collaborating system between all the stakeholders in the e-waste management system is required for a successful transition to a sustainable e-waste management system.

The effective collection, management and update of data on e-waste generation can be sustained if national guidance that stipulates the registration, report on the market input and output, the fundamental of the level playing field for operators in the EEE import and manufacturing is strictly adhered to. For instance, the POM data represent a key parameter used in the computational calculation of waste generation. The preservation of consistent datasets such as the National e-waste registry is one of the key instruments for the assessment of entire lifecycle production and distribution through the final recovery and recycling of e-waste.

There is a need for an effective and sustainable data management system for UEEE and EEE imports. A consistent computation of POM data set from the National Bureau of statistics will be necessary to serve as an alternative source of data that can be used to complement or compare the data from the national e-waste registry. The e-waste generation data can be used as a basis for further analysis and how such analysis can be used to make future projections that would serve as a caution for the proliferation of environmentally hazardous substances that emanate from these e-wastes. These steps are important steps for e-waste management in Nigeria. The calculated e-waste generated further highlights the potential business opportunities associated with the huge volume of waste in Nigeria. At the end of multiple uses of electronic appliances and components, there is still a gap that needs to be filled by an effective recycling system in the management of pollutants and e-waste-related hazardous health effects, while also transiting to the attainment of the set United Nations Sustainable Development Goals (SDG). As observed in the study, it is still difficult to estimate and maintain data for the quantity of POM of imported UEEE. Furthermore, the non-availability of data on the quantity of transboundary movements of UEEE and WEEE creates difficulty in addressing issues such as proper estimation of collection and recycling to meet legislative targets. The establishment of trade codes for used appliances will facilitate effective tracking of the imported used electronic appliances.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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APPENDIX

Supplementary Table 1. Put on market data (POM) data.

Year	Laptop	DVD	Desktop	Refrigerator	CRT TV
1980	0	0	0	167,064	2,412,814
1981	4,939	0	0	179,983	2,599,390
1982	10,148	0	0	193,323	2,792,058
1983	15,634	0	23,816	207,179	2,992,172
1984	21,414	50,530	48,933	221,702	3,201,910
1985	27,517	103,889	75,454	237,025	3,423,209
1986	33,968	160,310	103,495	253,211	3,656,983
1987	40,786	219,985	133,145	270,253	3,903,114
1988	47,985	283,077	164,478	288,147	4,161,533
1989	55,569	349,666	197,525	306,835	4,431,434
1990	63,538	419,807	232,307	326,283	4,712,311
1991	71,902	493,576	268,861	346,493	5,004,196
1992	80,597	570,555	306,956	367,155	5,302,608
1993	89,717	651,401	346,946	388,694	5,613,680
1994	99,279	736,269	388,907	411,142	5,937,887
1995	109,298	552,822	432,913	458,468	7,820,576
1996	47,873	574,345	283,191	448,617	6,485,730
1997	166,473	1,440,304	609,241	431,327	4,956,483
1998	157,840	1,310,667	592,354	586,225	5,162,406
1999	123,579	1,597,213	598,630	881,539	5,375,906
2000	87,011	852,891	604,806	879,775	5,301,909
2001	58,397	817,327	850,502	877,248	8,549,785
2002	28,142	1,951,023	1,569,450	761,768	10,386,693
2003	39,609	2,928,800	2,120,349	639,262	12,217,242
2004	214,942	4,866,974	1,905,973	1,923,539	21,741,158
2005	217,543	4,651,200	1,682,156	2,090,593	22,347,379
2006	414,242	4,967,610	2,184,597	2,979,155	22,512,487
2007	617,372	6,406,774	2,302,107	3,312,415	564,310
2008	1,016,481	6,595,319	2,793,064	3,194,005	289,915
2009	1,561,711	6,923,248	2,532,924	1,639,396	0
2010	1,364,679	5,667,213	3,276,933	1,659,398	0
2011	1,155,622	7,413,011	4,059,929	1,679,252	0
2012	1,112,905	6,386,911	4,418,338	1,443,896	0
2013	1,645,423	6,265,890	2,745,397	3,808,947	0
2014	2,206,403	6,133,437	2,020,756	3,486,493	0
2015	2,796,980	4,484,364	1,779,173	3,376,122	0
2016	1,997,811	6,220,463	1,531,350	3,512,874	0
2017	2,290,760	5,135,076	2,577,893	1,637,473	0
2018	2,317,663	4,886,778	2,501,821	1,686,217	0
2019	2,344,305	4,620,924	2,419,607	1,741,120	0
2020	2,370,665	4,336,763	2,330,985	1,799,674	0
2021	2,396,705	4,033,487	2,235,662	1,858,874	0

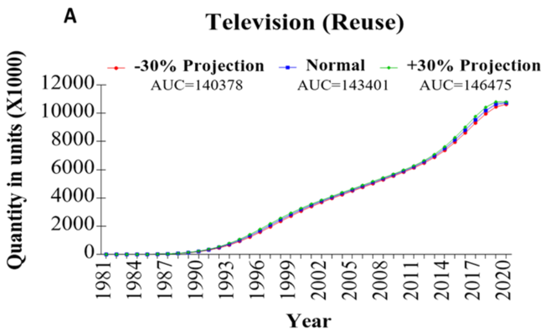
Supplementary Table 2. E-waste generated with repair and reuse effectEwaste generated under Reuse and repair effect.

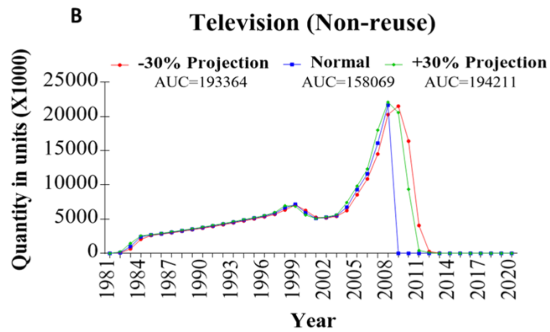
Year	DVD	LAPTOP	Desktop	TV	Refrigerator
1981	-	0	-	6	2,414
1982	-	58	-	116	6,691
1983	-	241	-	699	12,670
1984	-	620	64	2,620	20,220
1985	53	1264	321	7,477	29,223
1986	328	2235	952	17,849	39,558
1987	1,118	3592	2,174	37,536	51,108
1988	2,842	5383	4,234	71,735	63,760
1989	6,035	7644	7,398	127,087	77,404
1990	11,335	10405	11,937	211,480	91,938
1991	19,451	13683	18,117	333,475	107,268
1992	31,126	17485	26,187	501,234	123,309
1993	47,084	21812	36,363	720,903	139,983
1994	67,982	26659	48,825	994,614	157,229
1995	94,359	32013	63,706	1,318,553	174,998
1996	126,315	37865	81,096	1,681,897	193,600
1997	163,376	43359	100,516	2,067,565	212,414
1998	205,606	49644	122,191	2,455,305	230,923
1999	253,610	56641	146,312	2,826,558	251,199
2000	307,899	63827	172,771	3,169,434	276,654
2001	368,285	70571	201,330	3,481,423	305,536
2002	433,419	76322	232,291	3,768,282	336,947
2003	502,801	80551	267,783	4,039,709	368,503
2004	578,036	83275	311,105	4,304,449	398,295
2005	663,747	86569	364,146	4,567,394	445,035
2006	766,397	90802	427,172	4,829,757	505,329
2007	892,143	98395	501,220	5,091,329	588,839
2008	1,048,156	112014	587,203	5,353,201	694,172
2009	1,242,145	136492	686,366	5,619,699	814,512
2010	1,480,489	178359	798,387	5,899,467	924,128
2011	1,766,009	235212	923,767	6,206,360	1,026,943
2012	2,098,595	302751	1,064,462	6,559,686	1,122,934
2013	2,475,319	377770	1,222,142	6,982,502	1,208,109
2014	2,888,145	463625	1,392,489	7,496,250	1,317,223
2015	3,325,165	564757	1,567,961	8,110,579	1,435,341
2016	3,769,816	686017	1,740,962	8,809,337	1,558,328
2017	4,203,910	815776	1,904,020	9,537,055	1,686,173
2018	4,610,238	952730	2,053,315	10,193,027	1,789,219
2019	4,972,064	1093587	2,185,972	10,639,956	1,874,462
2020	5,275,553	1207823	2,299,227	10,730,002	1,944,124

Supplementary Table S3. E-waste generated without repair and reuse effect

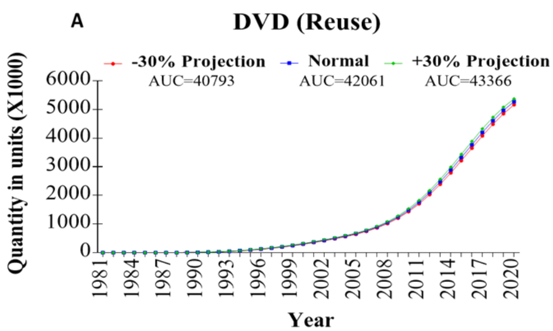
Year	DVD	LAPTOP	DESKTOP	TV	REFRIGERATOR
1981	-	-	-	3,384	319
1982	-	10	-	128,568	7,842
1983	-	388	-	995,809	50,167
1984	-	3,122	790	2,412,982	137,400
1985	1,610	8,235	6,412	2,689,599	181,299
1986	16,763	13,648	21,845	2,886,185	195,323
1987	58,635	19,351	45,268	3,091,176	209,306
1988	112,235	25,367	71,541	3,306,575	223,966
1989	169,142	31,724	99,368	3,533,862	239,418
1990	229,316	38,442	128,781	3,773,572	255,716
1991	292,901	45,537	159,853	4,025,610	272,867
1992	359,986	53,016	192,628	4,289,619	290,852
1993	430,622	60,884	227,131	4,564,964	309,632
1994	504,767	69,141	263,348	4,851,122	329,166
1995	582,402	77,766	301,274	5,146,816	349,390
1996	655,150	86,777	341,002	5,453,930	370,302
1997	665,787	96,083	376,171	5,849,174	392,980
1998	621,300	100,845	389,715	6,639,105	419,921
1999	825,150	85,184	410,965	7,144,607	445,180
2000	1,246,216	112,873	495,979	5,943,748	453,028
2001	1,392,925	159,406	578,835	5,126,265	494,538
2002	1,320,430	137,117	606,403	5,257,789	642,010
2003	1,018,496	102,124	683,749	5,528,861	819,595
2004	1,196,749	69,684	946,830	6,747,744	872,421
2005	2,089,100	43,481	1,411,409	9,310,290	840,043
2006	3,308,625	48,161	1,812,099	11,601,606	809,263
2007	4,440,022	136,681	1,910,516	16,105,772	1,054,880
2008	4,823,321	232,175	1,899,403	21,661,870	1,753,117
2009	5,343,692	343,150	2,060,294		2,329,952
2010	6,198,714	558,819	2,332,783		2,886,739
2011	6,610,607	880,428	2,568,264		3,132,417
2012	6,541,494	1,304,354	2,796,049		2,756,182
2013	6,392,183	1,443,671	3,216,397		1,963,257
2014	6,777,812	1,256,449	3,752,771		1,660,237
2015	6,533,483	1,181,654	3,817,581		1,714,995
2016	6,201,926	1,456,080	3,156,328		2,177,506
2017	5,723,128	2,003,929	2,334,265		3,225,616
2018	5,281,374	2,480,180	1,898,210		3,512,606
2019	5,567,206	2,393,561	1,883,546		3,351,993
2020	5,250,726	2,176,276	2,191,346		2,930,868

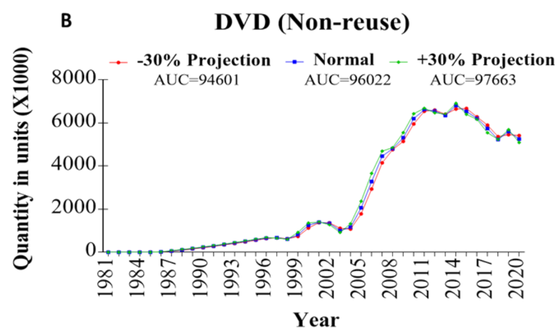
Supplementary Figure 1A-B. Sensitivity Analysis.



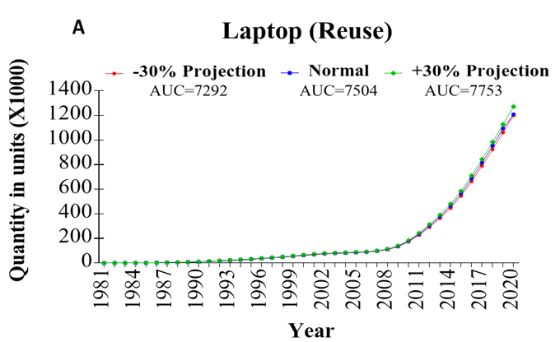


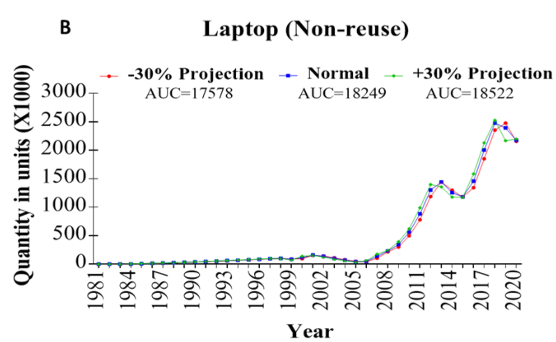
Sensitivity analysis for Television waste generated under Reuse (A) and Non-reuse (B) with ±30% projection AUC-Area under the curve. Source: Authors.





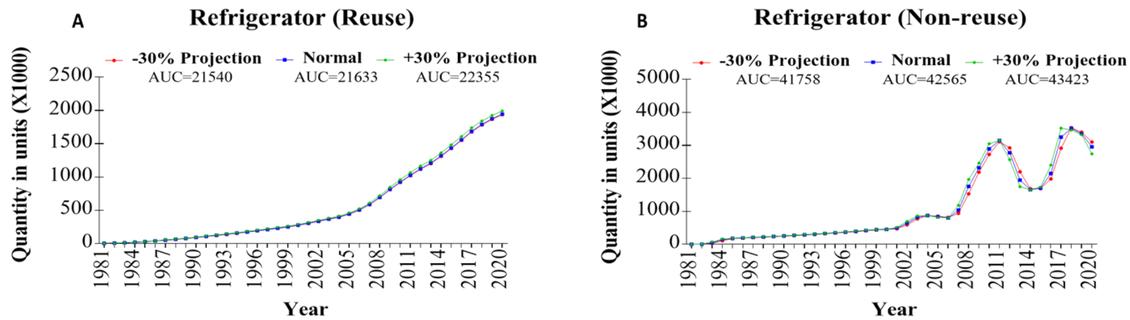
Sensitivity analysis for DVD waste generated under Reuse (A) and Non-reuse (B) with ±30% projection AUC-Area under the curve. Source: Authors.



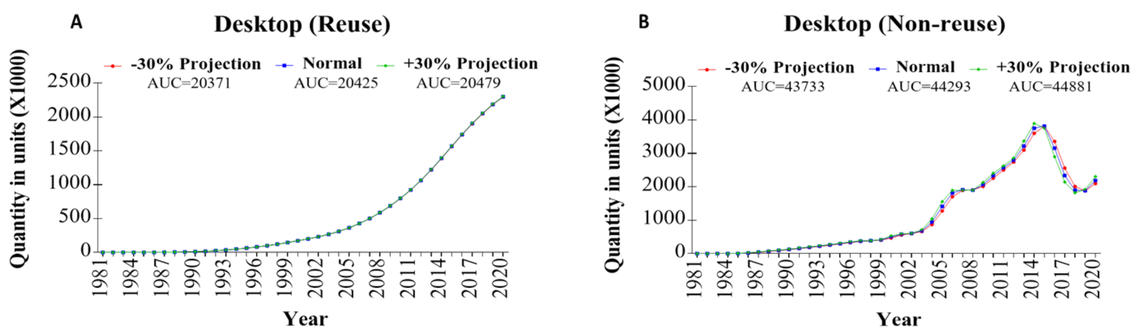


Sensitivity analysis for Laptop waste generated under Reuse (A) and Non-reuse (B) with ±30% projection AUC-Area under the curve. Source: Authors.

Supplementary Figure 1A-B Cont'd. Sensitivity Analysis.



Sensitivity analysis for Refrigerator waste generated under Reuse (A) and Non-reuse (B) with ±30% projection AUC-Area under curve. Source: Authors.



Sensitivity analysis for Desktop waste generated under Reuse (A) and Non-reuse (B) with ±30% projection AUC-Area under the curve. Source: Authors.

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Effects of climate variability on local communities living in and around Queen Elizabeth National Park, Uganda

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This paper explores the effects of climate variability on local communities living within and around Queen Elizabeth National Park (QENP), their coping mechanisms, and challenges encountered. Data was collected from 250 respondents through questionnaires administered to small holder farmers, salt miners, and fisher folks, as well as in-depth interviews and focus group discussions (FGDs) held with selected households in Katunguru, Lake Katwe, Kasenyi, and Kahokya parishes in and around the park. The results indicated that climate variability affects all households through long dry spells (drought), increased intensity of rain and occurrence of water related diseases. This resulted in decline in economic output in the context of reduced food availability, household incomes, and poor health of the household members. The results further showed that although diversification of livelihood activities was uniform, the coping mechanisms were heterogeneous across the three economic sectors. While the agricultural households engaged in agricultural intensification, fisher folks changed their fishing technologies, and salt miners drained their flooded saltpans. According to the findings of this study, the effects of climate variability were widespread across all households in and around the park. The study recommends that rural households be supported in a variety of activities in order to build capacity.

Key words: Climate variability, effects, coping strategies, challenges, rural households, Queen Elizabeth National Park, Uganda.

INTRODUCTION

Climate variability and change, as a major environmental threat, have become more severe as global warming continues to rise by 0.2°C per decade, especially over the next two decades (Niang et al., 2014; CDKN, 2014; IPCC, 2014). These extremes have had a global impact on crop and livestock production, food and water security, human health and safety, and thus the undisputed international recognition of our time (Harrington et al., 2018; FAO, 2016b). Climate change is evident in both developing and developed countries, for example, through changes in precipitation patterns and an unprecedented increase in temperature, all of which jeopardize livelihoods and overall socioeconomic development (Mbuli et al., 2021; Mthembu and Hlophe,

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2020; Taye, 2019). These effects have been unevenly distributed around the world, with countries in the global south suffering the most in a variety of complex ways (Islam and Winkel, 2017; Acheampong et al., 2014; Chikulo, 2014). Climate-related effects on national parks, for example, are increasing due to observable changes in temperature and rainfall, as well as a continuously degrading natural environment, according to van Wilgen et al. (2016), Tadesse and Dereje (2018), and Dube and Nhamo (2020). The presence of extreme weather events such as droughts and floods means that livelihood activities are disrupted and the community is more vulnerable to further climate conditions (Kilimani et al., 2016). As a result, in order to avoid a global food crisis, there is need to actively respond to these effects.

Furthermore, some scholars argue that there are differences in the effects of climate change even within the global south, with Sub-Saharan Africa bearing the brunt of these processes (Mihiretu et al., 2019; Zougmoré et al. 2018; Arndt et al., 2015). However, the literature highlighting these processes is skewed in that much of it focuses on dry-land areas (Thalheimer et al., 2021; Marengo et al., 2020; Jellason et al., 2019) and the cattle corridor (Nimusiima et al., 2018; Mulinde et al., 2016; Majaliwa et al., 2015), despite the fact that other communities living within and on the fringes of the parks are more vulnerable due to the land use restrictions accorded to national parks (Hoogendoorn and Fitchett, 2018; Bruno et al., 2018; Malakoutikhah et al., 2020). This study fills a scholarly gap in this context by focusing on the often overlooked but critical aspect of climate variability on local communities within and around conservation areas.

Climate change dynamics in Uganda

Uganda experiences climate variability and change[1,2], with noticeable monthly temperatures ranging from a minimum of 15°C in July to a maximum of 30°C in February (Mukasa et al., 2020; Nsubuga et al., 2014a). Furthermore, there have been significant changes in heavy rainfall events (Ongoma et al., 2015; Müller et al., 2014; Mayega et al., 2015; Mugagga et al., 2019), particularly during the March to May (MAM) season (Fuller et al., 2018; Ngoma et al., 2021; Egeru et al., 2019). As a result, frequent disasters such as floods, landslides, and droughts have been observed in and around the country, negatively impacting the economy (Akampumuza and Matsuda, 2017; Müller et al., 2014; Bagonza, 2014). This raises concerns about the need to sustain communities as well as the country's ability to meet both national development goals and global obligations. Uganda is highly vulnerable to the effects of climate change due to its reliance on natural resources, with rain-fed agriculture accounting for only 22% of total GDP and limited adaptive capacity (UBOS, 2020; 2018; Cooper and Wheeler, 2017; Adhikari et al., 2015). According to the Climate and Development Knowledge Network (CDKN), Uganda loses USD 2 billion due to climate and related impacts (CDKN, 2014). As a result, communities pursuing agro-based livelihood strategies have become vulnerable to climate change. This is especially important for local communities living in and around protected areas like Queen Elizabeth National Park (QENP), where resources are scarce.

While protected areas provide numerous benefits to local communities [regulate climate, provide cultural services such as social health, tourism, support biodiversity, and income diversification] (Mcneely, 2020; Jiricka-Pürrer et al., 2019; Jones et al., 2020), the livelihoods and well-being of rural poor who live within and on the fringes of the conservancies remain vulnerable to climate changes due to restrictions imposed by regulatory regimes that govern access to natural resources in the park. This has contributed to a decline in ecosystem diversity, productivity, and constant conflict between humans and wildlife as they compete for limited resources (Amin et al., 2015; Zwiener et al., 2017). Raids from wildlife seeking to expand their range into community-built lands frequently destroy their food crops, while enclave communities seek to explore protected areas for alternative livelihood sources exacerbates the situation (Nwe et al., 2020; Crawhall, 2015). Access to natural resources to support livelihoods becomes increasingly difficult. Policies to protect wildlife in Queen Elizabeth National Park (QENP) prevent communities from easily accessing national park resources, further limiting their livelihoods.

The current study was conducted in Western Uganda against this backdrop due to the frequent occurrence of disasters that have caused physical, environmental, and socioeconomic impacts (NEMA, 2019, 2016). The study thus sought to investigate the effects of climate variability and change on the local communities living in and around QENP, as well as how they cope with the effects and challenges they face, by seeking answers to the following questions: What are the spatial distribution and temporal trends of drought in Kasese district for the period 1981-2016? What are the effects of climate variability and change on the economic activities of the local communities living in and around QENP? In what ways do the local communities cope with the effects of climate variability? What challenges are encountered by the local communities?

Theoretical framework

The DFID Sustainable Rural Livelihoods Framework (SRLF) is used in this study to better understand how

[1]Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events.

[2]Climate change refers to a shift in average weather conditions, including measures such as temperature, humidity, rainfall, cloudiness and wind patterns – and changes in the frequency or severity of these conditions.

climate variability affects the local communities living in and around Queen Elizabeth National Park (QENP), how they cope with the effects, and the challenges they face. “A livelihood comprises the capabilities, assets, and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base” (DFID, 1999). The SRLF's main argument is that access to and use of various forms of capital, including natural, social, physical, financial, and human capital, translates into better or worse livelihood outcomes for rural communities (Krantz, 2001).

However, improved livelihood outcomes are dependent on people's abilities to use one or a combination of capitals and successfully navigate government policies, institutional rigidities, and societal cultures. Policies, institutions, and cultures are significant because they influence access to capital; 'mediate' the terms of capital exchange, and determine the gains from the livelihood strategies employed (DFID, 1999). The ability or inability to negotiate the numerous obstacles creates either ‘winners’ with better or ‘losers’ with worse off livelihood outcomes (Chambers, 1983).

In the context of this study, the local communities living in and around Queen Elizabeth National Park (QENP) are gifted with ‘natural capital’ (land, wildlife resources and lakes (Edward, George and Katwe), where salt is mined). The park contributes to maintenance of the ecosystem and provides biodiversity from which the local communities derive economic and health benefits (Atiqul Haq, 2016). The local communities have social capital in form of relations and networks. UWA gives the local communities 20% of the money collected from tourists as financial capital. Regarding human capital, the local communities use their inherent knowledge and skills to exploit the natural resources/capital. These in totality, when well utilized, should translate better livelihood outcomes for the communities within and around the park, more incomes, increased well-being, reduced vulnerability, and improved food security. Those who are unable to fully exploit the resources (natural, financial, physical, social, and human) live in poverty. This means that better or worse livelihood outcomes are determined by how local communities use the capitals at their disposal, as well as how they navigate structural rigidities imposed by the government or societal structures. As a result, the SRLF can aid in the holistic analysis and explanation of the environmental and socioeconomic dynamics of climate variability in the context of conservation, particularly within and around Queen Elizabeth National Park (QENP).

MATERIALS AND METHODS

Study area

Queen Elizabeth National Park (0° 12’S and 0° 26N Latitudes and 29° 42’E and 30° 18’E Longitudes) is located in Kasese district in Western Uganda (Figure 1). The park has a diverse ecosystem that includes savanna and grassland, wetland, lake, and riverine systems (NEMA, 2019, 2016). There are two rainy seasons experienced in the area; the first rainy season occurs during March, April, and May (MAM) while the second rainy season occurs during September, October, and November (SON), with mean annual temperature between 22 and 25°C and total annual rainfall of 1250 mm (Mugume et al., 2016). Variation in rainfall is due to its location along the equator and annual migration of the Inter Tropical Convergence Zone (ITZC) (NEMA, 2019; Mugume et al., 2016). The human population around the park is estimated to be 107 persons per km^2, with a district population of 702,029 people (UBOS, 2014). The major social-economic activities include subsistence farming involving crop production, livestock rearing, fish farming (in Lakes George and Edward and Kazinga channel), as well as bee keeping, tree growing, petty trade and salt mining around Lake Katwe and Kasenyi (UBOS, 2020).

Selection of study sites and respondents: Household surveys

The information from the Kasese District Local Government and Community Development Officer (CDO) indicates that specific places conduct specific activities. In light of this discovery, the study purposefully chose three study sites involved in farming, salt mining, and fishing (Table 1). Several key government reports sought do not provide information on the number of households engaged in the three dominant activities across the study area. Therefore, to obtain an appropriate sample, this paper uses the guidance provided by Mensah (2014). Since the number of participants in each of this activity was unknown, the sample size was derived by computing the minimum sample size required for accuracy in estimating proportions by considering the standard deviation set at 95 confidence level (1.96), percentage picking a choice or response (50%=0.5), and the confidence interval (0.05= ±5) (Mensah, 2014). The equation is:

$$n = (Z - score)^2 * StdDev * (1 - StdDev) / (errormargin)^2$$

where z= standard deviation set at 95% confidence level, p=percentage picking a choice of response, and c=confidence interval.

Although a total of 250 respondents were randomly selected from communities in and around Lake Katwe, Katunguru, and Kahokya parishes, 215 copies of the questionnaires were filled out and returned, representing 86% response rate.

Data collection

This study used both primary and secondary data sources to better understand the effects of climate variability on local communities, their coping strategies, and the challenges they face.

Primary data

The study was undertaken from June, 2017 to January, 2019, and data was collected from the local communities living in Kasenyi, Katunguru, Lake Katwe, and Kahokya. The study period [2017-2019] was chosen in light of the numerous processes that occurred during this time period, including severe reports of communities affected by drought episodes, land conflicts and violence, and reprisals (Reuss and Titeca, 2017; US Bureau of Demography Human Rights and Labour, 2017). Based on the nature of the

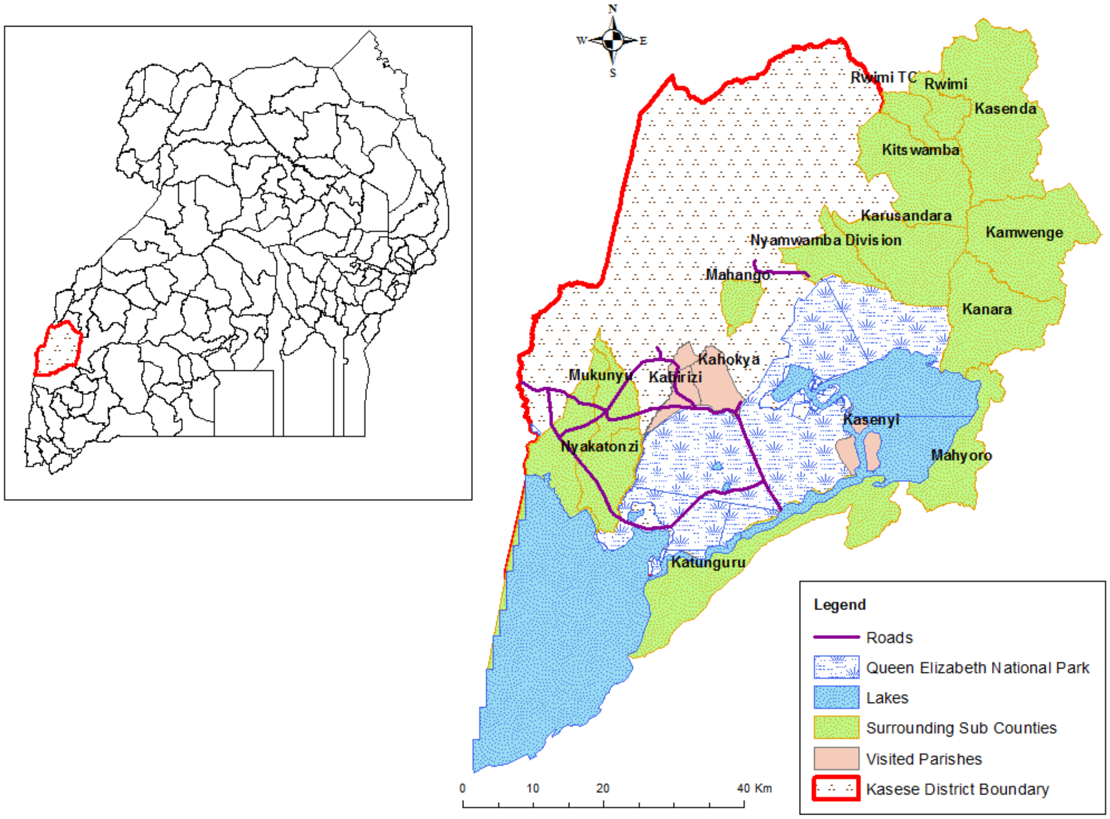

Figure 1. Queen Elizabeth National Park showing the study sites.

Table 1. Selected respondents.

Parish	Village	Dominant economic activity	Sample
Lake Katwe	Katwe	Salt Mining	59
Katunguru	Kasubi	Fishing	51
Kahokya	Kikorongo	Farming	105
Total			215

research, multiple data collection methods and tools were used for data collection. The mixed approach was well-suited for providing critical insights into multiple view points of the research problem (McKim, 2017; Molina-Azorin, 2016a; Norma and Ngulube, 2015). These included household survey, semi-structured interviews and focus group discussions (FGDS) to solicit information on effects of climate variability, coping mechanisms, and challenges faced by the local communities. The pretesting of the survey questions and interview guide was intended to confirm the questionnaire's reliability and validity before distributing it to the communities. Purposive sampling was used to select the key informants such as local village and parish leaders (3), Sub County Community Development Officers (1), officials from Katwe Information Centre (KIC), and District Environmental and Fisheries Officers (2). The information collected included effects of climate change, coping strategies, challenges faced by the local communities and any observed changes in the community as well as cross validating the information provided by respondents during the household survey and focus group discussions. Similarly, FDGs were used to elicit experiences that may not have been revealed during the administration of questionnaire interviews. Specifically, six focused group discussions (FGDs) comprising an average of 16 persons (an almost equal representation of male and female) of different age categories were conducted in the selected communities to validate the information from the questionnaire survey. The respondents to the focus groups, who were chosen with the help of the local council chairpersons, discussed the effects of climate variability, coping strategies, adaptive options, and challenges encountered.

Secondary data

Historical daily rainfall and temperature data for the period 1981-2016 were obtained from the Uganda National Meteorology Authority (UNMA) in the Ministry of Water and Environment and quality controlled using World Meteorological Organization (WMO) guidelines to understand both seasonal and annual trends. Furthermore, published articles were obtained from the internet

(Google scholar) to support the study findings.

Data analyses

The household survey questionnaire responses were coded, and the results were entered into the Statistical Package for Social Scientists (SPSS) to generate a data file that generated descriptive statistics in the form of graphs, tables, and the Chi-square test for significance, which were then presented.

Qualitative data from focus group discussions and interviews responses was transcribed on a daily basis to ensure that all the data was well captured. A critical synthesis of the transcribed data was carried out and this permitted the assignment of codes to the data. Considering that the research was guided by four research questions (RQ), the codes assigned to the data took the form of RQ1, RQ2, RQ3 and RQ4. Whenever a section of the transcribed data was applicable to a specific research question, that specific transcript was assigned a relevant code, copied, and pasted under the related research question. After coding all the data, another round that entailed familiarization with the coded and categorized data was undertaken. Coding and categorization of data based on research questions made it possible to generate themes which, in turn, formed the basis for deriving the meanings from the data, what Silverman (1998, 2021) termed as content analysis. The transcribed responses were then presented in the form of analytical discussions and quoted verbatim where appropriate.

To perform seasonal and annual rainfall and temperature trends, the daily rainfall and temperature data were analyzed using Mann Kendall and simple linear regression analysis with graphical methods (that is, a line graph) to illustrate the temporal trends of the time series of rainfall and temperature accordingly. Regression method was used because only weather data at weather station level (point data) was available. Furthermore, linear regression is a popular parametric method for analyzing the trend of climate variables. Other formats, such as gridded data, were not available for the study area, where other methods, such as spatial maps, would have been used. Drought indices were generated using climpack2 and temporal trends using R software. This study considers the simple linear model equation:

$\hat{y}\ i = a + bx\ i$

$$i = 1, 2, \cdots, n$$

Where X is the precision independent variable, a is the y-intercept, and b is the slope of the line.

RESULTS

Demographic characteristics of the respondents

Table 2 presents the demographic characteristics of the 215 households surveyed. According to the study findings, 61% of respondents were males, while 39% were females. The majority of respondents (49%) engaged in farming (crop production and livestock rearing), salt mining (27%), and fishing (24%). This finding is consistent with the traditional nature of rural livelihoods (Verner et al., 2018; Food and Agriculture Organization of the United Nations (FAO), 2018). The age distribution of the respondents revealed that a significant proportion (39 and 51%, respectively) fell within the categories of youth (18-35) and adult (36-59), which is within the productive employment age of active service. Only 10% were old people of 60 years and above. The average household size was 6 persons with majority (54%) having 1 to 5 persons. According to the population census, 2014, the total mean household size for Uganda is 5 persons which is the same for Kasese district. The reason behind the large house size is that it has a significant influence on household adaptation to climate change as proved by several researches (Molina-Azorin, 2016b; Opiyo et al., 2015; Opiyo, 2016). Findings also indicated that the levels of education were unevenly distributed with 53% of the household heads having received primary education. This means that they are in position to understand the study problem. While 20% had received secondary and 15% tertiary level, 12% had not received any form of education or qualification. According to UBOS, while primary education has increased from 8.5 million in 2013 to 8.8 in 2017 million, secondary school enrolment has reduced. Poverty was ranked highest by the respondents in the focus group discussions as the greatest causal factor for the variations in education attainment which led to early marriages and its resultant effects.

Primary sources of data

Livelihood activities

In the study area, the most common livelihood activities in order of importance are as shown in Figure 2. Farming (49%) shaped and informed by natural (land) and human (knowledge and skills) capital was primarily practiced in Kahokya parish. Moreover, salt mining (27%), which is heavily dependent on inherent skills and knowledge, was carried out at Lake Katwe as well as Kasenyi, and fishing (24%) was carried out in Katunguru parish on Lakes Albert, George, and the Kazinga channel. Traditionally, rural livelihoods are based on crop production and rearing of livestock as the dominant sources of livelihoods though supported by other economic activities such as trade and casual labour (UBOS Statistical Abstract, 2017).

Drought characteristics in Kasese district

Spatial patterns of drought

Spatial results indicated that the district suffered extreme drought conditions in 1995 mainly under SPI12 compared to SPI3 (Figure 3). During key informant interviews (KII) and focus group discussions FGDs), it was confirmed that salt miners experienced high salt production in 1995 due to the long dry spells that occurred. It was discovered that the South Eastern part of the district (areas around Lake Katwe) experienced more drought conditions than other parts of the district. This implied that the drought was both a boon for salt miners and a burden for farmers

Table 2. Demographic characteristics of respondents.

Parameter	Category	% Response
Sex	Male	61
	Female	39
Age	18-35	39
	36-59	51
	60 years and above	10
Marital status	Married	68
	Single	17
	Divorced/Separated	9
	Widowed	6
Education level	Non-formal	12
	Primary	53
	Secondary	20
	Tertiary and above	15
Household size	1-5 people	54
	6-10 people	33
	More than 11	13
Livelihood Activity	Farming	49
	Salt mining	27
	Fishing	24

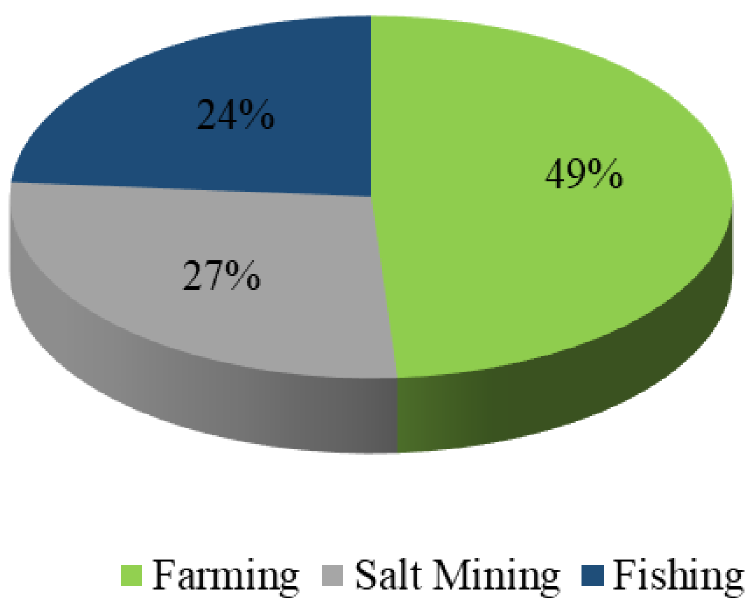

Figure 2. Major livelihood activities in the study area.

and fishermen. For salt miners, it meant less water in the lagoons where the salt is mined, which resulted in higher household incomes due to the sale of more salt. Meanwhile, farmers and fishermen paid a price in lower household income as a result of the drought, which reduced available water for farming and fishing.

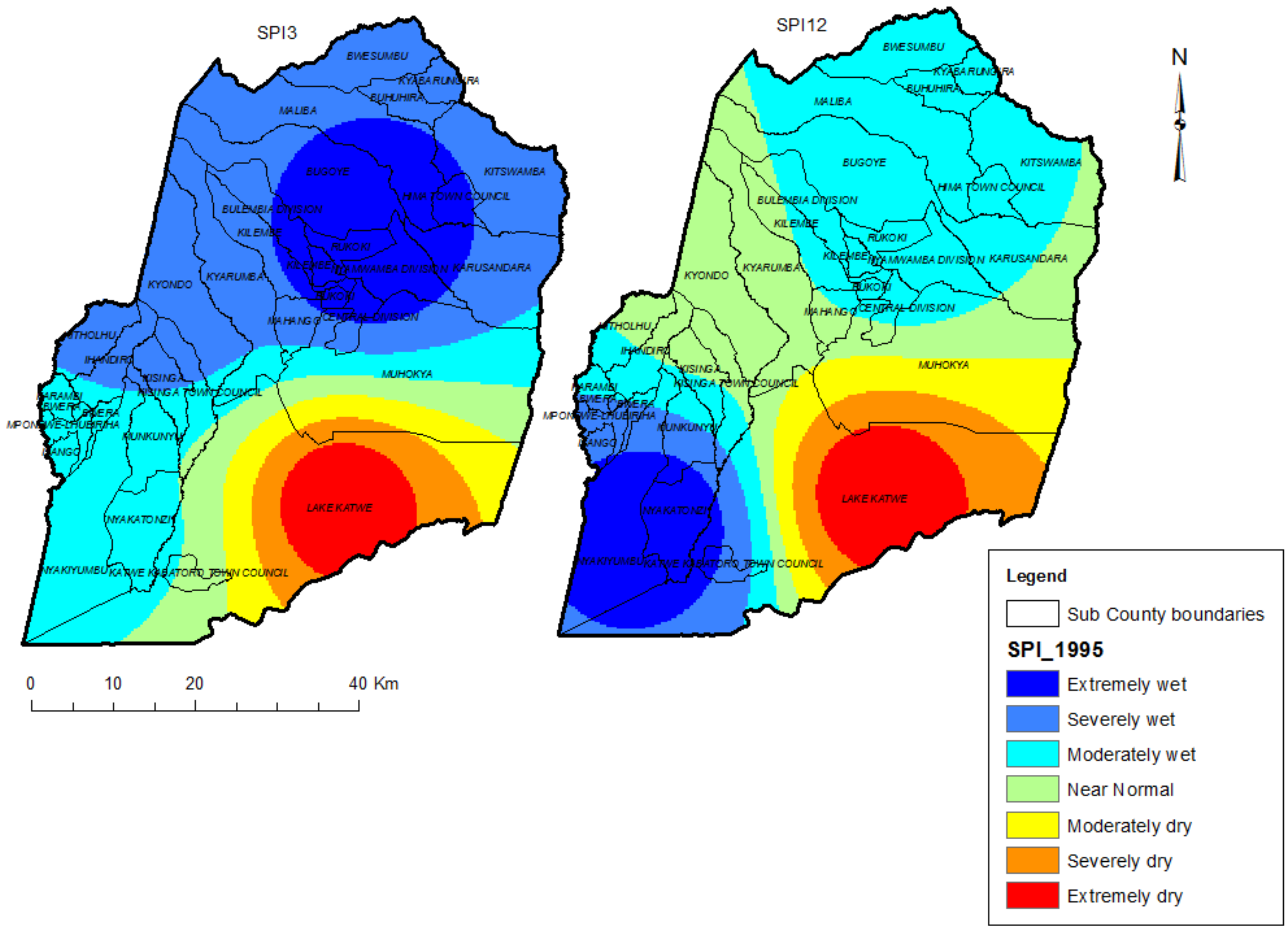

Figure 3. Spatial pattern of drought in Kasese district from 1981-2016.

Temporal trends of drought

Results on temporal patterns indicated that there was a general increasing positive trend under SPI3 with extreme dry conditions observed under 1984, 2000, 2004, 2009 and 2014 (Figure 4a). This implied a reduction in dry spells under SPI3, although the trend is not significant. On the other hand, a decreasing trend was observed under SPI12 though the trend is not statistically significant (Figure 4b). Generally, the trends in drought occurrences are not significant which implies that the district still experiences drought conditions.

Drought magnitude

The study went on to look into the severity of the drought in terms of magnitude. According to SPI3, the highest drought magnitude of about (-10.5) occurred around (1983-December to 1984-June) and lasted seven months, followed by the drought event of 2004-August to 2004-October with magnitude (-6.7) and lasted about three months (Figure 5a). However, the drought event of 2004-August to 2004-October had the highest intensity of about -2.2 implying a much negative impact on the livelihood activities. For SPI12, it was observed that the highest drought magnitude of about (-37.4) happened at 1994-June to 1995-June and had a duration of thirteen months, followed by the drought event of 1997-October to 1998-November with magnitude (-20.5) with duration of about fourteen months (Figure 5b). For the entire study period, SPI12 (-2.9) had the highest drought magnitude, duration, and intensity, implying a greater impact on water resources.

Rainfall variability

Monthly rainfall variations

Monthly averages were calculated from 1981-2016 per decade (Figure 6). Results indicated a shift of the two

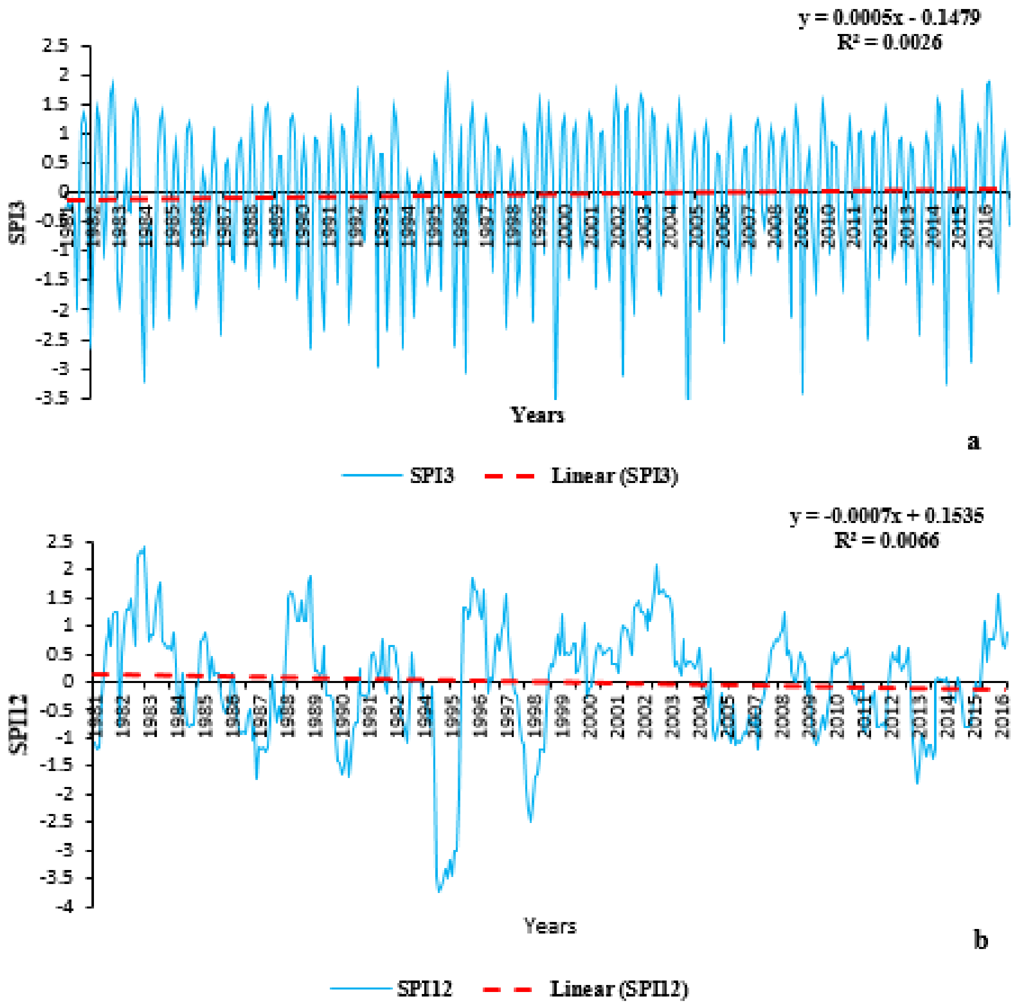

Figure 4. Temporal trends of drought in Kasese district from 1981-2016.

rainy seasons from the known wet months to the known dry months in the first two decades 1981/1990 and 1991/2000 (Figure 6a-b). In the study area, however, there was a clear distinction between the wet and dry seasons (Figure 6c-d), resulting in a known bimodal rainfall pattern.

Seasonal rainfall variations

On a decade basis, it was revealed that the MAM total seasonal rainfall throughout the study period registered the highest amount of rainfall compared to the SON seasonal rainfall (Figure 7). Overall, seasonal rainfall has been increasing, with the period 2001-2010 recording the highest score. The coefficient of variation values calculated per decade from 1981 to 2016 (Table 3) revealed that SON seasonal rainfall was less predictable than MAM seasonal rainfall. This was due to the high variability in rainfall amounts during the SON period.

Climatic shocks faced by the local communities

Changes in the biophysical environment were considered shocks in this study because they impacted agriculture, salt mining, and fishing, despite the fact that there are six major weather variables (temperature, precipitation, cloudy (type and cover), wind (speed and direction), humidity, and air pressure).Government agencies such as Uganda National Meteorological Authority (UNMA) emphasizes rainfall and temperature and their manifestation as the most important variables in the field of climate sciences to help trace extent and magnitude of climate variability and change (IPCC, 2007). As a result, the study focused on rainfall and temperature because the study area is heavily reliant on rain-fed agriculture, and these variables assisted in explaining various socioeconomic problems. Figure 8 depicts the climatic shocks that the community has experienced.

Across the livelihood activities, the study findings revealed that flooding events, occurrence of human

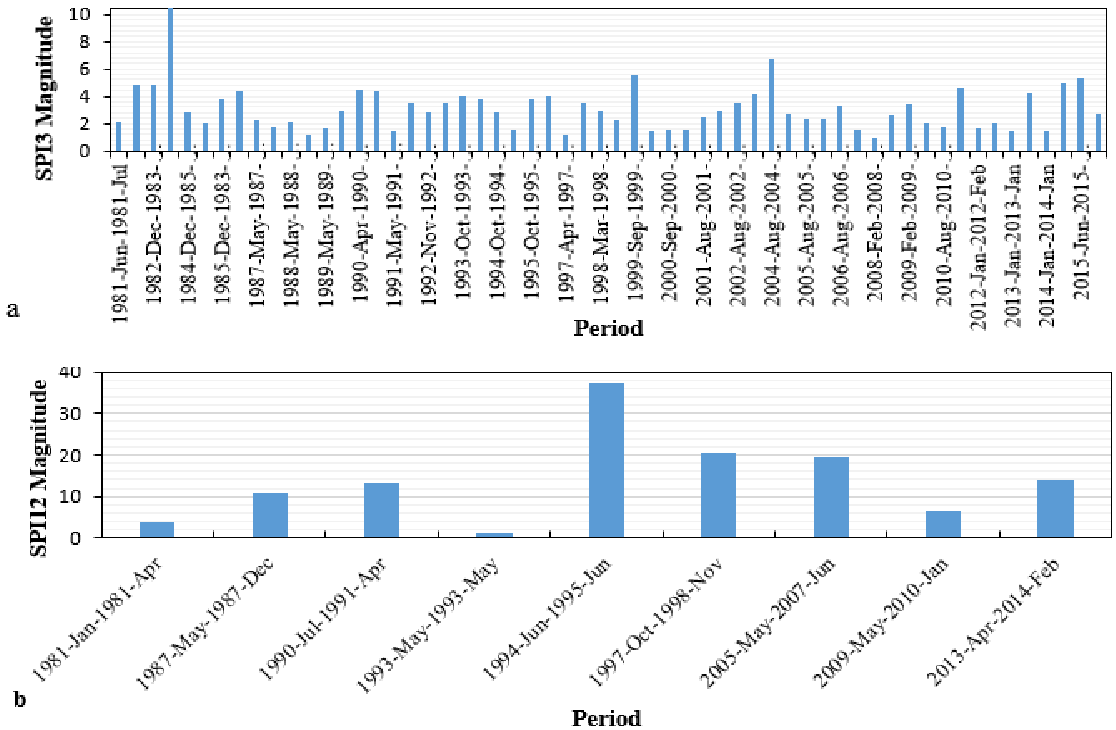

Figure 5. Drought magnitude in Kasese district from 1981-2016 (a-b).

diseases, increasing dry spells/drought, and increasing intensity of rains were the most noteworthy climatic shocks across the livelihood activities. However, reduced flooding events (53%) and occurrence of water related human diseases (100%) were outstanding among salt miners while increasing intensity of rains (55%) and dry spells/drought (100%) were outstanding among the farmers. Likewise, increasing intensity of rains (22%) and reduced flooding events (14%) were outstanding among fisher folks.

The aforementioned responses were confirmed by the focused group discussions and key informant interviews conducted. For instance, salt miners observed that 1995 as the year where salt production was highest due to reduced flooding events and intense rainfall. Furthermore, outbreak of water borne diseases like cholera and bilharzia were common as well as severe skin irritations due to constant contact with water. On the other hand, farmers revealed that it was common for crops to dry due to the increasing long dry spells and as a result, crop yields harvested were reduced. The fisher folks complained of increasing intensity of rains that swayed their boats away.

Effects of climate variability on economic activities of local communities

Understanding the effects of climate variability on economic activities of local communities is important because livelihoods in and around Queen Elizabeth National Park are highly dependent on natural resources that are vulnerable to changes in climate. Findings revealed that farming respondents experienced increasing dry spells, crop pests and diseases (100%), respectively, severe loss of pasture (98.1%), poor quality of crops (98.1%) and loss of soil fertility (93.1%). During the focus group discussions (FGDs), farmers noted that the destruction of crops due to longer dry periods coupled with a mere absence of buffer stock to handle demand led to scarcity of food. Loss of pasture meant that some families were compelled to sell off their animals at lowest prices while loss of fertility meant that the outputs from the gardens were minimal and this affected the food consumption patterns of the households. Yet output from the market was central in purchasing the essential inputs which the family lacked.

'A 35 year old man and father of 8 indicated that climate variability and change has and continues to significantly reduce his household income. In 2006, the respondent noted that, his family often obtained 2,000,000 million shillings (equivalent to 577 USD) from farming. The money was often used to pay school fees for the primary and secondary going children, buy farm input and other basic foods not produced at home. In 2017, however, the respondent explained that due to unpredictability of seasons, his farming was worth 500,000 Uganda shillings

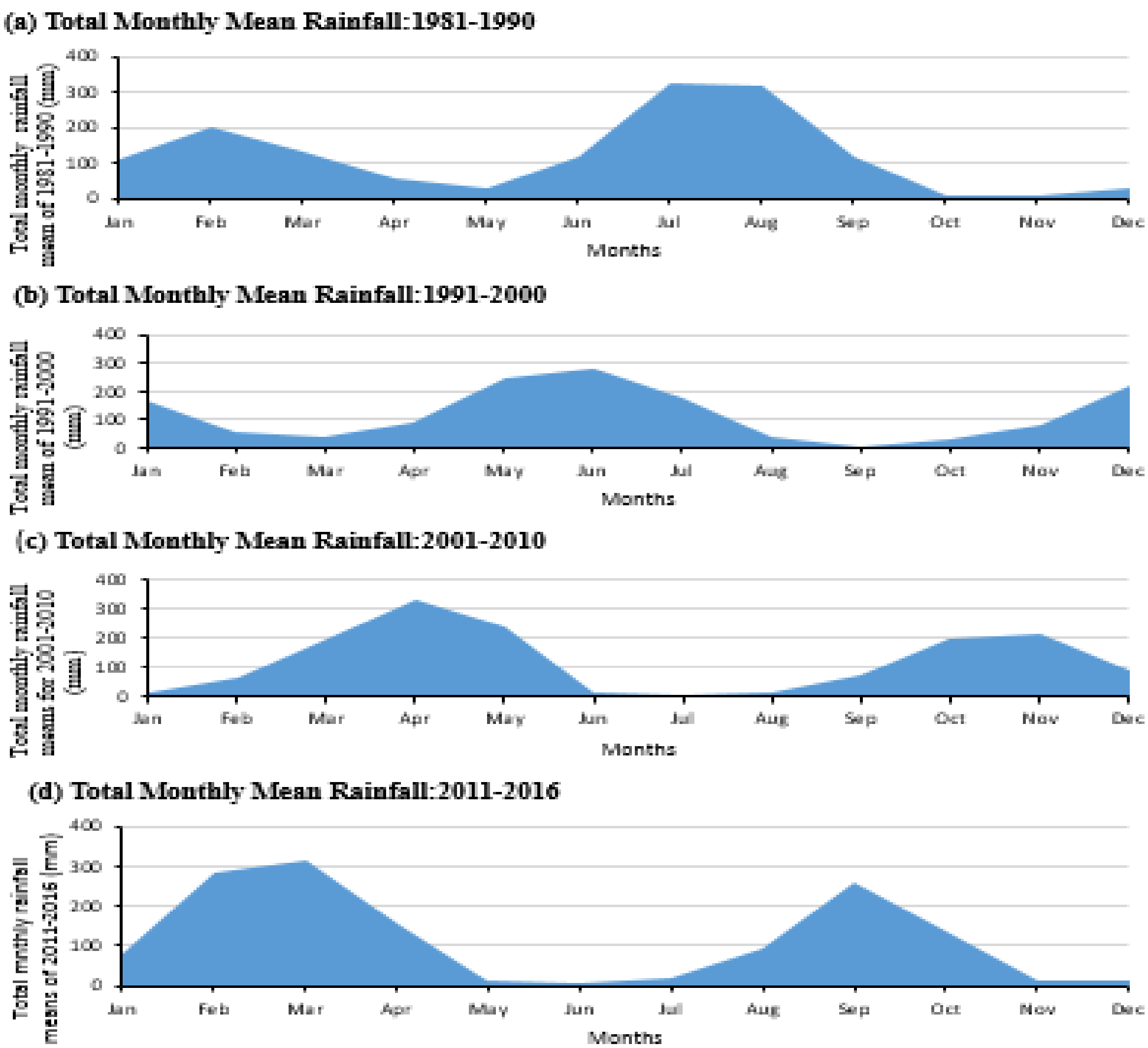

Figure 6. Total monthly mean rainfall in Kasese from 1981-2016 (a-d).

(120 USD) which constrained the ability of the household to pay school dues and buy farm inputs'.

The fishing community experienced less fish caught (98.1%) and poor quality of fish (96.1%). The District Fisheries Officer attributed the reduction in the quantity of fish in the lake to a number of factors. Firstly, the reduction of water levels, secondly, continuous movements of fish habitat, and thirdly, encroachment of the breeding zones as result of changing climate. The reduced water levels and poor quality of fish forced fisher folks to encroach on the breeding zones of the fish at the deeper ends of the lake. In the process, the breeding areas were destroyed which reduced the quantity of fish caught.

'One of the fishermen interviewed said that the quantities of fish had reduced. For him to capture fish, he uses different hooks called "Egyala". As opposed to the period before the reduction in water levels, he claimed that he now catches less than 200 fish yet fifteen years ago he could get 2000 fish per week. The Fisheries Officer confirmed that fish such as "Labeo" was common during the rainy season but had disappeared due to the prolonged dry season and could only be found in deep waters. One police commander also confirmed that some fishermen had been caught fishing in the breeding area and were taken to court and charged'.

Among the salt miners, all the respondents experienced water related human diseases (100%), less salt production (86%) and pollution of salt pans (86%). The effects of climate variability on the socio-economic activities of the local communities living in and around QENP are presented in Table 4.

'A 39 year old mother of 7 revealed that she has been working in the salt pans for 20 years but has noticed

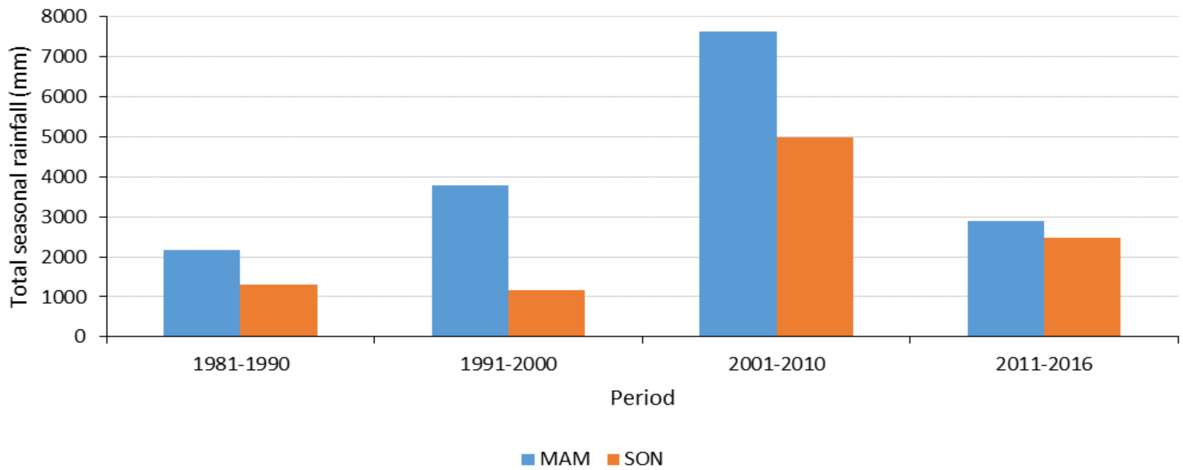

Figure 7. Seasonal rainfall variations in Kasese from 1981-2016.

Table 3. Summary of Seasonal Rainfall per decade from 1981-2016.

Period	Mean Total MAM seasonal rainfall(mm)	Mean Total SON seasonal rainfall(mm)	MAM Standard deviation	SON Standard deviation	MAM coefficient of variation	SON coefficient of variation
1981-990	218.4	131.1	126.01	133.91	57.7	102.2
1991-2000	380.1	163.9	178.16	158.20	46.9	96.6
2001-2010	767.8	486.1	96.55	121.04	12.6	24.9
2011-2016	483.5	413.4	130.83	75.80	27.1	18.3

reduction in water levels during the long dry spells. In addition, the key informant at KATIC stated that the area was faced by scarcity of and safe water. He further explained that River Nyamugasani was about 4 km away to the treatment plant which was broken and rusty rendering the water unsafe for human consumption while the asbestos iron sheets used by residents were dangerous for water harvesting'.

Coping strategies by the households

Coping strategies of farmers, salt miners and fisher folks take three forms: on-farm activities, off-farm and non-farm. First, there were various on-farm coping strategies adopted by the respondents as presented in Figure 9. Among the farmers surveyed, about 47.8% said they planted improved crop varieties, changed planting dates, and practiced mixed cropping. 46.3% of respondents practiced rotational grazing in order to cope with the drought conditions, while 43.9% planted cover crops and 42.4% practiced mulching in an attempt to retain soil moisture. 25.9% applied fertilizers, 23.4% used compost manure and 20.5% sold off some of the animals. Those farmers who opted to move to areas outside the park were only 3.9% while those who practiced shifting cultivation and accessed park resources were 3.4%.

On the other hand, fisher folks had their own coping mechanisms aimed at reducing the impact of poor quality and quantity of fish. 21.5% of the fisher folks had changed fishing technology (gear), 19.5% changed fishing spots while 13.7% changed the fishing time. To reduce the impact of less salt production and pollution in salt pans during the heavy rainy seasons, 28.8% of salt miners reported draining of water from salt pans. 23.9% of respondents across the three livelihood activities diversified into other livelihood activities. During the key informant interviews and focus group discussions, it was confirmed that the aforementioned strategies were being carried out at different levels.

Second, with regard to off-farm, there are often temporary shifts in livelihood activities by households in order to cope with the severity of impacts and economically sustain the households. During focus group discussions, it was stated that salt miners shifted to fishing or farming during the rainy seasons and when mining became a health risk, while salt miners (women) only shifted to agriculture. Among the fishing communities, majority of fisher folks resorted to salt mining with only a few farming far away from their home

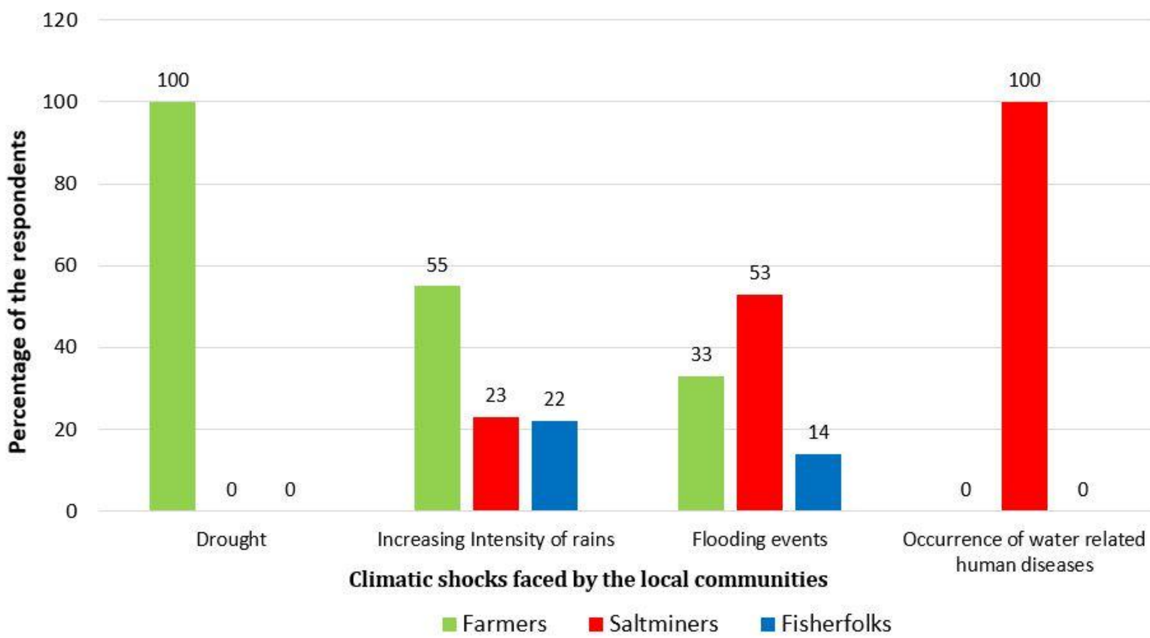

Figure 8. Climatic shocks faced by the local communities

Table 4. Effects of climate variability on economic activities of communities.

Effect of climate variability	% Response		
	Farmers	Salt miners	Fisher folks
Increasing crop pests & diseases	100	0	0
Increasing dry spells	100	0	0
Poor quality of crops & animals	98.1	0	0
Loss of pasture	98.1	0	0
Loss of soil fertility	93.1	0	0
Occurrence of water related diseases	0	100	0
Less salt production	0	86	0
Pollution of salt pans	0	86	0
Less fish caught	0	0	98.1
Poor quality fish	0	0	96.1

Farmers (n=105), Salt miners (n=51), Fisher folks n=59).

parishes. Likewise, the agriculturalist ventured into salt mining or fishing.

Third, for non-farm activities, households adopted various informal activities that cut cross the three livelihood activities. The activities included petty trade, saloons, food vending, casual laboring, produce trading and charcoal selling. In respect of specific livelihood activities but not limited to, fisher folks (men) were reported to be engaged in 'boda-boda' riding, local drivers for tourists, local mechanics (repairing bicycles, boats, cars, motorcycles, etc.) and car wash while the women fisher folks were into small businesses such as food vending around fishing sites, fish trading, charcoal selling, papyrus harvesting and mat weaving, selling of pancakes and fried fish supported by salt mining to a less extent. Male farmers were said to be involved in community development activities, retail business such as bar pubs and informal savings and credit cooperative organization (SACCOs). Women farmers were particularly more involved into petty trade, casual laboring and fish trading. Whereas male salt miners were said to be tour guides and traders especially in salt trading, women salt miners were into petty trade, fish trade and limited mat weaving. In-depth interviews from Lake Katwe Tourism Information Centre (KATIC) confirmed that local salt miners were often trained as tourist guides and cave farmers.

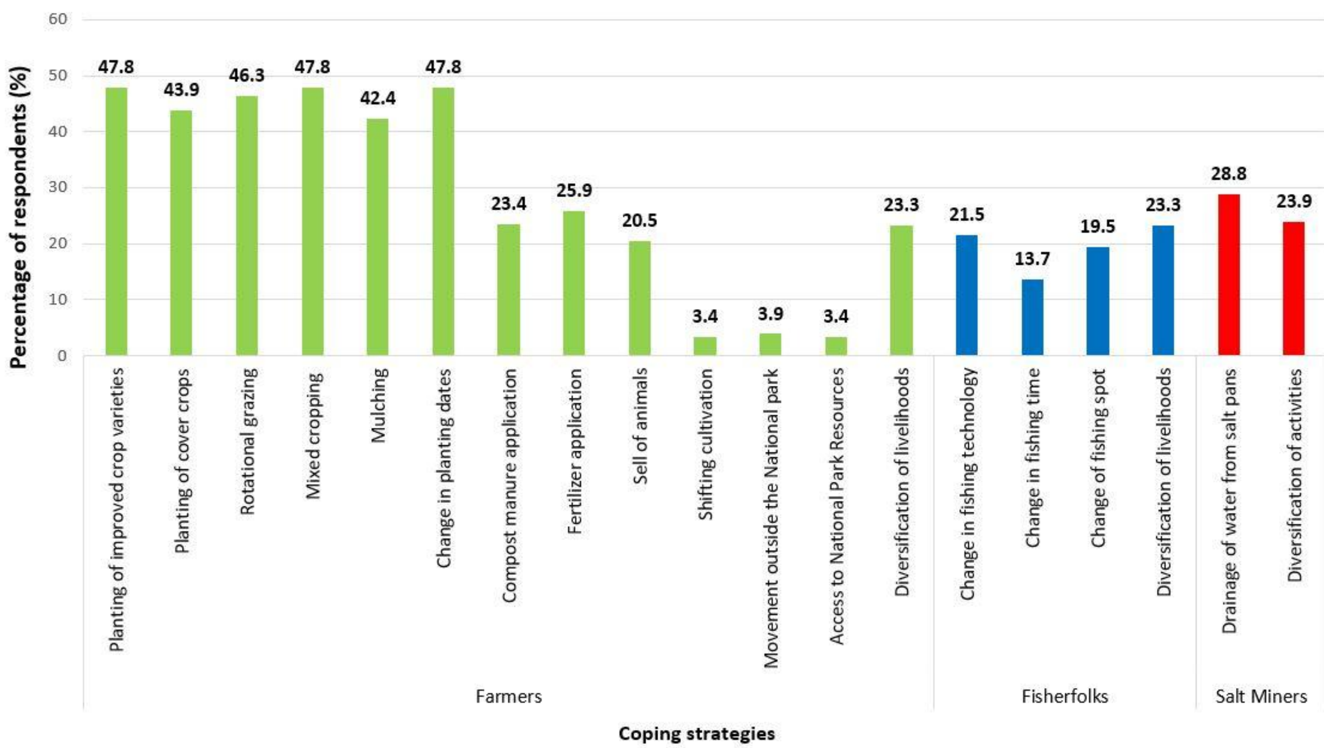

Figure 9. Major coping strategies employed by the community.

Challenges faced by the local communities

Price fluctuation

According to the study respondents, fluctuation of prices was dependent on season across any livelihood activity adopted. For instance, during the dry season, fish prices were higher due to reduced fish catch while salt prices were lower due to higher competitive production. Similarly for farmers, the prices of their farm products were dependent on the outcome of the seasons. Long dry spells or drought reduced productivity and quality thus affecting the prices of final produce.

Market for products

The market for finished goods was a common constraint for farmers and salt miners. According to the findings of the salt miners, the salt factory in the area had collapsed, resulting in competition with neighboring countries. Focused group discussions (FGDs), for example, revealed that Ugandan products were not allowed onto the Kenyan market due to poor quality, paving the way for Kenyan salt on the local market. Due to a lack of storage facilities, salt miners were forced to sell at a discount to traders, particularly those from Kenya and the Democratic Republic of the Congo who paid in advance.

Infrastructure

Most respondents argued that the poor development of the roads had hampered business especially during the rainy seasons. For instance, the access road that led to Kasenyi landing site was small, narrow, and only allowed one vehicle at a time. Most often, during the rainy seasons, the off-loading trucks were stranded for days especially during the rainy seasons. In-depth interviews revealed that Boda boda (*motorbike*) transport cost Uganda shillings 20,000 (≃5 USD) to Lake Katwe while hiring a motorbike was Uganda shillings 80,000 per day (≃21 USD). This was so expensive for an ordinary rural person that most people often used off-loading trucks as a means of transport.

Limited start-up capital/funds

Majority of respondents revealed that only a few managed to diversify from their primary livelihood activities due to limited start-up capital. For instance, only 12 of salt miners were able to join fishing or farming. Responses from the focus group discussions showed that there was a specific number of people registered for fishing for each recognized landing site. The activity, operated by law, required a significant amount of start-up capital including license costs of Uganda shillings 200,000 (≃50 USD) per boat per year. The fisher folks lamented that the license costs were high and involved a lot of bribery.

The salt miners (women) could only shift to agriculture as fishing was forbidden and expensive for them. The prices for renting land varied with an increment if the proceeds/harvest were good. However, most of the men were not willing to hire out land. Likewise agriculture was a no-go zone for the fishing community due to the land restrictions accorded to national parks and the lack of land itself. Many fisher women could not own land or even access it through their husbands. Shifting to salt mining had its financial constraints as well especially for women who had less or no incomes. The incomes generated from these activities were minimal yet startup capital was high. On average, most respondents resorted to intensification of their primary livelihoods regardless of the expected impacts.

Animal invasion

Invasion by park animals and cattle was reported as a common occurrence to the farmers and confirmed by key informants. Due to shortage of food availability and loss of pasture, park animals as well as cattle wandered for forage and ended up destroying people's crops both in the dry and rainy seasons. As a result, some people resorted to killing of the animals. This meant that drought resistant crops allergic to the park animals or wandering cattle were required.

Inadequate land and land use issues

The majority of respondents saw the park as an impediment to accessing their agricultural land. Specifically, the salt miners reported that communities were evicted from the park and land confiscated way back in the 1950s. However, according to reports from Uganda Wildlife Authority (UWA), the park was first gazetted in 1952 as Kazinga National Park and then renamed in 1954 to commemorate Queen Elizabeth II's visit to Uganda. In the selected parishes, respondents agreed that the fisher folks in Katunguru parish were the most affected because they were not permitted to carry out agriculture and also had no available land. Farmers considered land conflict as a serious management threat and complained of sharing the limited land with migrants and displaced persons. Case in point were the Basongora-cattle keepers who previously stayed in Busongora and left in the late 1998s in search of pasture in Democratic Republic Congo but were later evicted from the Viringa National Park in Eastern Democratic Republic Congo and returned home. For survival of their large herds of cattle, the herdsmen have resorted to mobile grazing. The outcome has been conflicts between cattle owners or other land users, farmers, park managers, and competition between humans and animal demands or needs. Likewise, in Nyakatonzi sub-county, pastoralists have turned to the national park as a grazing area since all the pasture in the area has dried up.

Environmental degradation

Respondents across the three livelihoods stated that environmental degradation was a major challenge to coping and adapting to climate variability. This was mainly caused by the increasing population which created excessive pressure on the limited available land. For instance forests were cut down to clear land for agriculture while fragile ecosystems like swamps were reclaimed for unplanned settlements and papyrus harvesting among the fisher folks. Among the salt miners, one key informant at Lake Katwe Tourism Information Centre (KATIC) revealed that numerous materials such as pegs, poles for demarcation of different pans and Apachi' (tree logs) were required from the park for the salt pans. These tree logs which were smuggled from the national park, once cut were not replaceable yet they were being substituted every six months. Other factors such as extreme climate events like drought and floods contributed to environmental degradation which in turn caused poverty and the reverse.

DISCUSSION

This paper provided an understanding of effects of climate variability on local communities living in and around Queen Elizabeth National Park, Uganda. The paper showed that changes in rainfall amounts and patterns are bound to influence cropping seasons and yields for particular crops further reducing flexibility of existing assets and hence output and consumption irrespective of the activity pursued by a given household (Mudelsee, 2019; Nsubuga and Rautenbach, 2018). This is reflected in the climatic shocks experienced among the farmers, fisher folks, and salt miners including drought, increasing intensity of rains and occurrence of water related human diseases. The observations from the current study imply that protected areas like Queen Elizabeth National Park are affected by changes in climate and that the effects increase the severity of the above listed climatic shocks in the national park (Misrachi and Belle, 2016; Rwenzori Region Agriclture Sector and Profile 2020). For instance, the increasing intensity of rains that usually cuts off trade routes, makes it difficult for the vehicles to navigate through. Equally, other studies too, indicate that the closure of major roads and inaccessible communities, damaged bridges and disrupted mobility and delivery of services are evidence of climate related events such as increased intensity of rains resulting in high transaction costs (Cooper and

Wheeler, 2017; CDKN, 2014). Given that the majority of rural communities practice subsistence agriculture and fishing, most farm produce and fish cannot reach the market on time. The results of this are losses arising from spoilt perishable produce and fish, limiting incomes for other basic needs of life like nutritional foods, descent accommodation, education, clothing and medical care of entire households. Therefore, shortage of food and reduction of household incomes has a significant impact on household livelihood security and survival.

In the same way, several studies by Katutu et al. (2019) and Diem et al. (2017), Mulinde et al. (2016) and Bagonza (2014) revealed that drought is a very severe event in Africa that harms food crops and reduces crop yields like maize, sorghum, millet and rice, causes loss of pasture and soil fertility, poor quality of crops and animals; hunger, poverty and increasing incidences of diseases as evidenced in the study area, which all lead to decline in the economy. In addition, warmer climate is known to affect fishing in coastal and aquaculture systems, and causes a decline in crop production, particularly in maize (Adhikari et al., 2015). The reduction in water levels affected multiplication of fish leading to less fish production. This was confirmed by the annual drought timescale (SPI12) that indicated high intensities of drought in the area. According to Dube and Nhamo (2020), the increase in temperature, decline in rainfall and/or fluctuation in water flow levels pose a potential threat to wildlife and may undermine future tourism operations and activities.

On the contrary however, some fisher folks believed that the quality of fish was dependent on the size of the fishing nets and fish tended to migrate to better breeding grounds because of the prolonged dry spells and drought. Those that remained had to compete among themselves for survival resulting into production of poor-quality fish. With the reduction in stock, fisher folks tended to use illegal fishing gear (that which catches fish of a small size) in order to increase the stock in terms of quantity. According to UNMA (2020), Kasese experiences higher temperatures due to the effect of equator and being located in the lee ward side of the mountain which contributes to the severity of droughts. Across the country, a general warming (1–3°C) as well as a decreasing rainfall trend (of 11%) in agreement with other future projections implies long-term droughts and occasional flooding (Acheampong et al., 2014).

Households, like those in other studies, have adopted innovative responses to mitigate the severity of climate variability. These include the use of improved crop varieties, changes in planting dates, migration, and off-farm activities (Zizinga et al., 2015; Rusinga et al., 2014); mulching and mixed cropping (Mubiru et al., 2018); and the application of fertilizer and compost manure (Alemayehu and Bewket, 2017; Fadina and Barjolle, 2018). Others are planting deeper into the soil, increased weeding, and changing the timing of land preparation (Umunakwe et al., 2015); food storage, livestock maintenance and laboring (Cooper and Wheeler, 2017); water conservation (FAO 2016a); rotational grazing and livelihood diversification (Kihila, 2018). Also, crop sales, petty trade, baking saloons, tailoring, formal employment and welding (Bagonza, 2014) are other coping strategies. Additionally, to address climate change effects among fisher folks, majority of the fisher folks had adjusted the fishing time, shifted to new areas, changed the fishing technologies and target species, sell of fishing assets (Raemaekers and Sowman, 2015; Limuwa, 2018; Musinguzi et al., 2016; FAO, 2016a; Mnimbo et al., 2017), all of which were in line with the study findings. While the use of the 41/2 inch fishing net was recommended by government, fishermen claimed that it limited the quantity of fish caught and entangling of nets was common. Change in the fishing spot was a good strategy though not sustainable since it destroyed the breeding grounds for the fish. Therefore, to regulate unnecessary fishing, nets were set in water around 4pm in the evening and got around 5am in the morning. Casual laborers were hired to drain the salt pans once a week during the rainy seasons but the costs were higher compared to the overall cost of packed salt. To demand accountability and lobby for appropriate action to improve their livelihoods, female salt miners, through efforts of National Association of Professional Environmentalist (NAPE) formed the Katwe Women Salt Miners Association in Uganda, a community-based association for the protection of natural resources.

There was a broad consensus that local communities faced multiple challenges. For instance, among the fisher folks and farmers, lack of sufficient storage facilities led to high losses of revenue due to price fluctuations. Similarly, Lam et al. (2016) found that global fisheries revenues fell by 35% as a result of the projected decrease in catches by the 2050s, which increased low-value fish and decreased catches. Climate change scenarios influenced market and price outcomes in agriculture (Masud et al., 2015; Cooper and Wheeler, 2017).

Conclusion

The study found that climate variability has a significant impact on livelihood activities, reducing livelihood options. The effects on the dominant activities of the local communities living in and around Queen Elizabeth National Park varied due to the nature of livelihood activities and adaptive capacity. Climate variability causes an increase in dry spells and/or drought, as well as an increase in the intensity of rains, all of which contribute to an increase in crop pests and diseases, as well as a loss of pasture and soil fertility, resulting in poor quality crops and animals, particularly among farmers. The fishing community experienced decreased fish production and poor-quality fish. While the salt miners experienced decreased salt production, pollution of salt pans, and the occurrence of water related human diseases. The resultant severe food shortages, reduction in household incomes, and poor health conditions at the household level, contributed to food and household livelihood insecurity. The most common coping strategies and adaptation options practiced by household members included agricultural intensification, draining of salt pans, and change in fishing technology, time and spot and livelihoods diversification. Regardless of the various forms of capital used to cope, the challenges faced are outside the control of the local communities, which further constrain the local communities.

RECOMMENDATIONS

The recommendations in this chapter are based on the study's findings. Based on farmer complaints about fake fertilizers and drought-resistant seeds, the provision of agricultural officers or extension workers will be critical. Rainwater harvesting should be promoted in communities. To prevent animals from destroying community crops, buffer zones or control methods should be established between the park and the farms. There was a need to build surplus storage facilities and provide necessary equipment. The local community can access a portion of the gate fee through a revenue sharing program for community projects. Formation and revival of cooperative societies or Savings and Credit Cooperative Organizations (Sacco) will help encourage saving and borrowing loans at the lowest interest. The funds can support livelihood activities regardless of the impacts like provision of protective gears such as gum boats, heavy gloves, and life jackets which are expensive for fisher folks. Finally, government should ensure the upgrading and rehabilitation of feeder roads which will ease transportation of products to the markets.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

LIMITATIONS OF THE STUDY

This study was hampered by language barrier and respondents' refusal to be tape recorded. Nonetheless, local research assistants were useful because they spoke the local language and took notes on a daily basis.

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Recycling Mwea irrigation water for sustainable agriculture

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Declining quantity and quality of irrigation water coupled with increasing water demand are serious challenges facing paddy rice production in the world. Reuse of agricultural waste water is increasingly popular in paddy systems but few studies have been done with regards to its quality and effects on soil productivity and environmental risks. The aim of this study was to assess the suitability of effluents from the Mwea Irrigation scheme in Kenya for recycling within the scheme and for reuse in new areas downstream. Water was sampled from River Thiba intake (point 1, control) and waste water from farmers plots, Kiruara drain (point 2) and Thiba main drain (point 3). Corresponding adjacent soils were sampled and analyzed for important physico-chemical quality parameters. Results showed that the EC, TDS, TSS, Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, HCO_3^-, NO_3^- and SO_4^{2-} significantly ($p<0.05$) increased in wastewater as point 1< point 2< point 3. Whereas, 88.3% of Mwea rice farmers experienced water shortage during peak demand, 51.5% of them recycled wastewater from paddy fields. The soil total N and available P from the wastewater reuse sites increased by 48.4 and 400% respectively to amounts that could save fertilizer P application once every 3 seasons. The wastewater NO_3^- concentrations increased above 8 mg/L likely to cause damage to N sensitive plants and eutrophication in the receiving water masses. The fresh water and wastewater in the Mwea scheme were suitable for irrigated rice production since all the nutrient parameters were within critical limits as recommended by FAO standards.

Key words: Irrigation, recycling, rice production, wastewater, effluent, physico-chemical, Water quality, precision agriculture.

INTRODUCTION

Rice is one of the most important staple foods in the world ranking third after wheat and maize in terms of production and consumption (Akinbile et al., 2011). However, Kenya faces a huge production deficit relative to demand, a gap that is filled through imports. Current rice production, estimated at 180,000 tons only meets about 20% of total demand which is estimated at 949,000 tonnes (IRRI, 2018), against the production target of 1.29 million tons by 2030 (National Rice Development Strategy-2, 2019-2030). Increasing rice production and productivity is critical and must address the immediate challenges of poor yields through increased use of hybrid

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rice, availability and quality of irrigation water, inefficient land and water use management, and low technology outlay (Atera et al., 2018).

Water scarcity is a major threat to irrigation development and the achievement of sustainable development goals, particularly in sub Saharan Africa. However, about 75% of total world rice output is produced under irrigation and this puts pressure on available freshwater resources (FAO, 2017). The major causes of global water scarcity include climate change; rapid population and economic growth; increased demands for irrigation water; increased demands for urban water; trans-boundary conflicts; and competitions between sectors such as agriculture, industry and energy and, matters relating to environmental protection (Bigas (Ed.), (2012) and Rogers (2004)). In 2012, UNEP identified Kenya to be among the countries likely to run short of water in the next 25 years (UNEP, 2012). Rice cultivation is one of the main crops feeding the global population and requires plenty of water for its effective growth.

According to Kuria (2004), the worst problem facing Mwea rice farmers was competition for and unavailability of irrigation water cited by 72.1% of farmer respondents. Nevertheless, wastewater has been extensively used in agriculture in many parts of the world to bridge the shortfall of freshwater for irrigation. Several such sources including surface and subsurface agriculture drainage water, storm runoff, sewage effluent and industrial wastewater recycling have been widely studied and used (Hettiarachchi and Ardakanian, 2016).

Wastewater arising from irrigation schemes vary in quality from effluent derived from domestic sources or industrial wastewater arising from urban areas. Whereas much work has been done on the latter around the world, very little research has been conducted on agricultural wastewater reuse particularly in water-scarce developing countries like Kenya. Work by Zulu et al. (1996) observed that agricultural water reuse supplemented the paddy water supply, and supplied up to 15% of the total irrigation water supply. Apart from meeting the water needs at peak demand periods, water reuse is a quick-response water supply solution during dry spells, increasing both the water reliability and crop security. However, research on the quality of wastewater and suitability for reuse on the paddy systems, rice land ecosystem and crop performance are conflicting and site specific, affected by the level of management and inputs applied and therefore inconclusive. For example, while Dong and Watanabe (2017), Ortega et al. (2001), Yoon et al. (2001), Hussain et al. (2002), Thu (2001) and Singh and Agrawal (2012) found that wastewater irrigation mainly increased rice yield by 10-50% with less amount of fertilizers due to nutrients, and improved soil structure by organic matters in wastewater, WHO (2006) and Nyomora (2015) did not observe such soil and yield increases and in contrast, found that wastewater irrigation applied with N-P-K fertilizer depressed the yield potential to 3.2 times of that obtained without its application and that high salt contents in wastewater was a potential hazard and eroded the soil structure resulting in less productivity. Furthermore, under wastewater irrigation, proper agronomic and water management practices were required to improve crop yields, safeguard the environment against pollution and increase value of fertilizer saved (Singh and Agrawal, 2012), and to reduce potential of contamination with microbes, heavy metals and organic toxic compounds in wastewater (Dong and Wanatabe, 2017).

The Mwea irrigation scheme is the largest in Kenya producing approximately 80% of paddy rice, on 26000 acres under irrigation and with a potential to increase this scheme by a further 10,000 acres. However, this is constrained by lack of sufficient water (NIA, 2020; Kuria 2004) where approximately 88.3% of the farmers experience water shortages during rice cultivation (Onderi, 2016). In spite of strong research evidence that agricultural effluent irrigation can make a significant contribution in reducing water demand, especially during peak demand periods, improving soil condition and crop yields, and reducing the amount of pollutant discharged into our waterways to protect the environment and public health, the quality of effluent from Mwea irrigation scheme is not known despite a majority of the smallholder farmers already using it. Hence there is need to assess its suitability for irrigation. The authors hypothesized that physico-chemical parameters of irrigation water change with intensity of water reuse affecting its quality, and that reuse of the Mwea irrigation scheme effluent affects soil quality and potential for sustainable rice farming. Therefore, our objective was to assess farmers' awareness on the effects of the quality of irrigation water on rice production, to determine the physico-chemical properties of Mwea irrigation scheme's water at source (River Thiba) and its irrigation effluents (Kiruara Drain and Thiba Main Drain), to investigate the effect of wastewater reuse on the quality of Mwea soils and rice yields and to assess suitability of the Mwea irrigation scheme effluents for reuse in irrigation in relation to FAO recommendations.

MATERIALS AND METHODS

Study area

This study was carried out in the Mwea Irrigation Scheme, Kirinyaga County, Kenya (Figure 1). The scheme was started in 1956 and has a total potential area of 30,350 acres, of which 26,000 acres have been developed for paddy rice, producing 86% of the total rice grown in Kenya (Muhunyu, 2012). Besides the nucleus region of the scheme, another 5,000 acres of rice are under cultivation in the out-grower region of the scheme bringing the total acreage under rice to 21000 acres.

The nuclear scheme is divided into 5 sections, namely Tebere (T), Mwea (M), Thiba (H), Wamumu (W) and Karaba (K) while the out grower region include areas of Kianugu, Ndekia, Curukia and

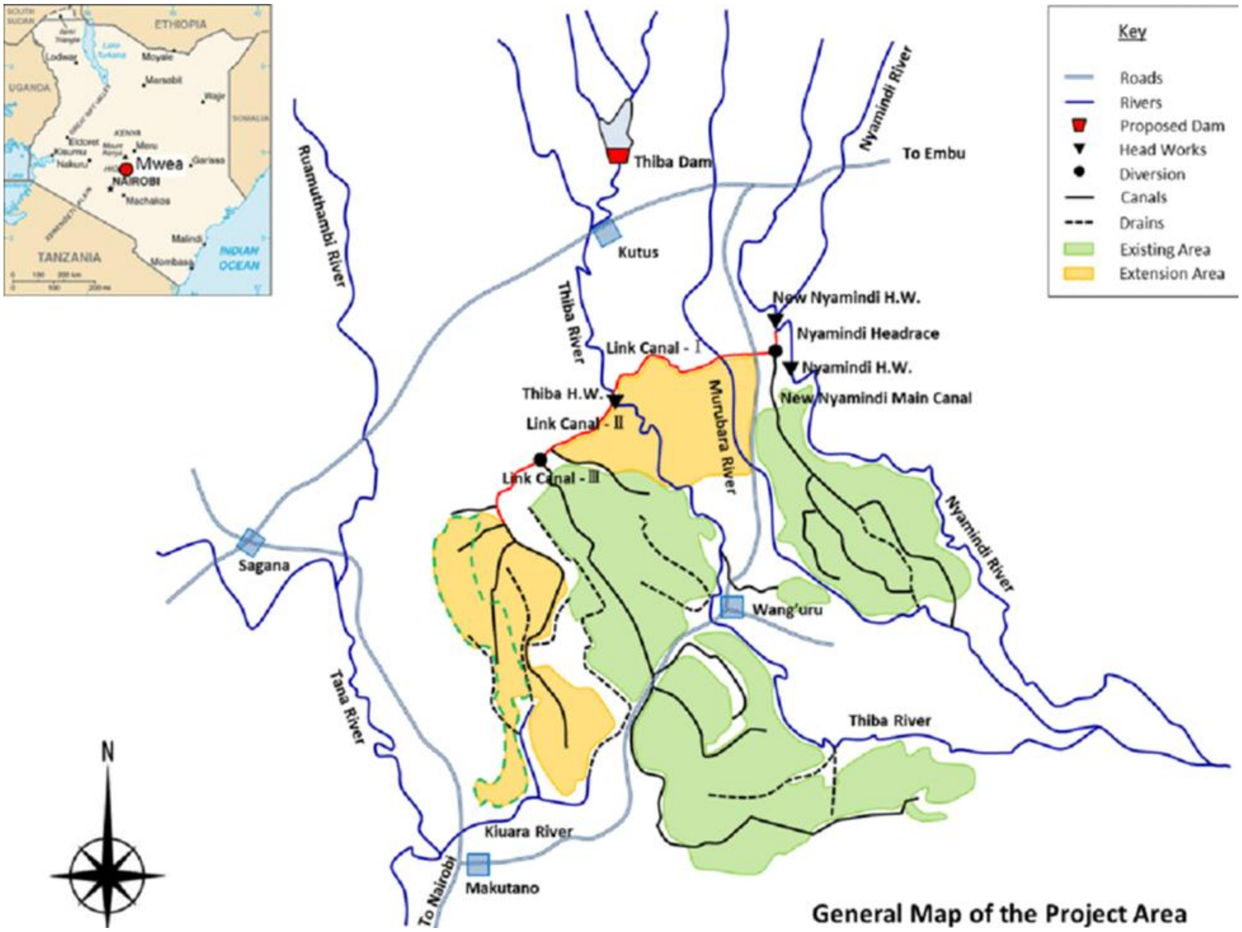

Figure 1. Base map of the Mwea rice scheme, Kenya. This map shows the location of Mwea irrigation scheme in relation to the Kenyan Map. In addition, it also shows the area covered by the Scheme (Adapted from Jacob et al., 2006).

Kiamanyeki (Figure 2). The sections are further divided into 70 blocks also known as water management units (WMU) to ease management.

The scheme is served by two main rivers viz: - River Thiba and River Nyamindi which irrigate 80% and 20% of the scheme, respectively (Wendot, 2019 *pers com*). Irrigation water is drawn from the rivers with the help of fixed-intake weirs by gravity and then conveyed and distributed via open unlined channels irrigating various blocks in turns depending on the irrigation schedules and quantities of water available.

Research design

The study employed the comparison of exposed and control site research approach. The control site was taken at the main inlet point of river Thiba (referred to here as point 1), the upper reach of the river which supplies the scheme with fresh irrigation. In contrast, exposed sites were taken in the lower two re-use points namely; Kiruara Drain and at Thiba Main Drain (referred to as points 2 and 3). This experimental approach involved fresh input water (at point 1), wastewater and soil sampling from the three different sites in the scheme followed by laboratory analysis. Non-experimental (Survey) design was also used to determine the existing farm-hold conditions at Mwea irrigation scheme and structured questionnaires administered to collect important information about the farmer population. Transverse walk and field visits were also undertaken to make any necessary observations such as whether farmers were actually re-using wastewater from paddy fields to accomplish the study.

Water sampling and analyses

Nine water and wastewater samples were collected, three from each of the 3 sites, that is, at the main inlet point of river Thiba (fresh river water, control point 1 treatment), and at two irrigation drainage re-use points namely; Kiruara Drain (treatment, point 2) and at Thiba Main Drain- (treatment, point 3). River Thiba main inlet (point 1) served as the control point since irrigation water was sourced from the river, assumed to be clean and free from contamination while Kiruara Drain and Thiba Main Drain were the first and second re-use points bearing effluents /wastewater from the rice fields.

Sampling was carried out according to APHA et al. (2005)'s recommendations, that is, filtering and use of sterilized bottles which were obtained from the laboratory. Sampling was done once every month, at planting, during the rice vegetative stage (34 days after transplanting) and at the reproductive stage (75 days after transplanting, 2018). Before sampling, the bottles and containers were rinsed thrice with water from the sampling site. .Then three samples of equal volumes were taken from the two edges and at

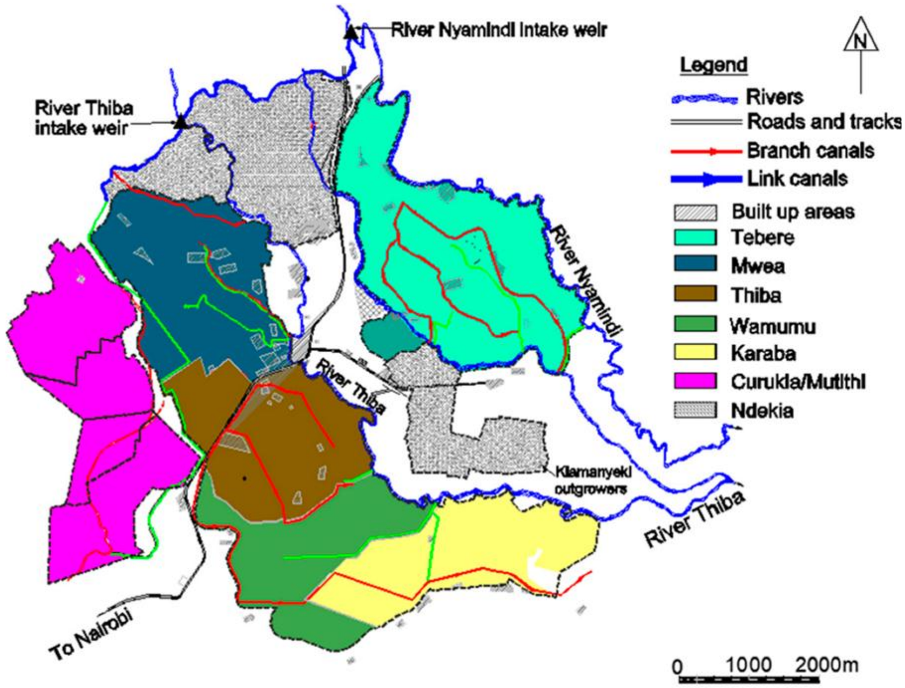

Figure 2. Map of Mwea irrigation scheme showing the various sections and blocks (Source: Mwea irrigation Scheme, 2019).

the middle of the canal and mixed to produce a composite sample from which a 500mls representative sample was drawn into labeled containers for subsequent analysis. Immediately after sampling, pH was determined using a portable pH meter; EC and TDS was measured by a portable waterproof multi-range conductivity/TDS meter (Model No: H1-9635) manufactured by Precision Scientific Instruments Corporation, India Mart. The samples were then carried in a cooler box which kept them as cool as possible without freezing to minimize the potential for volatilization or bio-degradation (Jayalakshmi et al., 2011), and immediately taken to the Government chemist laboratory in Nairobi within 3 hours. In the lab, the samples were acidified with nitric acid to a pH below 2.0 to minimize precipitation and adsorption of certain cations to container walls. Whenever immediate analysis was not possible, the samples were stored at 4^oC according to Jayalakshmi et al. (2011). Each sample was analyzed in triplicate giving each parameter 27 sets of results whose mean and standard errors were determined at 95% confidence limit.

The water and wastewater parameters measured for overall water quality assessment included:- pH, Electrolytic conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Calcium, Magnesium, Sodium, Potassium, Bicarbonates, sulphates and Nitrates. These parameters were determined using standard procedures as described by ALPHA (1998). The results were used to compute sodium adsorption ration (SAR) and further compared with FAO irrigation water quality standards.

SAR was calculated using the formula, Equation 1 below:

$$S.A.R = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}} \quad (1)$$

Source: Ayers and Westcott (1985)

Where: SAR – is the sodium adsorption ratio, a measure of the amount of sodium (Na) relative to calcium (Ca) and magnesium (Mg) in the water extract from saturated soil paste.

Soil sampling and pre-treatment

Soil samples were drawn from 3 sites adjacent and corresponding to the water sampling points described above. The soil sampling sites were: at the Mwea irrigation agricultural development (MIAD) farm (point 1) which receives water directly from river Thiba intake and is the first field to be irrigated; point 2 was at Curukia block - the first farm which receives its irrigation water from Kiruara Drain, and site 3 was at Mwea GK Prison farm which basically utilizes water which has passed through several fields before exiting back to river Thiba. Soil samples were taken at the end of the rice growing season for analysis of soil pH, Electrical conductivity, and total organic carbon, Total Nitrogen, Phosphorous, Calcium, Sodium and Magnesium.

From each of the 3 sites, 8 samples were obtained from 0-20 cm depth (as recommended by Carter and Gregorich (2006) for annual vegetation) by the zigzag method using a soil auger to ensure homogeneity. These were then thoroughly mixed and a composite sample of 1kg obtained, labeled, recorded in the field note book and immediately delivered to the MIAD laboratory in Mwea within 1 h for analysis. In the lab, soil samples were air-dried to minimize changes in soil physical and chemical properties, ground and sieved through a 2.0 mm sieve and stored in sample bags for subsequent analysis as outlined by Okalebo et al. (2002).

Soil analysis

The soil pH (1:2.5, soil:H_2O) was measured potentiometrically in the supernatant suspension using a pH meter (Carter and Gregorich, 2006). Electrical conductivity (EC) of the soil was determined by using an electro-conductivity meter. Organic carbon was determined by Walkley - Black method (Schumacher, 2002) and calculated using the formula, equation 2 below.

$$\text{OC (\%)} = 10\,\frac{(B-T)}{B} \times \frac{0.003\times 100}{wt\ of\ soil(g)} \quad (2)$$

Where: B=volume (ml) of ferrous sulphate used for the blank titration; T=volume of ferrous sulphate used for the titration of soil sample.

Actual organic carbon (%) = organic carbon estimated × 1.3

Organic matter (%) =Actual carbon % ×1.724. (1.724 is called the Van Bemmeler factor which is used because organic matter contains 58% carbon). Total nitrogen was determined by the Kjeldahl method (Carter and Gregorich, 2006). The digest solution was used for the potassium, sodium, calcium, magnesium and phosphorous determination using atomic absorption spectrophotometer (AAS) machine.

Statistical analysis

The physico-chemical laboratory results were analyzed using SAS software programme version 9.1 whereby the mean concentrations of the parameters were tested for significant variations ($P<0.05$) by a two-way analysis of variance (ANOVA) and further separated using Tukey's test. The means from point 2 and point 3 were then compared with FAO irrigation water quality standards.

Household survey

A structured questionnaire was developed, pre-tested by staff from KALRO Mwea and MOA Mwea East Sub-county and administered to 163 farmers. The interviews were conducted with the help of eight officers from MIS water users association.

Sample size

The sample size was estimated using the equation used by Valedes and Bamberger (1994) as:

$$d=n^{-1/2}(c^2pq)^{1/2} \quad (3)$$

Where: d is the precision of an estimate for a particular confidence interval with high values indicating low precision and low values indicating high precision. c is the Z-score for the selected level of confidence (in this case 95%). n is the sample size. p is the probability at which the event being measured is likely to occur and q is the probability that the event will not occur (q=1-p). Note: Though the desired precision of the estimate is half the width of the desired confidence interval (Webster, 1995) a higher value in this case was adopted because the scheme irrigators have a strong homogeneity in terms of farm and canal design characteristics; water distribution schedules; crop type; production programme and agronomic practices a case which exhibits strong internal similarity (Owilla, 2010: Webster, 1995).

The scheme has 4189 registered farmers. Using a confidence level of 95% (x=0.05), which corresponds to Z score of 1.96 and setting the d value at 0.786 and p at 0.5 (results in the highest precision) the sample size was found by substituting the values of d, c, p and q into the equation:-

$$0.786=n^{-1/2}(1.96)^2(0.5)\,(0.5)^{1/2} = 163 \quad (4)$$

Where n is the sample size.

Sampling frame

The scheme manager provided a list of all farmers in the scheme which comprises seven (7) sections and seventy (70) blocks. Then, systematic random sampling method was used whereby the sections were randomly numbered from one to seven. The first member listed in each block in each odd numbered section was interviewed and thereafter the 31st, 61st, 91st etc. members. Then the second member listed in each block in each even numbered section was interviewed as was the 32nd, 62nd, 92nd etc. members. The farmers' responses were categorized and tabulated. The overall sample size of 163 was apportioned to the sections of the scheme using nth value = 30 criteria as shown in Table 1. Data on rice production and irrigation water used for 2015/2016 season were collected from both original scheme tenants and farmers in the out-grower sections of the scheme.

RESULTS AND DISCUSSION

Mwea farmers' practices

Smallholder rice farmers' household survey found out that 88.3% of the Mwea Irrigation Scheme farmers experience water shortages during rice growing period (2016 to 17) thus indicating a slight increase from 85% reported by Muhunyu (2012).The study also found that the scheme had developed an irrigation water rationing schedule whereby only 59.5% of the smallholder farmers received irrigation water and only once per week. The rationing was due to water shortages during peak periods of rice irrigation. Despite advocating for the System of Rice Intensification (SRI) by the scheme management that could drastically reduce the quantity of irrigation water (Ndiiri et al., 2012) used by farmers, it was found that most farmers in the scheme used the conventional way of flooding paddy fields which uses a lot of water for rice growing. This is in agreement with previous findings that rice is the largest consumer of water in the agricultural sector (Ndiiri et al., 2012; Thakur et al., 2011). As a result, farmers predominantly use substitute water sources such as drainage canals, small rivers and ponds, in agreement with Rice MAPP (2016).

This study further found that 51.5% of the farmers in the Mwea Irrigation Scheme used wastewater from the paddy fields normally derived from overflows from neighbors' fields. This source is recycled via irrigation canals or through direct pumping from drainage canals. About 50.6% of the farmers who did not use the wastewater said it was not available due to the position and distance of their farms from the drainage canals. Since 68.7% of the farmers have grown paddy rice for over 10 years, it is evident that they recognize the positive role of wastewater reuse in rice production. The 48% of those who did not use wastewater had a negative feeling about it and this is supported by Githuku (2009) and USEPA (2012), who observed that "waste water re-use has not been fully accepted".

All farmers in the study area use different types of inorganic fertilizers to grow rice (Figure 3). For planting

Table 1. Number of farmers sampled per section.

Section	Frequency	%	Valid %	Cumulative %
Tebere	26	16.0	16.0	16.0
Mwea	30	18.4	18.4	34.4
Thiba	25	15.3	15.3	49.7
Wamumu	26	16.0	16.0	65.6
Karaba	26	16.0	16.0	81.6
Curukia	20	12.3	12.3	93.9
Kiamanyeki	10	6.1	6.1	100.0
Total	163	100.0	100.0	

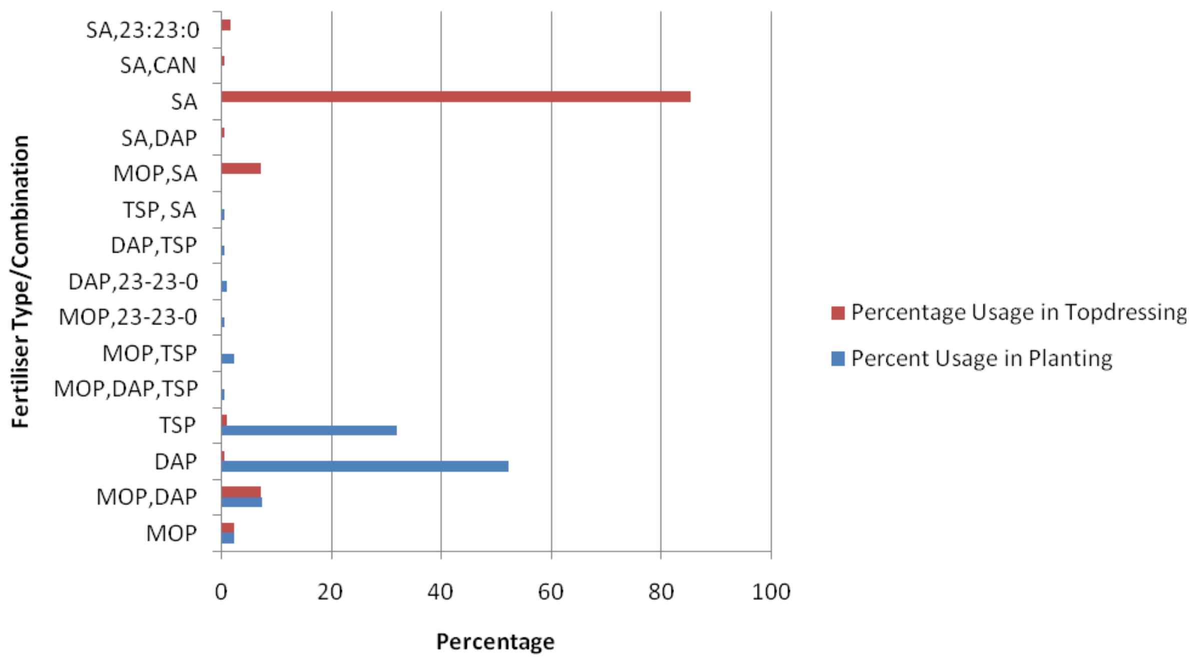

Figure 3. Inorganic Fertilizers Applied on Rice at MIS Mwea, Kenya in 2017.

52.1% used Diammonium phosphate (DAP), 2.5% used Muriate of potash (MOP) and 31.9% used Triple superphosphate (TSP) as shown in Figure 3. However, 85.3% of the farmers applied Sulphate of Ammonia (SA) during topdressing which has potential of acidifying soils and which causes heavy calcium ion losses in the form of calcium nitrate and calcium sulphate in irrigation effluent (Afullo, 2009). This study found significantly higher usage of pesticides (herbicides 87.1%; and insecticides and fungicides at 98.8%) comparable to previous studies by Muhunyu, (2012). This has a likelihood of negatively changing the composition of water leading to increased contamination on the environment, mainly water, river and underground water masses and soils. Muhunyu (2012) further observed that the use of herbicides is not encouraged by the Public Health officers because the contaminated water drains back to the canals and rivers and is used downstream thus posing an environmental and human health hazard in Mwea area. Therefore, there is need to use available alternatives to chemical pest control such as varietal resistance and integrated pest management (IPM) technologies in Mwea, Kenya.

The average paddy rice yield reported by farmers (Figure 4) was highest in the Karaba (K) section at 5.62 ton/ha (27.9 bags/acre; 1 standard bag equivalent to 80kg), followed by Wamumu farmers (W) at 5.46 tonnes (equivalent to 27.1 bags); Thiba (H) at 5.28 tonnes (or 26.2 bags/ acre); Curokia at 5.18 tonnes (or 25.7 bags); Mwea (M) at 5.06 (or 25.1bags); Tebere (T) at 4.90 tonnes (or 24.3 bags) and was least in Kiamanyeki at 3.19 tonnes (or 15.8 bags) of paddy rice .

The highest rice yield was 5.62 ton/ha obtained at the second wastewater re-use point 3 at Karaba section (Figure 4). This was followed by Wamumu (5.46 ton/ha)

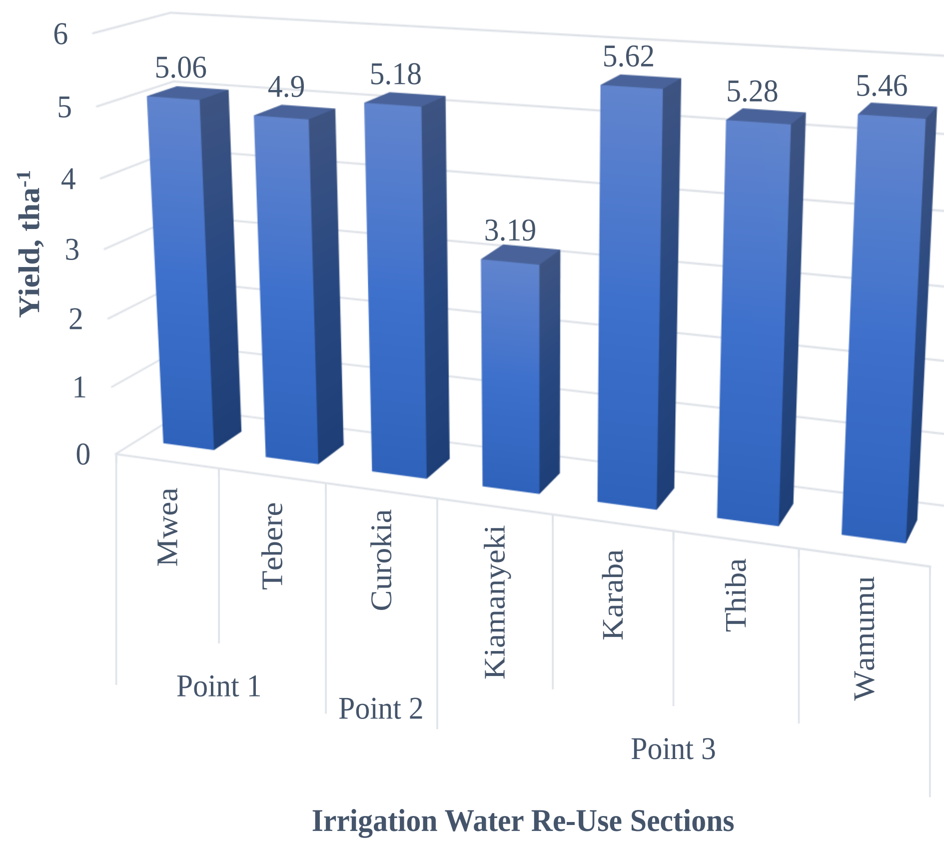

Figure 4. Rice yield at Mwea Irrigation Scheme, Kenya in 2017.

and Thiba (5.28ton/ha) sections while the least rice yield was 3.19 ton/ha obtained from Kiamanyeki in the same block using second wastewater at point 3. The second highest rice yield (5.18 ton/ha) was obtained from Curokia section (point 2 block) which was irrigated with first waste water drained from point 1 block sections of Mwea. Except for Kiamenyeki, the lowest yields were obtained from point 1 block which include Mwea (5.06 ton/ha) and Tebere (4.90 ton/ha). The highest yields obtained from point 3 sections (except for Kiamanyeki) could be explained by its location, which is at the tail end of the scheme thus utilizing irrigation water mixed with second stage wastewater, richer in nutrients drained from paddy fields irrigated with first drainage waste water. The pattern of yields increase followed the order point 3 > point 2 > point 1, corresponding to nutrients concentration increases in wastewater (Table 2) and soils (Table 4) thus suggesting that increasing concentrations of Ca, N, K and Mg nutrients in drainage wastewater (Table 2) and from associated higher soil N, P, Ca and Mg contents (Table 4) improved rice nutrition and observed high grain yields. Despite having inadequate and unreliable water supply, farmers at the Curokia out-grower section reported higher rice yields compared with those from the Mwea section, confirming that water mixed with first drainage effluents contained higher nutrient cations than fresh irrigation water directly from river Thiba inlet. Least rice yields obtained at the Kiamanyeki section can be explained by inadequate water received in this section due to its far-off position in relation to the main irrigation infrastructure. These results compare well with the optimum yield of aromatic rice varieties of 5.5 ton/ha (27.8 bags of 80kgs/acre) as given by Muhunyu (2012) for the Karaba section.

The physico-chemical parameters

The results of the present study show that irrigation water pH, EC and TDS values increased from point 1 control < point 2 < point 3 (Table 2), indicating higher concentration in wastewater compared to fresh river water which served as the control. Water pH was alkaline but increase was not significant (p=0.05) indicating that the N fertilizers in residual water draining from point 2 and 3 did not alter the water pH. Values in columns followed by the same lower case letters are not significantly different (p=0.05). Point 1 represents the first drain wastewater. Point 2 was the second drain wastewater and the parenthesis show percent of the control.

The study findings indicate that salinity increased down the irrigation canals. Though these values fall within FAO

Table 2. The physico-chemical composition of irrigation effluents used in Mwea irrigation scheme.

Parameter	Physical parameter				Cation				Anion					
	pH	EC dS/m	TDS mg/l	TSS mg/l	Ca^{2+} me/l (%)	Mg^{2+} me/l (%)	Na^{+} me/l (%)	K^{+} mg/l (%)	HCO_3^- me/l	NO_3^- mg/l	SAR me/l	NO_2^- mg/l	Cl^- me/l	SO_4^- me/l
Point 1 River Thiba (Control)	7.26[a]	0.05[b]	36.8[b]	41.3[b]	0.16c	0.82[b]	0.20[b]	1.23[b]	0.90[b]	5.83[a]	0.31[a]	0.02[a]	0.79[a]	0.67[b]
Point 2 Kiruara Drain	7.29[a]	0.12[ab]	74.1[ab]	71.5[ab]	0.39[b] (143)	0.99[ab] (20.7)	0.47[a] (135)	1.77[b] (43.9)	1.47[b]	7.10[a]	0.48[a]	0.06[a]	0.87[a]	2.36[a]
Point 3 Thiba Main Drain	7.68[a]	0.20[a]	130.7[a]	139.0[a]	0.69[a] (331)	1.74[a] (112)	0.54[a] (170)	2.80[a] (128)	2.41[a]	8.05[a]	0.37[a]	0.07[a]	0.88[a]	6.87[a]

recommended standards (Table 3), irrigation water should contain a minimum EC of at least 0.2dS/m or its TDS exceeding 200mg/L to prevent surface dispersion. This means that River Thiba (point 1) and Kiruara drain (point 2) waters are corrosive and tend to deplete the surface soils of their soluble salts and exchangeable cations (Onderi, 2016) and Ca is amenable to this washing (Afullo, 2009) making the effluent at Thiba Main Drain (point 3) better for use compared to River Thiba waters. This study revealed that TDS correlates positively with EC as found out by Jayalakshmi et al. (2011). Also noted was a progressive increase in the values of TSS from point 1 (41.3 mg/L) to 3 (139 mg/L) and this depended on the high number of paddy fields irrigation water sweeps through before it is discharged back to the river.

Similarly, cations and the anions concentrations followed the same trend and increased in the order of point 1 (fresh water, control) < point 2 < point 3 (Table 2). compared with the control, Ca^{2+}, Mg^{2+},Na^{+} and K^{+} increased by 143%, 20.7%, 135%, and 43.9% respectively in the first drainage wastewater and by 331, 112%, 170 and 128% respectively in second drainage wastewater. Increase in TDS and EC was associated with increasing alkalinity (high PH) of the irrigation water as well as Calcium concentrations in water. Higher cations and anions in wastewater could be explained by continued heavy applications of inorganic fertilizers, DAP, SA and MOP for rice production. Observations during field visits revealed that farmers used manure on their rice fields increasing soil organic matter content which is the key modifier and buffer of soil quality. In addition, continuous topdressing with sulphate of ammonia (SA) fertilizer has been shown to increase Ca losses in form of calcium nitrate and calcium sulphate in drainage water (Afullo, 2009). Moreover, in contrast, the use of organic manure observed during field visits might have buffered Ca from being lost. This finding is supported by Fenton and Conyers' (2002) who reported that very low organic matter causes calcium deficiency. Also the high pH values in the water and wastewater may have favoured calcium availability. Likewise, Analysis of variance (p=0.0947 between points 1 and 2, p=0.0278 between points 1 and 3 and, p=0.0402 between points 2 and 3) indicated gradual significant increments in magnesium from point 1 (0.82 me/L) through point 3 (1.74 me/L) again re-affirming that the agro inputs used by Mwea Irrigation Scheme farmers did contribute to the substantial changes in magnesium levels. Although analysis of variance show significant differences (p=0.0096) in Na levels between River Thiba intake (point 1) and Kiruara drain (point 2), with no difference between Kiruara drain (point 2) and Thiba main drain (point 3), the overall low sodium concentrations of below 3me/L in the drainage irrigation water sources indicated that none of the sources pose toxicity to sodium sensitive crops (Ayers and Westcot, 1994). Unlike the other cations, K^{+} concentration in drainage wastewater at point 3 was higher than FAO recommended standard values for irrigation water (Table 3) thus indicating that the irrigation water is being enriched as it mixes with wastewater down the irrigation drains. This concur with previous work reported by James et al. (1982) that water direct from mountain sources is too low in K but irrigation water that comes by way of return flow adds considerable K to offset removal (Figure 5a and b).

The values of NO_3 in irrigation water showed a progressive increase from the intake at point 1 to point 2 and point 3:- as 5.83 mg/L < 7.10 mg/L < 8.05 mg/L for point 3 respectively. These values are within FAO recommendations and statistical analysis did not show any significant difference between the three points (as p>0.05). Nevertheless, the NO_3 levels exiting from the scheme through Kiruara Drain, point 2 and Thiba Main Drain, point 3 need to be disposed off well for purposes of conserving the environment and avoidance of undesirable miscellaneous problems such as excessive vegetation at the expense of produce and, one of the best ways is through recycling.

Bicarbonate values for point 3 (2.41 me/L) was significantly higher compared with the control (0.90 me/L, point 1) and point 2 (1.47 me/L;

Table 3. Comparison of Kiruara drain (Point 2) and Thiba main drain waters (Point 3) to FAO recommendations.

Parameter	pH	EC dS/m	TDS mg/l	TSS mg/l	Ca^{2+} me/l	Mg^{2+} me/l	Na^{+} me/l	K^{+} mg/l	HCO_3^- me/l	NO_3^- mg/l	SAR me/l
Point 2	7.29	0.12	74.1	71.5	0.39	0.99	0.47	1.77	1.47	7.10	0.48
Point 3	7.68	0.20	130.7	139.0	0.69	1.74	0.54	2.80	2.41	8.05	0.37
FAO standards	6.0-8.5	0-3	0-2000	-	0-20	0-5	0-40	0-2	0-10	0-10	0-15

FAO standards (Ayers and Westcot 1985).

p=0.0045). Point 1 and point 2 values (p=0.2128) were not statistically different. Observed bicarbonate differences could be explained by the intensity of wastewater reuse whereby irrigation water swept through many paddy fields (farms in approx. four sections) between point 1 and point 3 compared to only a few rice fields between point 1 and point 2. These values are within FAO recommended standards (Table 3) but from previous studies, a high bicarbonate water (>2me/L) as in point 3 (2.41me/L) in the water used for flooding and growing paddy rice is reported to cause severe zinc deficiency (Mikkelson, 1983). Also high presence of bicarbonates will precipitate Ca when the soil is dry leading to an increase in Na relative to Ca causing development of thin surface crusts which impedes water infiltration and accelerates runoff. The effluent parameters were compared with FAO recommended standards as shown on Table 3.

This research found out that the quality of effluents from Mwea Irrigation Scheme fall within the FAO recommendations for irrigation water save for potassium at point 3 thus suitable for reuse in paddy rice production. Though Nitrates fall within the FAO recommendations of 0-10mg/L, Pierzynski et al. (1994), reported that the threshold for eutrophication in freshwater environments is 0.5-1.0 mg N L^{-1}. Therefore wastewater from Mwea Irrigation Scheme has a potential of contaminating receiving masses downstream and recycling of these wastewater will solve the problem.

Soil quality changes as affected by wastewater irrigation

Results obtained from soil analysis at varying intensity of wastewater reuse indicate contrasting recharge and depletion effects on micronutrient and major macronutrient cations on the smallholder farms (Table 4). Whereas soil N and available P significantly accumulated in soil upon reuse of wastewater, in contrast, potassium and zinc particularly depleted in soils to a deficiency range, with increasing intensity of cultivation.

The results further show that although all major cations accumulated, all the micronutrients tested declined in soils (Table 4). Nevertheless, these results have serious implications on rice nutrition because except for potassium and zinc, all the chemical parameters tested were in adequate range for rice nutrition at site 3 soil, which was cultivated using second recycled drainage water.

The soil pH remained fairly alkaline from 7.48 to 7.59 and did not decrease as expected owing to continuous application of ammonium fertilizers in soil. This was probably due to high Ca concentration in wastewater used for irrigation, coupled with the frequent use of organic manure observed during field visits that might have buffered soil pH.

Soil total N increased from 0.182 to 0.31% at point 3, the latter being sufficient for adequate N availability in soil. Likewise, available P in soil progressively and significantly increased from 6 ppm at the control point 1 soil to 11 ppm at point 2 and finally to 30 ppm P at point 3, an increase of 400% compared with the control.

Therefore the soil N and P increased from a deficiency to sufficiency range in soils after irrigation with second category wastewater suggesting nutrient deposition and potential for fertilizer savings and economic benefits for the smallholder farmers because fertilizer inputs are expensive. Further, the increased nutrient concentrations in soil may explain the observed higher rice yields obtained by farmers in block 3 fields. With P values of 30ppm, rice farmers can do a season without application of P fertilizers hence a saving on production costs. On average, farmers apply 80kg of basal fertilizer @ Ksh. 64 per kg retail price for DAP/ TSP meaning a saving of about Ksh. 5000/- per acre can be achieved in that one season. This study results correspond with the findings of Singh and Agrawal (2012), who reported that organic carbon, total nitrogen, available phosphorous, electrical conductivity, nitrate nitrogen and ammonium nitrogen were higher in wastewater irrigated soils compared to soils irrigated using clean water.

The finding of depletion of soil K at point 3 (from 0.2 to 0.14 me%) was surprising due to farmers' regular application of muriate of potash (KCl) fertilizers for rice production. However, this observation of a negative K balance could be reinforced by a positive N and P balance found in this study and supported by the work of Magen (2008) that K deficiency normally occurs in intensively cropped areas with high levels of N and P application. Unbalanced N-P-K nutrition amongst Mwea rice farmers has been reported in this study, whereby

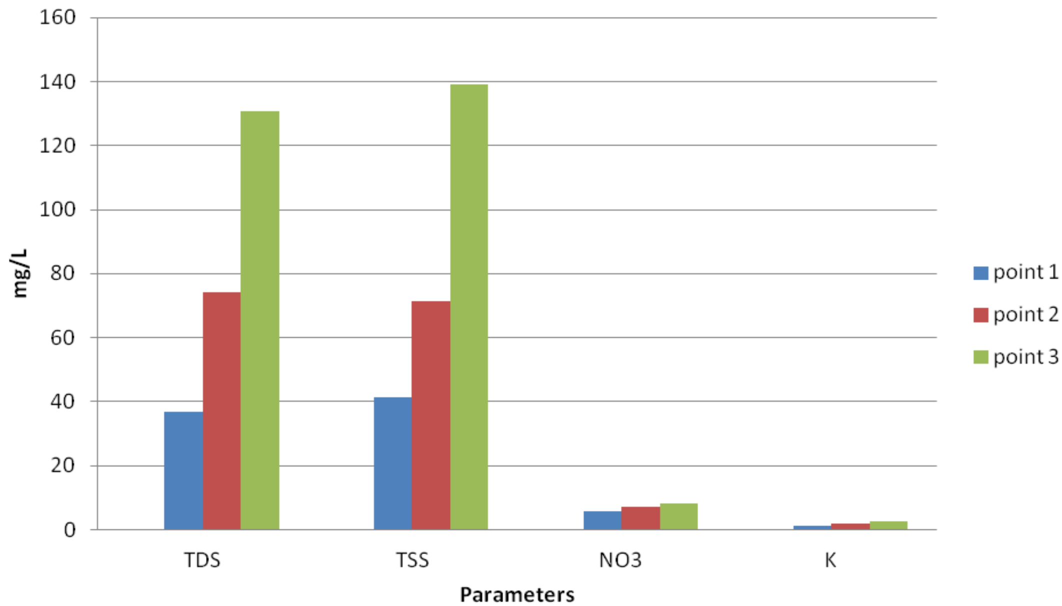

Figure 5a. Effect of intensity of wastewater reuse on the quality of irrigation water (as denoted by points of water intake.
Point 1, control; point 2 = drain water from only first section irrigated and point 3 = second drain water from 4 sections irrigated).

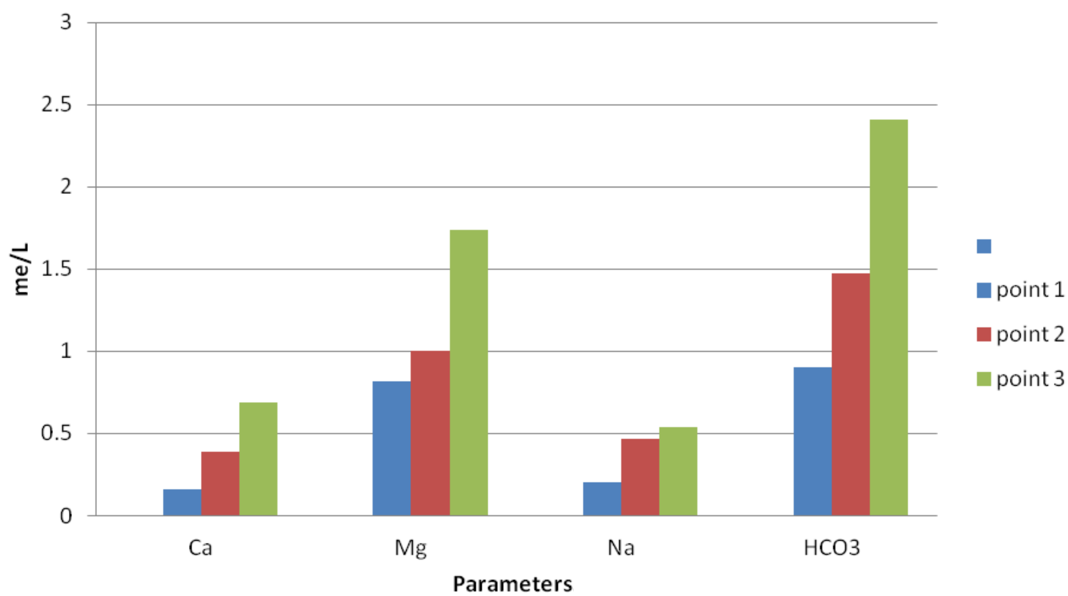

Figure 5b. Effect of intensity of wastewater reuse on the quality of irrigation water (as denoted by points of water intake.
Point 1, control; point 2 = drain water from first one section irrigated and point 3 = second drain water from 4 sections irrigated).

only 2.5% of the farmer respondents reported using muriate of potash (KCl, MOP) for planting rice while another 10.4% used it in combination with other fertilizer types. (sic N and P fertilizers). This coupled with high drainage and leaching losses due to high solubility of K (Table 2) caused the negative K balance, decreased K soil fertility, and could decrease rice productivity. K fertilizer needs to be applied in adequate amounts in most irrigated rice fields. Further, reasons for a negative K balance stem mostly from farmers' lack of knowledge

Table 4. Effect of wastewater reuse on soil quality at 3 different sites at Mwea Irrigation Scheme, Kenya.

Soil parameter	SITE 1		SITE 2		SITE 3	
	Value	Class[1]	Value	Class[1]	Value	Class[1]
pH	7.48	Alkaline	7.71	Alkaline	7.59	Alkaline
Total N, %	0.182	Low	0.175	Low	0.31 (15.4%)	Ideal
Total organic C, %	1.54	Adequate	1.49	Adequate	1.86	Adequate
Olsen P, ppm	6	Very low	11	Low	30 (400%)	High
Potassium (K) me%	0.2	Low	0.18	Low	0.14	Low
Calcium (Ca), me%	12.7	Adequate	6.7	Adequate	14.7	Adequate
Magnesium (Mg), me%	2.17	Medium/Adequate	4.03	High	3.69	High
Manganese (Mn), me%	0.99	Adequate	0.27	Adequate	0.11	Adequate
Copper (Cu), ppm	3.09	Adequate	3.43	Adequate	1.28	Adequate
Iron (Fe), ppm	338	Adequate	95.8	Adequate	18.3	Adequate
Zinc (Zn), ppm	4.32	Low	4.62	Low	2.4	Low
Sodium (Na), me%	1.42	Adequate	0.7	Adequate	1.49	Adequate
EC mS/cm	*		*		0.78	Ideal

[1] - Soil test class according to Horneck et al., 2011. *Threshold value too low to warrant EC to be determined. Site 1- MIAD Block; Site 2 - Kiruara area; Site 3 - Prison Farm.

and socioeconomic factors (Magen, 2008).

The soil micronutrient elements decreased with cultivation at point 3, implying attendant danger of micronutrient depletion with continuous rice growing. Soil Mn, Cu, Fe and Zn all decreased at point 3 in response to increasing uptake and leaching. However, the lowest zinc values at site 3 could be explained by the high bicarbonate content in waste waters at the tail end of the scheme. This agrees with Mikkelson and Brandon (1879), that high bicarbonate water (> 2 me/l) in water used for flooding and growing paddy rice is reported to cause severe Zinc deficiency. Concentration of Iron (Fe) in soil decreased from 338 to 18.3 ppm at point 3 but this was still adequate for rice nutrition. However, in alkaline soils like in this study, Fe concentrations is low and according to Masuda et al. (2019), plants encounter Fe deficiency when grown in calcareous soil with low Fe availability.

Conclusion

This study established that farmers in Mwea irrigation scheme are aware of the effects of the quality of irrigation water on rice production and that 51.5% of farmers used irrigation effluents while 50.6% of those who did not use it were located far from the drainage canals, and said the waste/drain water is recycled until it gets finished before reaching them. So they only depended on irrigation water which is often rationed or difficult to reach through irrigation canals resulting in water conflicts during times of shortages and low production of paddy rice. We found that wastewater reuse increased water availability and reduced peak period water scarcity amongst farmers. The farmers in Karaba section (point 3) had highest paddy rice production at 5.62 ton/ha which they attributed to the availability and use of irrigation water mixed with effluents draining from other sections of the scheme mainly Mwea, Thiba and Wamumu sections.

The physico-chemical quality of Mwea irrigation scheme effluents were higher than the fresh water source of river Thiba waters in EC,TDS, TSS, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and $HCO_3^{-}SO_4^{2-}$. Generally, there was a progressive increase of all parameters from Thiba intake (point 1) < Kiruara drain (point 2) < Thiba main drain (Point 3) including pH, nitrates, nitrites, chlorides and SAR but these were not statistically different . This study also found out that waste waters (effluents) from the two drainage sites of Kiruara drain and Thiba main drain are suitable for reuse in paddy rice production. The physico-chemical properties of MIS effluents obtained from the two effluent drain sites fell within FAO irrigation water quality recommendations therefore reusing the effluents would increase the quantity of water available for growing rice.

It was also found that soils of site 3 which utilizes water mixed with waste water/effluents draining from other paddy fields recorded ideal soil nitrogen and phosphorous contents and higher electrical conductivity compared to other sites hence the waste water has a positive effect on the soil fertility and productivity. Therefore, accumulation of N and P in soils at site 3 implies that wastewater from point 3 can be used without or with reduced fertilization thus lowering the cost of producing rice.

Recommendations

The authors recommend that waste water should be reused on paddy rice production in Mwea to increase available water for irrigation, and to reduce inorganic N and P fertilizer use. Reused water should be monitored, season to season, to keep track of chemicals build-up in water. The scheme management and WUA should put up measures to harness any little waste water draining from Thiba main drain for use at the lower part of the scheme. Finally, continuous soil testing on farmers' fields irrigated with wastewater should be carried out to ascertain that there is no risk of accumulation of heavy metals.

CONFLICT OF INTERESTS

The authors have not declared any conflicts of interests.

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Towards a sustainable electronic waste management in Uganda: A stakeholder perspective

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The management of electrical and electronic waste (E-waste) requires a collaborative approach against unsustainable electronic waste management. This paper attempts to assess the role of E-waste actors in regard to E-waste management sustainability by evaluating their course of action. It proposes an E-waste management conceptual framework based on key stakeholders and validates it with 346 top government employees in strategic positions across 10 Ugandan cities. The study utilized Partial Least Square (PLS) technique, a statistical analysis method well-known under Structural Equation Modeling (SEM), for data analysis. The calculated and considered model explains 48.5% of the variance in E-waste management sustainability. The results demonstrate that E-waste handlers role ($\beta = 0.102$, $t = 2.004$, $p<0.05$), financial institutions role ($\beta = 0.268$, $t = 2.024$, $p < 0.05$), local government role ($\beta = 0.249$, $t = 3.612$, $p < 0.05$), role of media ($\beta = 0.316$, $t = 6.637$, $p < 0.05$), and producer role ($\beta = 0.144$, $t = 2.845$, $p<0.05$) have significant influence on E-waste management sustainability. However, consumer role in E-waste ($\beta = -0.051$, $t = 0.838$, $p > 0.01$) had an insignificant influence on E-waste management sustainability, although, its importance is discussed. The attention of policymakers and waste management planners is drawn towards strengthening the Public-Private Partnerships (PPP), fast-tracking the implementation of the Extended Producer Responsibility (EPR) model as an E-waste management model and initiation of E-waste Web-based applications are some of the policy recommendations in this paper. This will ensure sound E-waste management practices for better public health and environmental outcomes.

Key words: E-waste, electronic, electrical, sustainability, health, environment, management.

INTRODUCTION

Globally, electronic waste (E-waste) is among the fastest-rising waste streams. Masuduzzaman et al. (2018) state that the E-waste production rate in advanced nations rose from 1 to 2% annually compared to the total municipal solid waste ranging from 0.01 to 1% in developing countries. E-waste contains hazardous chemicals and materials which are harmful to people and the environment. These chemicals and materials according to Ilankoon et al. (2018) include phosphor coatings of CRTs, high-lead content in the CRT funnel glass, batteries, polychlorinated biphenyls in capacitors, mercury-containing parts, and plastics containing

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halogenated flame retardants (typically bromine). The composition of these materials and chemicals are 60.20% metal, 15.2% plastics, 11.87% screens (CRT and LCD), 4.97% metal plastics mixtures, 2.70% pollutants, 1.71% printed circuit boards, 1.97% cables and others account for only 1.38% (Gilal et al., 2019). As such, the growth of E-waste encourages serious pollution or toxic problems to the environment and human life. Forti et al. (2020) also acknowledge that the increase in levels of E-waste, coupled with low collection rates as well as non-environmentally sound waste stream disposal and treatment approaches are significant risks to human health and the environment. Yano and Sakai (2016) assert that waste deterrence is one of the primary drivers for stakeholder work collaboration to minimize costs and maximize benefits within the supply chain. Dieste et al. (2018) stress reduction in solid waste generation is a significant factor in the sustainability assessment of E-waste. This effort requires the management of E-waste in a collaborative approach against unsustainable E-waste management.

Increasingly, various stakeholders are currently involved in the E-waste management value chain to address E-waste challenges. They include E-waste generators such as households, businesses, consumers, and government, then government agencies tasked with regulation (Schluep et al., 2012; UNDP, 2016). Other stakeholders include a network of informal and formal actors performing activities from the source of E-waste to its recycling, and refurbishment, which may be disposed of in landfills.

The country's National Development Plan (NDP) for the period 2015/2016 to 2019/2020 was developed while incorporating the Strategic Development Goals (SDGs). Upon reviewing the SDGs, specifically SDG 7, the prior research recommends that sustainable development practices are expressed in economic, environmental, and social sustainability. Gray (2010) recognized that sustainable development emerges as a complex concept upon which economic, environmental, and social issues should be addressed at policy, personal and organizational levels.

Problem statement

Consistently, seeking solutions to the worldwide E-waste problem is becoming more and more urgent (Baldé et al., 2017). The volume of E-waste globally has doubled in the last five years from approximately 20 to 40 million tons annually (Xiao and Zhong, 2019). Similarly, Forti et al. (2020) show that in 2019, the global generation of E-waste was at 53.6 million metric tons (Mt), of which, only 17.4% was formally recognized as accurately collected and recycled. The report also indicated an increase of E-waste generation to 1.8 Mt by 2014 and with over-all 9.2 Mt E-waste generation increase. This is evidence that the rate of E-waste recycled is not at par with the worldwide view of E-waste growth. In Uganda, the E-waste generated in 2019 and placed in the market was 32 kilo tones (kt) whereas the E-waste that was documented and destined for collection and recycling in 2018 was at 0.18 kt (Forti et al., 2020). Several studies (Zhang et al., 2020; Lin et al., 2020; Awasthi et al., 2019; Maphosa and Maphosa, 2020) have considered the consequences of E-waste but fell short of providing solutions to address E-waste management in a developing country context despite the paucity of solid research. This study fills that gap with evidence from recent studies to mitigate the consequences of E-waste and also provide the potential of sustainable E-waste management based on the role of key actors. This study is aimed at informing policy on E-waste environmental and human consequences based on a stakeholder approach toward E-waste management best practices. In Uganda, there has been an increase in the number of Discarded Electronic and Electrical Equipment (DEEE) in the government, the private sector, and at the individual level (Gillwald and Mothobi, 2019; UNDP, 2016) for both domestic and commercial use. Also, the import volumes of EEE have been growing at an annual average of 22% (UCC, 2018). Consequently, the government enacted National Environment (Waste Management) Regulations (2020) to address some of the existing policy gaps in the management of E-waste in Uganda.

Theoretical frameworks

Both developed and developing countries have extensively adopted and applied the Extended Producer Responsibility (EPR) model. Baldé et al. (2017) noted the increasing development of various EPR schemes among African countries as an alternative to address some E-waste problems. Similarly, most USA states enacted E-waste legislation based on the EPR approach that is also practiced across all EU countries (Namias, 2013). The EPR approach is intended to promote social responsibility where manufacturers are encouraged to consider end-of-life management in the planning and implementation throughout the product design stage. One of the pre-conditions of the EPR approach is the availability of E-waste guidelines, legislations, and policy, stakeholder involvement, construction of recycling centers and plants, and monitoring of E-waste financial and material flow. Despite the challenges and pre-conditions (Kiddee et al., 2013); maintained EPR as ideal for all or most countries' adoption in order to minimize the E-waste generation since the responsibility of E-waste generation post-Basel Convention is shifted to the producers. Pongrácz et al. (2004) also considered the Waste Management Theory (WMT) a unified knowledge body regarding waste management, founded on the anticipation that management of waste prevents it from being harmful to both the environment and human health and moreover, promotes resource use optimization. Therefore, we regard the EPR model and, the WMT as suitable frameworks for the study. The WMT is a very important framework introduced to channel environmental and engineering sciences design with emphasis on waste reduction by applying extra efficient manufacturing technologies, prevention at source and stringent avoidance of waste creation, and re-use of product parts (Pongrácz et al., 2004). In addition, the WMT also stresses waste quality improvement and disassembling of complex products, external recycling as well as production waste internal recycling, which bode well with sustainability E-waste management (Pongrácz et al., 2004).

Hypothesis development

Electronic producers' role and sustainability of E-waste management

Tasaki et al. (2015) found product producers or manufacturers of a product as responsible stakeholders in an EPR scheme. With the E-waste legislations mostly based on the EPR principle, producers have the foremost responsibility to establish, support financially, and also either collectively or individually operate an E-waste take-back system, through the Producer Responsibility/ Compliance Organization (PROS) or (PCOs). EPR requires that manufacturers are financially responsible for the entire life cycle of the product including the take-back and final disposal of obsolete products (Atasu et al., 2013; Manomaivibool et al., 2007). EPR was intended to promote cleaner production and cleaner waste management schemes (Manomaivibool et al., 2007) toward environmental public concern for waste management and awareness. Theoretically, EPR principles swing the E-waste responsibility away from consumers, designated authorities, municipalities, and products manufacturers. The EPR principle reflects product life cycle re-thinking, deterrence of pollution, and payment by polluters (Oklahoma, 2016). EPR also involves the sustenance of public awareness programs about the impacts of E-waste originating from human health products, the environment, and other measures towards reducing probable human health and environmental implications. Summarily, Wang et al. (2013) indicate some of the responsibilities attributed to producers include designing products with longer lifecycles; funding the collection, recycling, and managing of E-waste; green design and production of EEE; setting up the take-back program to offer free recycling services to the consumer, and providing information on the components and hazardous substances present in their products. Therefore, we hypothesized that:

H1. The role of electronic waste producers positively relates to the sustainability of E-waste management

Local government role and sustainability of E-waste management

Government departments and institutions are involved in the formulation, planning, and implementation of regulations relating to the generation, treatment, and handling of disposal of E-waste. Honda et al. (2016) state that government has an obligation of providing the regulatory and policy frameworks that guide the activities regarding E-waste management. Governments in countries such as China and Singapore play a stronger role beyond framing the legislation coupled with its implementation and avoiding legislation in favor of voluntary mechanisms, respectively (Honda et al., 2016). Also, the government encourages research and development initiatives linked with E-waste to enable the advancement of safer ways of disposal of waste and conducting public awareness programs consistently in order to harness a positive attitude amongst the general public on E-waste management. The responsible government departments and agencies in Thailand discuss and compile periodical reports on the human life and environmental impact of E-waste for proper E-waste management in the country (Honda et al., 2016). Besides, the government of Thailand formulated an electronic equipment framework for recycling E-waste to support the regulation and monitoring of pollutants produced through E-waste recycling (Honda et al., 2016). Baragde and Jadhav (2020) reported that in Indian government departments, there are partnerships to promote E-waste management into a positive sustainability initiative and reporting. Meanwhile, the governance of E-waste in the Netherlands is based on the successful conditions that support the public-private arrangement as well as interactive governance (Börner and Hegger, 2018). Such an initiative results in sustainable management of E-waste in the long run-run. On the otherhand, Brazil formalized its informal E-waste management status that empowered small-scale businesses based on cooperative recycling enterprises, through a solid waste policy framework of 2010 that also had the EPR scheme incorporated or introduced. In Uganda, the responsibility of E-waste is vested in the District Local Governments under the Local Governments Act. Accordingly, we seek to hypothesize that:

H2. The local government role regarding E-waste positively relates to sustainability of E-waste management.

Media role and sustainability of E-waste management

The demand for outmoded or second hand electronic and electrical devices, and the ever unsustainable recycling and disposal of E-waste may possibly be due to the inadequate knowledge of its negative effects on the environment, human health, society, and the economy as a whole, thus requiring the role of the media. Akpoghiran and Okoro (2014) assert that the broadcast media, when well and appropriately used, can influence people's attitudes toward the management of E-waste. It is a well-known fact that heavy reliance and exposure to the media shape people's perceptions, beliefs, and attitudes towards solid waste management. Banjo et al. (2009) show that household management refusal is tied down to their socio-cultural beliefs, perceptions, and practices. The conscious and mindful communicative effort and approach that brings individuals to an understanding of the environmental problems around them; will inspire them to stop harmful actions to the environment and sensitize them to demonstrate greater commitment toward activities directed at the protection of the environment (Nwabueze, 2007). Thus, the role of the media in supporting the challenge against unsustainable E-waste management is of paramount significance. Saphores et al. (2006) found that in California, the youth are encouraged to promote recycling and disposal through education. The media as a strategic tool that can harness, rejuvenate, and raise environmental awareness regarding E-waste management in general. Therefore, we hypothesize that:

H3. The role of the media positively relates to the sustainability of E-waste management.

Consumers' role and sustainability of E-waste management

Consumers are corporate organizations or individuals that own electronic and electrical equipment (EEE) considered to have ended its usefulness and value. Consumers can be organizations, end-users, agencies, or individuals that use EEE and then discard them as waste after the equipment has reached its end of life by either dumping the E-waste illegally, storing it, throwing it in the garbage, or recycling it (ILO, 2014; Manomaivibool et al., 2007). The consumer's responsibilities would include buying eco-friendly products and avoiding burning and landfilling products but rather taking E-waste to the appropriate recycling facility. They participate in the value chain of E-waste through the purchase, use, and storage of EEE and are also responsible for returning the E-waste to the collection points. Dieste et al. (2018) acclaims the requirement for customers to consent to the return of used electronics/products to suppliers while also arranging the return of used products to importers/ manufacturers. UNDP (2016) advises governments on the responsibility of consumers to be obliged to separate E-waste from other waste to facilitate easy collection, treatment, and recycling. However, the consumers lack a designated collection point, limited consumer education, and awareness, and also lack incentives for E-waste collection services. Moreover, Nicolescu and Jula (2015) find that consumers are more inclined to recycle E-waste where a larger number of collection points are available, after compensation, and where recycling is attractive, visible, and obvious. In addition, the consumers whether businesses or households are viewed as the weakest link in the E-waste value chain, yet their behavior determines the route and fortune of E-waste (Otto et al., 2018). Although it is relatively difficult to quantify consumer behavior and attitudes objectively, their levels of environmental awareness can be gauged subjectively depending on the country (Otto et al., 2018). Hence, we hypothesize that:

H4. The role of consumers regarding E-waste positively relates to the sustainability of E-waste management.

E-waste handlers' role and sustainability of E-waste management

One of the key actors in the growth and management of E-waste is the E-waste management organizations or handlers. These comprise E-waste collectors, refurbishers, recyclers, and importers. E-waste collectors engage in its sorting to separate the components for refurbishment (reuse) from those for recycling, collection of E-waste from households, businesses, public and private offices, and transportation of E-waste for treatment facilities in a responsible manner (ILO, 2014). E-waste collectors are organizations or individuals that go door-to-door to buy or accumulate used EEE or are allowed to scavenge dumps for E-waste. In the E-waste value chain, collectors are active participants in the last stage of E-waste collection and delivery to refurbishers and recyclers (Woggsborg and Schroder, 2018). Collectors are of two categories: formal and informal. The informal collectors go door-to-door collecting E-wastes voluntarily though occasionally at a small fee while the formal collectors are those who work in a formal, tax-paying business entity deliver the collected E-waste to legitimate recyclers for environmentally-sound treatment (Woggsborg and Schroder, 2018). Recyclers are individuals or organizations who dismantle, isolate/or separate fractions and recover or recuperate material from E-waste following the lifespan or lifetime of the equipment. Those engaged in it are mostly in the informal sector comprising main individuals with only a few registered operators. Engel et al. (2016) suggest a recent rise in gold and other components of E-waste that may encourage recycling due to its profitability. Refurbishing and reuse of E-waste is the commonest option for E-waste management in developing countries (Paulson et al., 2010). The refurbishers are composed of many entities such as the repair units, service centers, etc. Refurbishers are known for extending the functional life of electronic equipment and subsequently feeding it into the secondary market or second-hand market for reuse. They participate in the final stage of the e-waste value chain by enabling the extension of life to the E-waste products through repair which gives consumers hope of re-use the electrical products instead of dumping them (Schluep et al., 2012). They also generate E-waste from the equipment that cannot be repaired, ensure that unusable material is transferred to collection centers or licensed recyclers, and also provide incentives to the consumer to donate used devices (Edmonds et al., 2019). Importers of E-waste transport huge quantities of used and obsolete EEE that exist in all sizes, ranges, and models mostly non-reusable and unsellable materials. This E-waste is imported both legally and illegally. The illegal shipment across borders is often unfortunately designed as a legal trade transaction, in disregard for safety, health, and environmental standards. We thus hypothesize that:

H5. The role of E-waste handlers positively relates to the sustainability of E-waste management.

Financial institutions' role and sustainability of E-waste management

Governments often lack both the technical and finances for regulation and implementation. Thus, Non-Government Organizations (NGOs) including financial institutions, both international and local, play a key supportive role in driving awareness of issues regarding E-waste. This is due to the fact that solutions through legislation and individual take-back program are inadequate to address the E-waste problem. A financial institution such as the bank of agricultural and rural development in India provided prerequisite initial capital investments in an effort to promote sustainable rural development appropriate to transform rudimentary E-waste management (ILO, 2014). This is driven by several challenges at the levels of government, producers, and other stakeholders. Likewise, in a bid to streamline, transform, and promote sustainable rural development, to rudimentary E-waste management, the Indian government initiated the agency corporate social responsibility (CSR) funds as an intervention. In this effort, businesses were mandated to reserve 2% of net profits on average in support of CRS activities (Jain, 2015). Similarly, Paulson et al. (2010) found that several Bolivian corporations working in the sector have CSR-run programs encompassing inter-institutional efforts with key actors around the life cycle of electronic products. This facilitates the cause to reduce the undesirable effects of those products on job creation, human health, and the environment, and increases the secondary resources recovery through the management of E-waste in a sustainable manner. As part of that effort, E-waste community development centers were established to provide the low-income workforce with economic opportunities as they transit from rudimentary to formal procedures to improve on the efficiency and safeguards of E-waste management, and perhaps in partnership with the cities/municipals (Sushmita, 2013). In addition to agricultural development, in Serbia, cooperatives for E-waste management were established and financially supported to provide employment opportunities where E-waste pickers, considered as key actors in the country's E-waste management sector (ILO, 2014), possibly will strengthen their businesses, by tapping competitive volumes of raw materials/ constituents, and improving on their bargaining power, income and working conditions. Integrating cooperatives into the recycling programs by far is socially necessary, economically feasible, and environmentally sound. Also, in Serbia, the government launched landmark initiatives to reach higher recyclable targets by certifying and compensating E-waste collectors through an Environmental Fund (ILO, 2014). The business enterprises in Bolivia have a reliance of strength in raising awareness of E-waste consequences and encouraging people to deposit or gather their E-waste in designated company collection points (ILO, 2014). This is in compliance with the health protection guidelines and the environmental laws coupled with decent occupational conditions principles. The general population tends to keep their old electronic equipment at home in the hope of fixing them for reuse or to sell as second-hand devices. NGOs are also making efforts intended to address the problems as a result of E-waste by providing E-waste management facilities/services to homes and businesses, as well as raising awareness regarding its dangers, accordingly with initiatives focusing on shaping a probable sector based on a green economy. Thus, we seek to hypothesize that:

H6. The role of financial institutions regarding E-waste positively relates to the sustainability of E-waste management.

Proposed model

Figure 1 is the proposed model for E-waste Management Sustainability– Stakeholder Approach

RESEARCH DESIGN AND METHODOLOGY

A cross-sectional study was used since data was collected at a single period in time (Zikmund et al., 2013) where the role of E-waste actors is profiled specifically in the Ugandan context. A

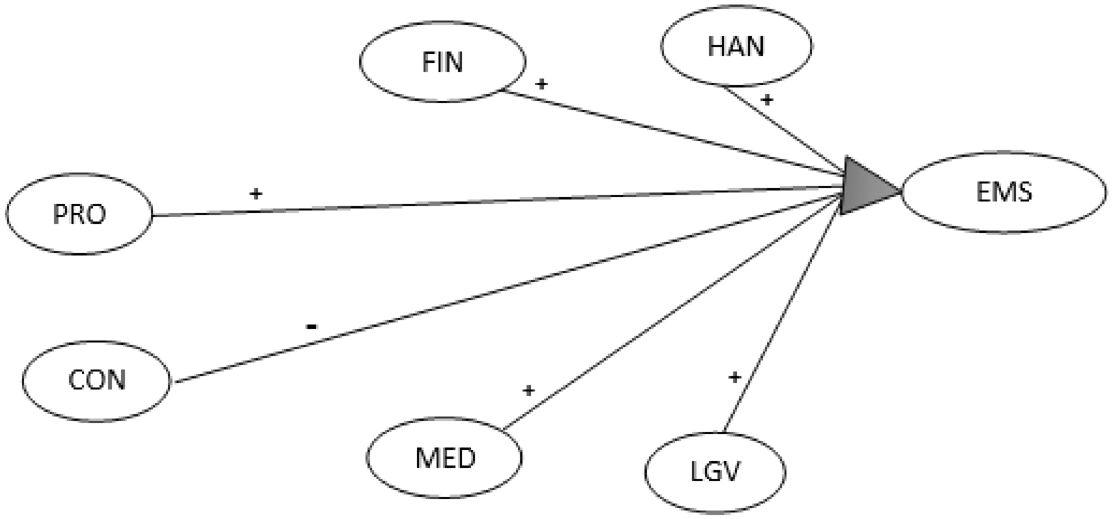

Figure 1. Proposed model for E-waste management sustainability-stakeholder approach. CON: Comment; HAN: E-waste handers; EMS: E-waste Management Sustainability; FIN: financial institutions; LGV: local government; MED: media; PRO: producer.
Source: Authors

positivist approach was adopted being the most appropriate for the study (Lee, 1991). A survey of senior managers knowledgeable on E-waste management at an organizational level in the Ugandan 10 cities was conducted to support the empirical model and hypothesis testing. The survey questionnaire was two-fold based; to increase the participants or respondents' numbers and observance of the duration (time) to the optimal level, due to the COVID-19 pandemic. As such, convenience sampling, an extensively used sampling method in information systems (IS) studies (Eze et al., 2011) was employed given the circumstances. Besides, the sample drawn is close to hand. Hence, only those top managers at the highest hierarchy and deputies and immediate supervisors were sampled to meet criteria of this study. Respondents were employees with position of responsibility or knowledge about waste management in the organization. Personally administered survey questionnaires were administered in 10 Ugandan cities. The study objective was expounded properly to the potential subjects, where an informed consensus and an understanding was sought before issuing the survey questionnaire.

Descriptive statistics and constructs

The demographic information in the survey questionnaire include descriptive characteristics such as gender, education, age, and working experience, and also comprises information about the different constructs as contained in the theoretical model. The latent constructs were measured on a scale of 7-point Likert-type with a range from 1-*strongly-disagree* to 7-*strongly-agree.* A pilot study was conducted and a resultant final survey questionnaire was accordingly developed.

The study distributed 410 survey questionnaires, and 346 (84.4% as response rate) were returned. Unusable (incomplete) questionnaires were eliminated from use in the analysis. All the theoretical model latent construct measures were derived from the earlier literature and revised in the context of E-waste sustainability. The latent construct items including the role of E-waste actors such as producers, local governments, the media, consumers, E-waste handlers, and financial institutions and E-waste management sustainability (Pongrácz et al., 2004) were adapted from past literature, for instance, producers (Wang et al., 2013; Atasu et al., 2013); E-waste handlers (Bouvier and Wagner, 2011; Woggsborg and Schroder, 2018); role of government (Westgate, 2017; Honda et al., 2016); media role (Akpoghiran and Okoro, 2014); consumer role (Nicolescu and Jula, 2015); and financial institutions (ILO, 2014). A technique, that is, the partial least squares (PLS) method, based on structural equation modeling (SEM) was the statistical analysis technique applied for testing hypothesized constructs and model validation.

Demographic characteristics

Table 1 exhibits the demographic characteristic where 186 (53.8%) participants are male while 160 (46.2%) are female, in the survey results. Most respondents 102 (29.5%) while 100 (28.9%) are aged between 31 - 40years and 41 - 50 years, respectively. Further, most research participants 186 (53.8%) had a 5 years and below working experience in a city setting.

DATA ANALYSIS AND RESULTS

Assessment of measurement model

For the measurement model assessment, the discriminant validity internal reliability, and convergent validity were evaluated shown in Table 2. The outer loadings ought to be above 0.7 whereas the outer weights above 0.1 thresholds, respectively for appropriate measurement model assessment (Henseler et al., 2015). Cronbach's alpha values and composite reliability values were utilized

Table 1. Respondents' demographic information.

Variable	Description	Frequency	Percent
Gender	Male	186	53.8
	Female	160	46.2
Age (years)	20 - 30	60	17.3
	31 - 40	102	29.5
	41 - 50	100	28.9
	51 - 60	54	15.6
	>60	30	8.7
Level of education	Diploma	46	13.3
	Undergraduate Degree	144	41.6
	Master and Postgraduate Diploma	150	43.4
	Ph.D.	6	1.7
City setting working experience (years)	<5	186	53.76
	5 - 10	80	23.12
	11 - 20	51	14.74
	>21	29	8.38

Source: Authors

to determine the internal reliability, with threshold level of 0.7 regarded as satisfactory internal consistency indicator or loading (Henseler et al., 2015). In addition, the convergent validity was assessed through the average variance extracted (AVE) with threshold value of 0.50 where the item loadings greater than 0.50 is considered acceptable (Henseler et al., 2015). In this case, the Cronbach's alpha values and composite reliability values computed are greater as recommended (ranged from 0.773 to 0.924) and composite reliability (0.867 to 0.949), respectively, an account of a strong internal reliability. Also, AVE (ranged from 0.684 to 0.786) is above the threshold levels, thus satisfying the conditions for convergent validity. Furthermore, outer loadings ranging between 0.723 and 0.956 as shown in Figure 2 and also Table 2, are thus adequate for analysis usage.

In addition, the AVE square root and cross-loading matrix was further utilized for measuring the discriminant validity. Henseler et al. (2015) assert that AVE square root of a construct has to be of greater value than its correlation with some other constructs to confirm discriminant validity. This is approved in Table 3.

Assessment of structural model

To assess the structural model of the E-waste management sustainability, we look at the R-squared (R^2) value of the dependent variable and the path coefficient produced from the PLS algorithm calculation. Thus, the R^2 values for E-waste management sustainability is 0.485 as indicated in Figure 3, indicating that 48.5% of the variation of E-waste management sustainability in the model is explained by the exogenous-latent variables used in the model.

To pinpoint the associations amongst the constructs, a structural model was developed and employing the bootstrapping method ($p < 0.05$) for testing the hypotheses. We tested the relationship between the enlightened variables by way of path coefficient (β) and t-Statistics ($t > 1.960$). Secondly, we explored the moderating influence of financial institutions in the relationship between the role of E-waste consumers and E-waste management sustainability. Table 4 indicates the calculated path-coefficients with significance in addition to its corresponding t-Statistics. Further, the calculated and considered model explains 48.5% of the variance in E-waste management sustainability. The results demonstrate that E-waste handlers role (β =0.102, t=2.004, $p < 0.05$); financial institutions role (β =0.268, t=2.024, $p < 0.05$); local government role (β =0.249, t=3.612, $p < 0.05$); role of media (β =0.316, t=6.637, $p < 0.05$); and producer role (β =0.144, t=2.845, $p < 0.05$) have significant influence on E-waste management sustainability. However, consumer role in E-waste (β = -0.051, t=0.838, $p > 0.01$) had an insignificant influence on E-waste management sustainability hence, contradicting hypothesis H4. All stated hypotheses (Table 4) had statistical significance with high reliability $t \geq 1.96$, thus significance at $p \leq 0.05$ (Henseler et al., 2015).

Table 2. Measurement items, loadings, CA, CR and AVE.

Variable/ Reference	Measurement Items	Loadings	CA	CR	AVE
Producer role	PRO1: Our electronic producers can ensure electronic components are easily separable when ready for recycling or disposal.	0.807	0.87	0.91	0.71
	PRO2: Our electronic producers can fund the collection of E-waste in the organization.	0.873			
	PRO3: Our electronic producers can set up or operate the take back program that in turn offer us free recycling services.	0.841			
	PRO4: Our electronic producers can provide information related to the components with hazardous substances present in their electronic products.	0.849			
Government role	LGV1: Our local government is aware of its responsibility to start a collection center for receiving E-waste generated within its authority/control.	0.902	0.92	0.94	0.075
	LGV2: Our local government can charge a fee for the receipt of electrical or electronic waste from industries, commercial enterprises or institutions.	0.881			
	LGV3: Our local government can collaborate with other stakeholders to provide required incentives that encourage the public to deliver E-waste to a collection center to ensure proper E-waste management.	0.921			
	LGV4: Our local government can liaise with the producers of electronic products to ensure safe storage without causing harm during disposal of the collected E-waste.	0.723			
	LGV5: Our local government can keep periodic records of quantities and types of E-waste with waste handlers and other government collection facilities.	0.883			
Consumer role	CON1: We separate our E-waste from the other waste to facilitate easy collection and disposal.	0.921	0.92	0.95	0.82
	CON2: We store our E-waste to avoid landfilling, burning and illegal dumping as much as possible.	0.941			
	CON3: We buy eco-friendly electronic products.	0.858			
	CON4: We take our E-waste to appropriate recycling and disposal facilities.	0.890			
Financial Institution role	FIN1: Some financial institutions in the country support organizations that drive awareness campaigns to address E-waste management issues.	0.959	0.92	0.95	0.86
	FIN2: Our financial institutions in the country should be encouraged to support E-waste initiatives to reach higher disposal targets.	0.948			
	FIN3: Our financial institutions in the country should be supported by government to start-up Environmental Funds to support E-waste collectors.	0.879			
E-waste Handlers	HAN1: Our waste handler upon receiving E-waste ensures they are secure.	0.834	0.89	0.92	0.69
	HAN2: Our waste handler upon receiving solid waste ensures they are segregated from the different components or materials.	0.924			
	HAN3: Our waste handler upon receiving solid waste ensures the hazardous components are segregated from other wastes.	0.904			
	HAN4: Our waste handler upon receiving solid waste ensures the recycling or disposal target, if any, met.	0.766			
	HAN5: Our waste handler upon receiving solid waste ensures the waste doesn’t cause harm to the environment and human health.	0.733			

Table 2. Contd.

Media role	MED1: The media has the role to influence people's attitudes or perceptions and assertiveness in the management of E-waste.	0.789	0.77	0.87	0.68
	MED2: The communicative effort through the media allows an individual to understand the harmful environmental problems caused by E-waste through public sensitization.	0.861			
	MED3: The communicative effort on effects of E-waste through the media demonstrates greater commitment towards activities directed at protection of human health through awareness campaigns.	0.829			
E-waste Mgt. sustainability	EMS1: Leads to improved resource utilization goals.	0.820	0.85	0.89	0.69
	EMS2: Leads to improved environment.	0.780			
	EMS3: Leads to improved health and safety.	0.856			
	EMS4: Leads to improvement in waste quality.	0.860			

Source: Authors

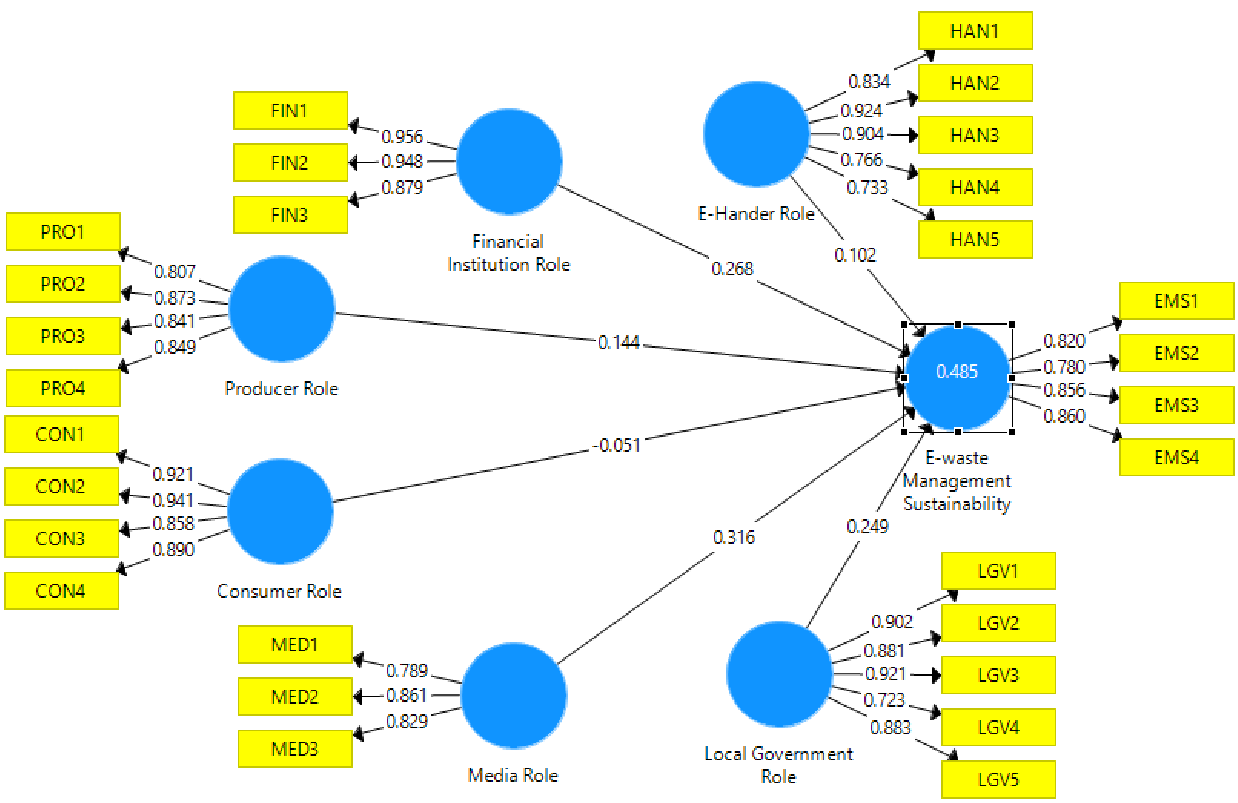

Figure 2. Model fit test (Measurement model).
Source: Authors

Moderating effect of financial institutions

After another analysis, where financial institutions moderated the relationship between consumer role and E-waste management sustainability, the results were found to be significant (β =-0.104, t=2.961, $p < 0.05$) as shown in Table 5 and Figure 4 below.

DISCUSSION

The study aimed to profile the role of key E-waste actors in E-waste management in ensuring best practices are adhered to, thus influence decision-making. The relationship between the role of the media and E-waste management sustainability is significant at the 0.05 level,

Table 3. Discriminant validity.

Variable/model constructs	(CON)	(HAN)	(EMS)	(FIN)	(LGV)	(MED)	(PRO)
CON	0.903						
HAN	0.637	0.836					
EMS	0.450	0.361	0.830				
FIN	0.399	0.199	0.406	0.929			
LGV	0.578	0.503	0.530	0.112	0.865		
MED	0.431	0.157	0.531	0.275	0.454	0.827	
PRO	0.345	0.441	0.438	0.167	0.593	0.235	0.843

CON=Producers; HAN=E-waste Handers; EMS=E-waste Management Sustainability; FIN=Financial Institutions; LGV=Local Government.
Source: Authors

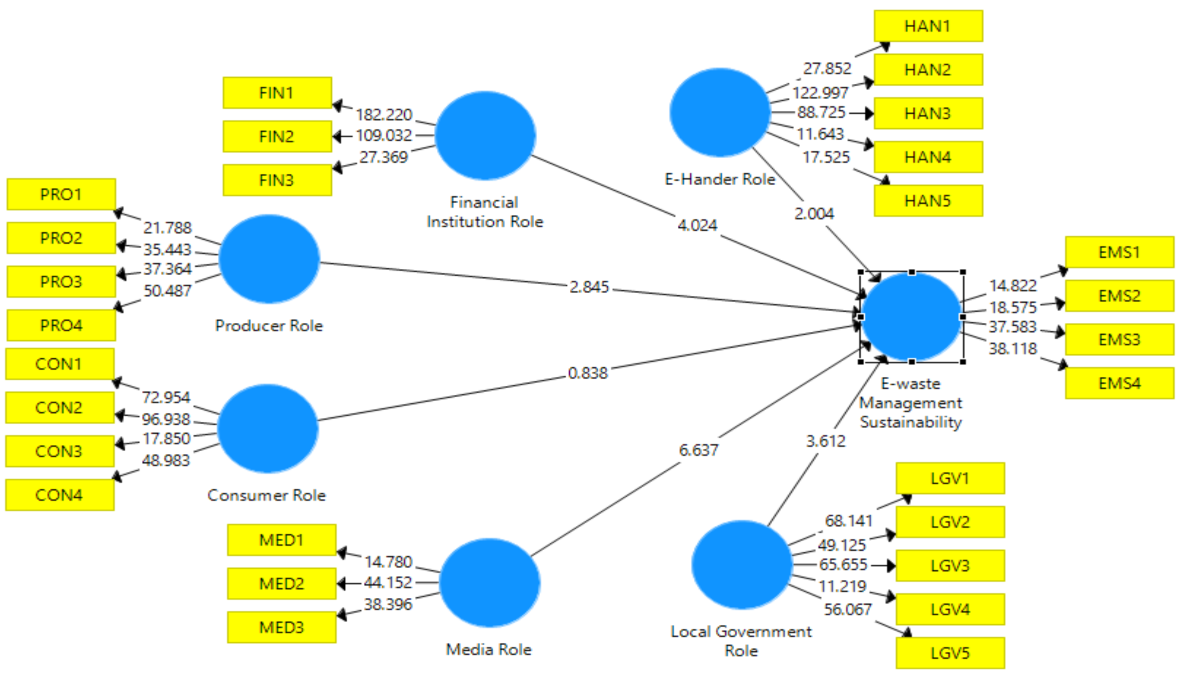

Figure 3. Model fit test (Structural model).
Source: Authors

Table 4. Path coefficient, R-squared values and T-statistics for E-waste Management Sustainability.

Exogenous variable	Endogenous variable	Path coefficient (β)	T-Statistics	P (two-tailed)	Decision
CON	EMS	-0.051	0.838	0.403	Not supported
HAN	EMS	0.102	2.004	0.046	Supported
FIN	EMS	0.268	4.024	0.000	Supported
LGV	EMS	0.249	3.612	0.000	Supported
MED	EMS	0.316	6.637	0.000	Supported
PRO	EMS	0.144	2.845	0.005	Supported

Significant at $P < 0.05$.
Source: Authors

Table 5. Path coefficient, R-Squared values and T-Statistics after moderation.

Exogenous variable	Endogenous variable	Path Coefficient (β)	T-Statistics	P (two-tailed)	Decision
CON	EMS	-0.130	1.981	0.048	Supported
HAN	EMS	0.121	2.755	0.006	Supported
FIN–CON	EMS	-0.104	2.961	0.003	Supported
FIN	EMS	0.207	2.353	0.019	Supported
LGV	EMS	0.225	3.451	0.001	Supported
MED	EMS	0.319	6.426	0.000	Supported
PRO	EMS	0.144	2.533	0.012	Supported

Significant at P < 0.05.
Source: Authors

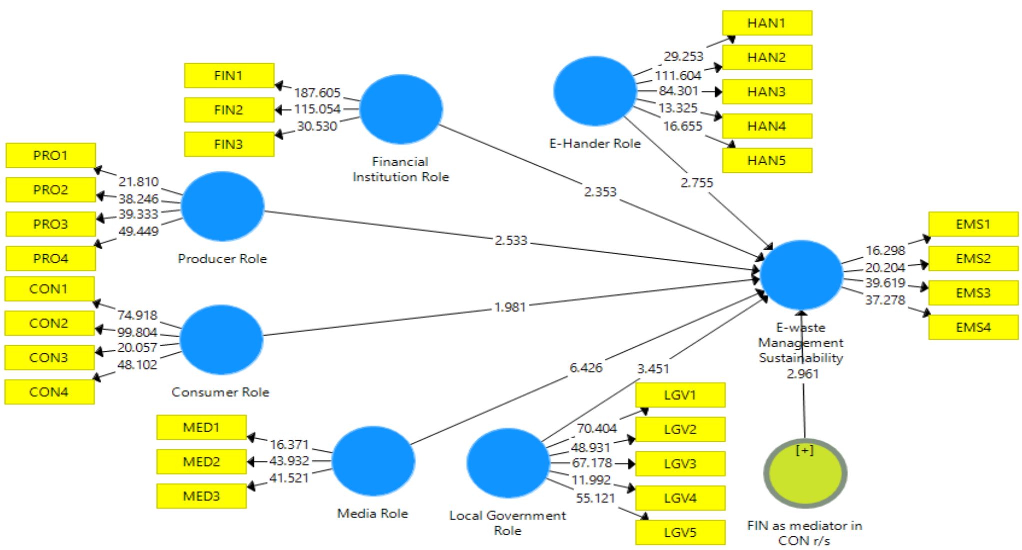

Figure 4. Model fit test (Structural model after moderation).
Source: Authors

β = 0.316, p=0.000 and t=6.637. This demonstrates that media role, with the impact coefficient of 0.316, plays the greatest role in E-waste management sustainability. Hence, it is apprehensible that the role of the media is the most influential factor in management of E-waste in a sustainable manner. Consistent with Akpoghiran and Okoro (2014), we found that the media has the role to influence people's attitudes or perceptions and assertiveness in the management of E-waste. Also as highlighted by Saphores et al. (2006), the study pinpoints that through the media communicative effort, an individual can understand the harmful environmental problems caused by E-waste through educative campaigns and public sensitization. Thus, in addition, the communicative effort on effects of E-waste through the media demonstrates greater commitment towards activities directed at protection of human health through awareness campaigns.

In addition, the relationship between the role of financial institutions and E-waste management sustainability is significant at 0.05 level, β = 0.268, p=0.000 and t=2.024. The results show the financial institutions role as the second most influencer of sustainable E-waste management. This is consistent with ILO (2014) and Paulson et al. (2010) who believed that financial institutions in the country play a big part to support organizations that drive awareness campaigns to address E-waste management issues such as reducing the undesirable effects of those products on job creation, human health and the environment. The study is also in agreement that financial institutions should be encouraged to support E-waste initiatives to reach higher disposal targets through Environmental Fund to facilitate E-waste collectors. In order to deliver professionally managed E-waste and avoidance of risks during processing in the US, Kahhat et al. (2008) emphasized combination of legislation and incentives aimed at assisting informal E-waste merchants to deliver them to the central collection sites. Kahhat et al. (2008) also pushed for provision of incentives intended to encourage investors towards acquiring infrastructure for recycling E-waste to generate employment, and minimize accumulation of E-waste to support all opportunities in the electronic recycling industry.

Also, the relationship between the E-waste handlers role and E-waste management sustainability was found to be significant at 0.05 level, β = 0.102, p=0.046 and t=2.004. It is held that unused E-waste cannot either be donated to other users through some incentives or transferred to collection centers or licensed recyclers (Edmonds et al., 2019; Woggsborg and Schroder, 2018). Handling E-wastes improperly may result in hazardous circumstances (Jayaraman et al., 2019) and can cause harm to the environment and human health due to its toxic components (Islam, 2016). Indeed, in line with those findings, the current study echoes the need to safety and security, segregation of the different components or materials, and to ensure the hazardous components are segregated from other wastes, upon receipt of E-waste from handlers. The findings also suggest that the recycling or disposal target, if any, are met and that the waste does not cause any harm to the environment and human health.

Besides, the study found that the relationship between the role of local government in E-waste management and E-waste management sustainability is significant at 0.05 level, β = 0.249, p=0.000 and t=3.612. In consistent with Honda et al. (2016) about government's obligation of providing the regulatory and policy frameworks that guide the activities regarding E-waste management, the study encourages government to own collection centers for the receipt of E-waste generated within its authority/control and also charge some E-waste collection fees. The study also finds that government collaboration with other stakeholders through providing incentives that encourage the public to deliver E-waste to a collection center for safety storage ensures proper E-waste management. Besides, in line with Baragde and Jadhav (2020), the study encourages local governments to keep periodic records of quantities and types of E-waste with waste handlers and other government collection facilities.

Furthermore, the relationship between the producers role and E-waste management sustainability is significant at the 0.05 level, β = 0.144, p=0.005 and t=2.845. In congruent with Tasaki et al. (2015), Atasu et al. (2013) and Wang et al. (2013), the study finds that producers have a responsibility of funding the collection of E-waste and ensuring that electronic components are easily separable when ready for recycling or disposal. Producers can also set up or operate the take back program that in turn offer users free recycling services while providing information related to the components with hazardous substances existent in electronic products. Atasu et al. (2013) advice manufacturers to work together to manage E-waste through its life cycle by a collective producer responsibility (CPR) rather than independently by way of independent to achieve the E-waste mandated targets. The EPR principles incorporate the costs of E-waste management into the retail pricing of the EEE products. Mutsau et al. (2015) urged the government of Zimbabwe to support environmental education on the impact of E-waste to improve community awareness, establishment of a well-coordinated framework for monitoring E-waste activities, and lastly, finding sustainable E-waste management stakeholder engagement methodologies.

On the other hand, the relationship between consumer role and E-waste management sustainability is not significant at the 0.05 level, β = -0.051, p > 0.01 and t=0.838. Hence, the role of consumers will yield valuable E-waste effects but may not impact on E-waste management sustainability. Manomaivibool et al. (2007) and ILO (2014) assert that consumers have no problem discarding EEE when they reach their end-of-life by either dumping illegally, storing it, throwing in the garbage, or even recycling. This is inconsistent with the study findings indicating that consumers do not separate E-waste from the other waste to ensure their easy facilitation of collection and disposal. Besides, for consumers, there is no emphasis on their part for buying eco-friendly electronic products and E-waste storage for appropriate disposal.

Interestingly, when the role of financial institutions is factored in, as a moderator in the relationship between consumer role and E-waste management sustainability, the result is significant (β =-0.104, t=2.961, p < 0.05) as shown in Table 5. This only emphasizes the importance of financial institutions in their pursuit in supporting awareness campaign programs since it is one of the drivers of effective E-waste management.

Conclusion

In the study, the results demonstrate that all the identified E-waste stakeholders or actors, with the exception of the role of consumers, play a significant part in the sustainability of E-waste management with the media and financial institutions roles as the most impactful E-waste stakeholders towards sustainability management of E-waste. However, and interestingly, the role of consumers in E-waste management turns out as an important factor only when it is a moderator in the relationship between financial institutions role and E-waste management sustainability.

Policy recommendations

Public health experts and environmental stakeholders can lobby government for inclusion of E-waste management as part of public health issues in media policies (weekly/monthly media briefings) and periodic coverage. This can play an important role in eradicating the adverse human health and environmental impact of E-waste to the society. Training of journalists could be covered in such important initiatives. The government through its appropriate agencies and other stakeholders especially those in advocacy may support activities related to E-waste management such as E-waste inventory and accounting, and organizing short, long, and mid-term training through awareness programs to their employees. Similarly, government and stakeholders had better support organizations that engage in environmental protection projects and researches so that a proper framework for E-waste management in the country is developed. This effort might involve introducing organizational structures at all government departments with responsibilities to ensure proper management of E-waste.

Besides, the necessity to strengthen the Public Private Partnerships (PPP) is required to appropriately tackle the E-waste management sustainability issues. The establishment of partnerships with E-waste vendors support the indispensable role to collect, transport, recycles and finally dispose of E-waste. Interesting collaborative partnerships can emerge and assist the establishment of an E-waste management system that operates on the basis of formal practices, and decent working conditions to mitigate the negative impacts of the growing volume of E-waste.

Government can encourage financial institutions through a PPP to foster actions towards sustainable E-waste management. Government can also initiate, certify and support the E-waste collectors through an environmental fund, to support higher recycling targets. One other government initiative to deal with financial challenges, might involve construction of a public-private recycling centre, operated by government-managed cooperative associations and a designated E-waste stakeholder, until the recycling business becomes self-sustainable. This can be supported through the EPR model when implemented in the country with relevant laws in place. Government is advised to fast track the implementation of the Extended Producer Responsibility (EPR) model as an E-waste management model and other suitable models. The country's policies, guidelines and relevant laws have had the EPR policy conceptualized to facilitate appropriate sustainability of E-waste management. Under the EPR approach, sustainable product development, green manufacturing, creating initiatives through green manual awareness and the approach of eco-friendly recycling, can collectively provide a suitable E-waste management solution. Government can as well initiate E-waste Web-based applications to support all stakeholders in the E-waste cycle chain.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests

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Full Length Research Paper

Diet study of *Nannothrissa stewarti* (Poll & Roberts, 1976) Clupeidae in Lake Mai-Ndombe, Democratic Republic of Congo

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In order to determine the diet of *Nannothrissa stewarti* in Lake Mai Ndombe, 667 specimens with total length between 9.0 and 49.84 mm were studied. These fish were sampled by active fishing during the 24 h cycle between September 2018 and October 2021. The vacuity (%) and intestinal coefficients were 38.71% and 0.69 ± 0.03, respectively, classifying *N. stewarti* as invertivorous. The calculated feeding indices showed that zooplankton are the essential prey (%F_{fi} = 88.8; %IP = 90.0; and %IRI = 90.8) while phytoplankton are the incidential prey. Larvae feed on cyclopoid, copepods, and *nauplius* while adults consume cladoceras, copepods, rotifers and phytoplankton. This fish begins its feeding activity early in the morning (5:00 am), his stomach fills up around 1:00 pm and empties completely around 1:00 am. Thus, *N. stewarti* in various steps growing ages both males and females are zooplanktons feeders.

Key words: Lake Mai-Ndombe, *Nannothrissa stewarti*, food indices, diurnal.

INTRODUCTION

Food is the only source of energy acquisition that the animal uses to accomplish its different functions (Lévêque et al., 1994; Lévêque and Paugy, 2006). The study of the diet of fish in the natural environment is an essential approach to the knowledge of their biology and ecology. Not only on the presence, abundance and availability of food potential in the natural environment, but also, it allows us to understand the relationships between fish and prey, as well as interspecific relationships (Rosecchi and Nouaze, 1987; Froese and Pauly, 1999; Kouamélan, 1999; Kouamé et al., 2006, Pwema et al., 2015; Thumithol et al., 2016). Stomach content analysis is one of the possibilities to know the feeding habits of fish (Kouamélan, 1999; Thumithol et al., 2016).

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Work on fish diets should also precede the implementation of conservation or management policies for ichthyological populations (Ouattara et al., 2014).

In Lake Mai-Ndombe, *Nannothrissa stewarti* (Clupeidae) constitutes 90% of all fish species landed in the shore seine fishery. It contributes to the animal protein supply of the population in this area (Micha et al., 2020). The concern would be on how its exploitation is done without respect for ecological principles and the maintenance of essential processes of conservation of critical habitats and other systems on which they depend, which could lead to the rarefaction or even extinction of species (Inogwabini et al., 2009; De Keyzer et al., 2020).

This work aims to determine the qualitative and quantitative diet of *N. stewarti* in Lake Mai-Ndombe based on food indices.

MATERIALS AND METHODS

Study environment

Lake Mai-Ndombe (Figure 1) is located at 1° 32' - 2° 43' South latitude and 18° 03' - 18° 36' East longitude. It is 146 km long, 18 km wide and covers 2300 km^2 (Ebengo, 2022).

Climatic data

According to Bultot and Griffits (1971), the Lake Mai-Ndombe region has an Af-type climate according to the Köppen classification. Analysis of 41 years of data revealed that the monthly and annual diurnal air temperature varies, respectively from 25.96 to 27.25°C, the average of 26.4 ± 0.49°C and from 25.69 to 27.3°C, the average of 26.5 ± 0.44°C. Consequently, the monthly and annual rainfall amounts are, respectively 69.91 to 153.61 mm while the mean is 115.42 ± 28.16 mm and from 1000.9 to 1740.7 mm, the mean is 1376.22 ± 184.34 mm.

Umbrothermal diagram for the Lake Mai-Ndombe region is as shown in Figure 2. The umbrothermal curve of Lake Mai-Ndombe indicates that the Lake Mai-Ndombe region does not experience the marked dry season, but a decrease in rainfall is observed in the months of June and July.

The diet of *N. stewarti* was determined from 667 fish caught from September 2018 to October 2021 at Lake Mai-Ndombe.

Sample collection

Fish were sampled using shore seines in February and September on a 24-h cycle from 2018 to 2021 (8:00 am, 12:00 pm, 4:00 pm, 8:00 pm, 24:00 am and 4:00 am) using two types of monofilament nets with 0.1 and 2.5 cm knots, 500 m length and 2 m drop.

Analysis of the samples

Method of studying the diet

Captured fish were measured to the nearest millimeter total length (TL) and standard length (SL) using a 200 mm long digital caliper (accuracy 0.1 mm). The fish were then weighed to the nearest gram using the "Digital pocket scale" model 200, precision 0.001 g, and then preserved in jars containing 4% formalin before the study of the stomach contents. In the laboratory, the fish were dissected and the digestive tubes preserved in pillboxes containing 4% formalin for adults. The stomach contents thus obtained were placed on a 25 × 75 mm slide, then diluted with 2 to 5 drops equivalent to 0.08 to 0.2 ml of distilled water to visualize the prey. As for the larvae they were crushed and immediately observed under microscopy because of their very tiny size. Observations of the digestive contents were made under a MOTIC (swift line) light microscope at 100x magnification. Prey were identified using the keys established by Dussart (1967a, 1967b, 1982), Bourrelly (1972), Harding and Smith (1974), and Descy et al. (2016).

For this purpose, we used the method of estimating the volume ingested and the relative proportions of each type of prey contained in the stomach or point (volumetric) method. In this method, each food item contained in the stomach is assigned a number of points based on its volume. A total of 16 points are assigned to the highest volume of the diet item and all other items are 16, 8, 4, 2, 1, and 0 points based on volume relative to the component with the highest volume (Manko, 2016).

Expression of results

Determination of fish size classes

Size classes of sampled specimens were determined from Sturge's rule (Scherrer, 1984):

$$NC = 1+ (3.3 \log10 N)$$

where NC is the number of classes; N: total number of individuals for the considered sample. The class interval is determined by the following relationship:

$$CI = \text{Maximum size - minimum size / Total number of classes}$$

Intestinal coefficient (IC)

The intestinal coefficient gives an indication of the diet of a fish. It was obtained according to the following relationship:

$$CI = Li / Ls$$

where Li is the length of the intestine (mm) and Ls is standard length of the fish (mm).

Coefficient of vacuity (CV)

The vacuity coefficient is the number of empty stomachs in relation to the total number of stomachs examined. Its formula is:

$$CV = (\text{Number of empty stomachs / Number of stomachs analyzed}) \times 100$$

Numerical index (N)

The numerical index is the percentage of the number of individuals of a prey category for the whole sample compared to the total number of prey. Its formula is:

$$N = (\text{Total number of individuals of the prey (i) / Total number of prey inventoried}) \times 100$$

Occurrence index (F_{fi})

The occurrence determines the number of stomachs in which a prey or a category of prey is present. It is expressed as a

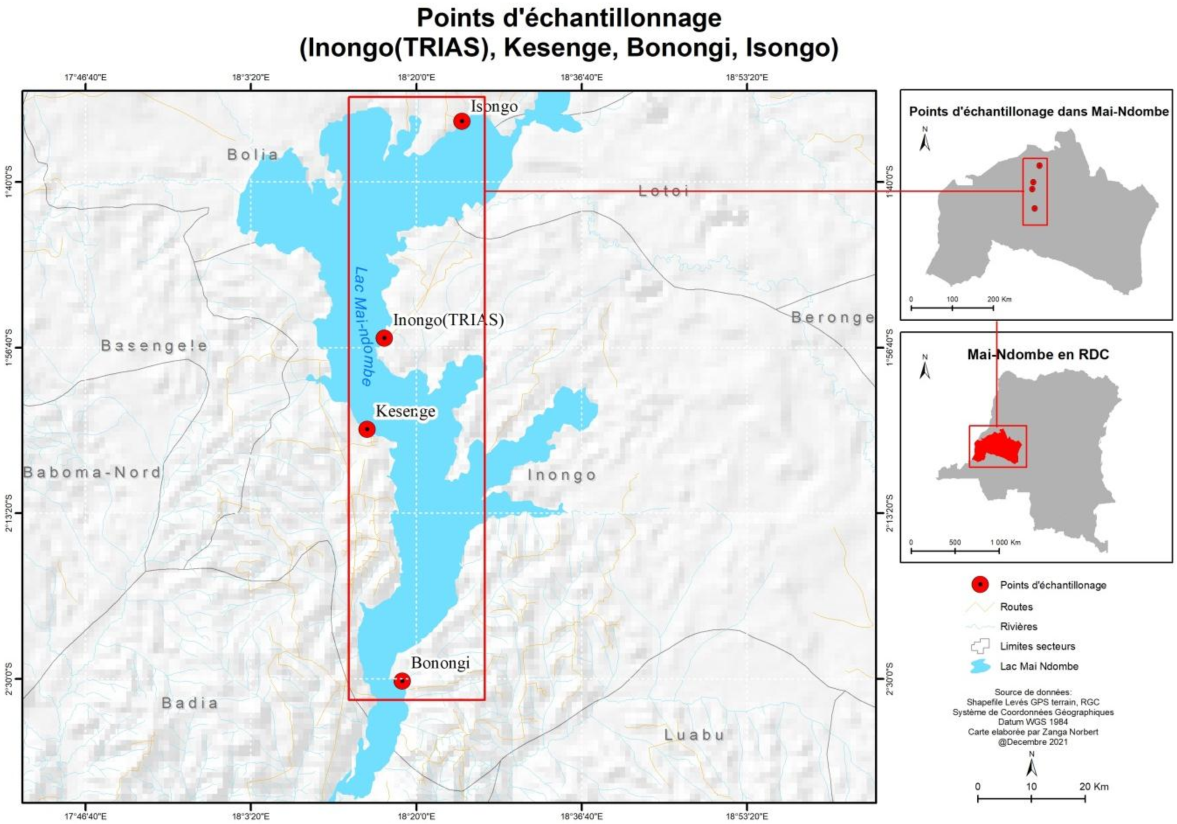

Figure 1. Map of sampling sites at Lake Mai-Ndombe (red dots).
Source: Ebengo (2022).

percentage of the total number of stomachs. Empty stomachs havebeen set aside because it can significantly change the results. It is calculated by the following relationship (Rosecchi and Nouaze, 1987; Manko, 2016; Zacharia, 2016; Mahesh et al., 2019):

$$\%Ffi = (N_{fi} / N_f) \times 100$$

where $\%F_{fi}$ is the frequency of occurrence of a given item i, N_{fi} is the number of stomachs in which an item i is found, and Nf is the total number of stomachs examined.

Rate of feeding activity

The filling state (replenishment) has been defined as follows: stage 0, empty stomach; stage 1, 25% full stomach; stage 2, 50% full stomach; stage 3, 75% full stomach; and stage 4, 100% full stomach (Garrido et al., 2008).

Volumetric index (Point method)

The percentages of volumes in each subsample were calculated as follows (Bertran and Calvez, 1988; Manko, 2016; Mahesh et al., 2019):

$$\alpha = (\text{Number of points assigned to the } \alpha \text{ component / Total points allocated to the subsample}) \times 100$$

where α is the volume percentage of the prey component α.

Preponderance Index

The preponderance index developed by Natarajan and Jhingran (1961) gives a unique value for each attribute. It is based on the frequency of occurrence and volume of different foods. It is calculated using the following formula (Lauzanne, 1976; Baker et al., 2014; Mahesh et al., 2019):

$$IPi = (Vi\ Ffi / \Sigma Vi\ Ffi) \times 100$$

where Vi is the percentage of volume of food item i, F_{fi} is the percentage of occurrence of a given food i.

By comparing the values obtained, the foods are ranked in order of dominance. This index varies from 0 to 100. Thus, prey can be classified into 4 categories according to the value of their food indices: IA< 10: prey of secondary importance; 10< IA< 25: important prey; 25< IA< 50 essential prey; IA> 50: largely dominant prey.

Relative importance index (IRI)

The IRI is used to describe fish diets and determine the relative importance of common food categories (Diaha et al., 2018). The IRI is calculated as follows:

$$IRI = (\%\ Ni + \%\ Vi)\ \%\ Ffi; \text{ and } \%\ IRIi = (IRIi / \Sigma IRIi) \times 100$$

where % Ni is the percentage of the specific food category by number, % Vi is the percentage by volume, % F_{fi} is the frequency of

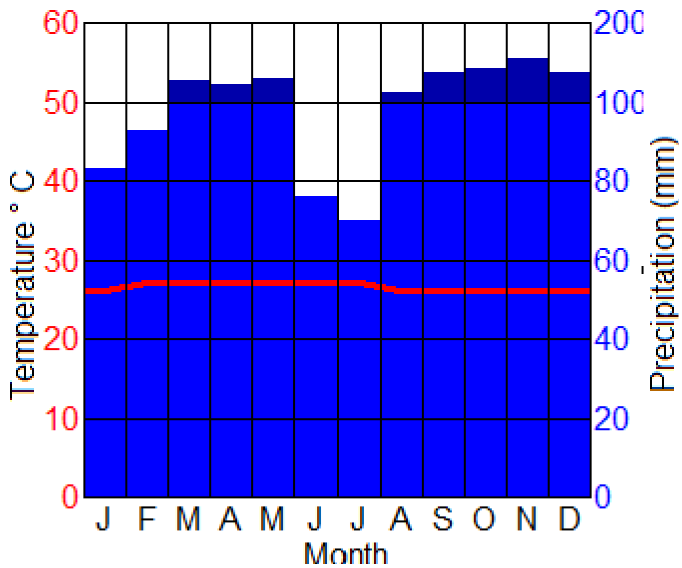

Figure 2. Umbrothermal diagram of the Lake Mai-Ndombe region. Source: Analysis of 41 years data from meteorological station Centre de Recherche en Ecologie et Foresterie (CREF) Mabali.

occurrence, % IRIi is the percentage of relative importance index, IRIi is the relative importance index for each prey category, ΣIRIi is the sum of relative importance index for each prey category.

Statistical analyses

Multi-variate and correlation statistical analyses were performed using Past 4.03 and Statistica 7.1 software, respectively (Scherrer, 1984). Trophic similarities were assessed by subjecting these data to a cluster analysis in order to eventually group size classes with similar diets.

Spearman's rank correlation coefficient (rs) analysis was used to indicate the degree of relationship between male and female diets. If rs = 1, the diets are strictly identical. If rs = -1, the diets are strictly inverse. Finally, if rs = 0, the diets are independent (Scherrer, 1984).

RESULTS

Size frequencies

The size frequencies of *N. stewarti* specimens were determined from Sturge's rule as shown in Figure 4.

Ten size classes of *N. stewarti* were determined with 3.95 mm interval based on Sturge's rule. Size classes 8, 9 and 10 were merged into one class because of the low number of specimens in each. Thus, 8 size classes were established (Figure 3).

Class interval frequency

Diet of N. stewarti

The aspects of diet addressed in this work were the vacuity coefficient (CV), feeding activity rate, intestinal coefficient (IC), numerical index (% IN), occurrence (or frequency) index (%Ffi), volumetric index (% IV), preponderance index (% IP), and relative importance index (% IRI).

Coefficient of vacuity (CV)

For all individuals examined, the calculated vacuity coefficient was 38.71%.

Feeding activity rhythm

Figure 4 visualizes the evolution of the degree of replenishment of *N. stewarti* in Lake Mai-Ndombe. *N. stewarti* had begun its trophic activity early in the morning at 5:00 am where the stomach begins to fill to peak at 1:00 pm and begins to empty to cancel at 1:00 am.

Intestinal coefficient (IC)

The calculated intestinal coefficient for 667 specimens of *N. stewarti* ranged from 0.5 to 1.0 (mean 0.69 ± 0.03). The relationship between total fish length and gut length is as shown in Figure 5.

Gut length ranged from 0.7 to 24.22 mm with an average of 15 ± 3.78 mm. The relationship between total length and fish gut length demonstrated the simultaneous increase between the two variables (r = 0.98; SD = 0.73; N = 667).

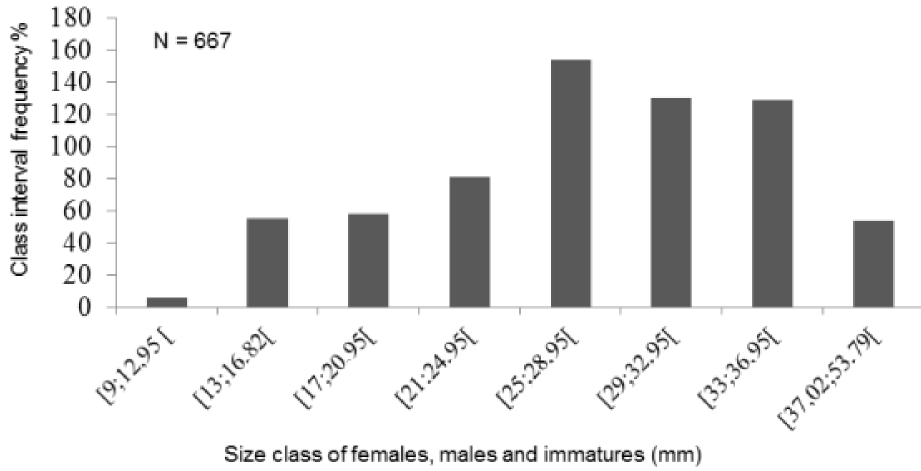

Figure 3. Histogram of size class frequencies of *N. stewarti* determined in Lake Mai-Ndombe.
Source: Analysis of *N. stewarti* length from 667 specimens

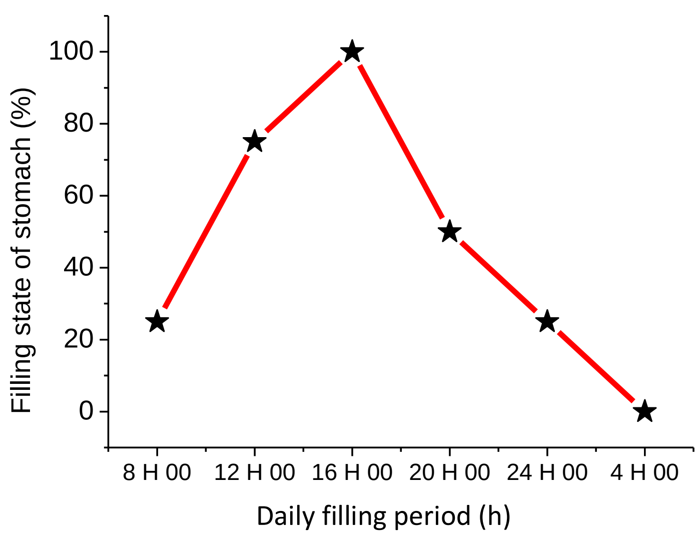

Figure 4. Nycthemeral variation in replication of *N. stewarti*.
Source: Analysis from 667 stomachs diet of *N. stewarti*

General diet composition of *N. stewarti*

Table 1 presents the general diet of *N. stewarti* in Lake Mai-Ndombe. Qualitative analysis of 667 stomachs containing prey items identified 19 food types, grouped into 4 categories: zooplankton, phytoplankton, insects, and worms. Zooplankton were the most consumed prey (%IRI=90.8). Phytoplankton (%IRI = 9.18), insects (%IRI = 0.003) and worms (%IRI = 0.000) are less observed or sometimes absent in the food bowl of this fish.

The preponderance index thus calculated had allowed us to classify the food according to the following order: zooplankton (PI > 50) is the dominant prey, phytoplankton 10< PI< 25: important prey, the remains (insect and worms) (PI < 10) are secondary prey.

Diet by sex of individuals

Table 2 presents the diet of *N. stewarti* according to sex except immatures. Table 2 indicates that female and male *N. stewarti* had consumed the same prey categories, so there is no significant difference in diet with respect to sex (t = 0.42566, p value = 0.68157 at the 0.05 significance level). Spearman's rank correlation coefficient (rs), calculated on the basis of the index

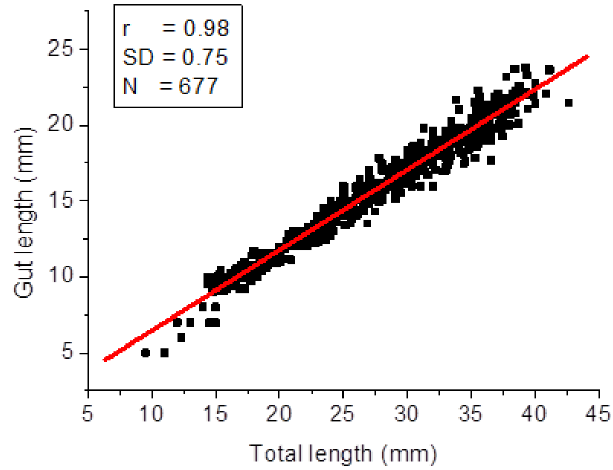

Figure 5. Relationship between total length and intestine length (mm). r = Coefficient of correlation, SD= standard deviation, N = number.
Source: Analysis from 667 guts and length of *N. stewarti*

percentages of food consumed by females and males, shows a significant correlation (N = 552; rs = 0.83; p = 0.01).

Diet as a function of individual size

The size classes determined by Sturge's rule are presented in Table 3. The diet of individuals in each size class is presented in (Figures 6a, b, c, d, e, f, g, h). Individuals in all size classes feed on plankton and composed of Cladocerans, Copepods, Rotifers, Daphnia, Diatoms, and Euglenophyceae.

Individuals in the size class [9; 12.95], consisting mainly of larvae, feed on copepods (*Nauplius*), with the relative importance index (%RI = 91.66).

Individuals belonging to the size class [13; 16.82[, consisting of juveniles, feed at the expense of zooplankton (Copepods (% IRI = 81.92) and Cladoceras (% IRI = 16.76)).

Fish belonging to the size class [17; 20.95], especially sub-adults feed on Cladocerans including (% IRI = 66.56), Copepods (% IRI = 22.35), Rotifers (% IRI = 6.89) and Diatoms (% IRI = 4.15)

Fish in the size classes [21; 24.95] and [37.042; 53.79] were considered as adults feed mainly on Cladocerans (% IRI 51.76 and 83.03%), Rotifers (% IRI 11.47 and 21.93%), Diatoms (% IRI 2.71 and 16.64) and Copepods (% IRI 1.73 and 11.62).

Dietary similarity between individuals belonging to the different size classes

The dendrogram (Figure 7) visualizes the grouping of size classes of *N. stewarti* based on prey consumed.

The food similarity dendrogram (correlation coefficient 0.97) based on the food items consumed by individuals of each size class of *N. stewarti* established from the Relative Importance Index (RI) highlighted two main trophic groups. The first group (1) is distant from the second by 73. The first one, made up of individuals belonging to classes I and II. These individuals feed at the expense of copepods (IRI = 81.92 - 91.66%) and cladocerans (8.33 - 16.76%) composed of *Nauplius* and *Diaphonosoma* species, respectively. Other prey such as Daphinia, Eglenophyceae and Rotifera are consumed in very small quantities (%IRI = 0.004 and 0.89) (Figure 7). The second group consisted of classes III, IV, V, VI, VII and VIII consuming cladocerans (IRI = 51.76 - 83.03), copepods (IRI = 1.73 - 22.35), rotifers (IRI = 6.89 - 21.93), and Diatoms (%IRI = 6.89 - 21.93). The rest of the preys are very weakly represented. This second group is subdivided into two subgroups; the first subgroup includes classes IV and V which had consumed more Cladocerans (%IRI = 57.26 - 70.27), Copepods (%IRI = 3.46 - 4.14), Rotifers (%IRI = 13.78 - 21.93) and Diatoms (%IRI = 12.47 - 16.64). The second subgroup includes classes III, VI, VII and VIII that feed on Cladocerans (%IRI = 66.56 and 83.0), Copepods (%IRI = 1.73 and 22.35), Diatoms (%IRI = 2.71 to 12.47) and Rotifers (%IRI = 6.89 to 13.78). Subgroup 2 broadens its food spectrum on prey on Euglenophyceae, insects and worms.

DISCUSSION

The average vacuity coefficient determined in the *N. stewarti* fish specimens studied was 38.71%. These

Table 1. General diet composition of *N. stewarti*

Group/taxons	IN (%)	F_{fi} (%)	IV	IP	IRI
Zooplanktons	75.2	88.8	69.4	90.0	90.8
COPEPODA					
Tropodiaptomus spp. *Thermocyclops* spp. *Nauplius*	7.0	16.9	13.9	7.9	5.9
CLADOCERIANS					
Bosminopsis spp. *Bosmina* spp. *Diaphanosoma* spp. *Alona* spp.	40.1	50.5	42.2	72.5	70.0
ROTIFERA					
Keratela cochlearis *Keratela serulata* *Keratela tecta* *Trichocera marina*	28.0	21.2	13.1	9.5	14.7
DAPHNIDAE	0.0015	0.07	0.08	0.0002	0.0001
Daphnia spp.					
Phytoplanktons	24.7	10.7	29.7	9.9	9.1
DIATOMS					
Phacus spp. *Pinnularia* spp. *Plectonema* spp.	24.7	10.1	28.8	9.9	9.1
EUGLENOPHYCAE					
Oscillatoria spp.	0.02	0.5	0.9	0.018	0.009
Insects	0.007	0.3	0.5	0.007	0.003
Chaoborus larvea	0.007	0.3	0.6	0.007	0.003
Worm	0.003	0.15	0.16	0.0009	0.0004
Nemathelminthe	0.003	0.15	0.16	0.0009	0.0004
Σ	100	100	100	100	100

%IN: Numerical index; % F_{fi}: occurrence index; %IV: volumetric index; %IP: index of preponderance; %IRI: index of relative importance.
Source: Analyse from 667 stomachs diet of *N. stewarti*

results are similar to those obtained by Ouattara et al. (2014) (CV = 42.22% in flood season) and (CV = 15.03% in flood periods) in *Engraulis encrasicolus* (Linneaus, 1758) from the Ivory Coast. The trophic activity of *N. stewarti* starts early at 5 am where the stomach starts to fill up to reach the peak around 1 pm and starts to empty to cancel at 1 am. Similar results were obtained by Kaningini (2003) in Lake Kivu who observed empty stomachs in *Limnothrissa miodon* (Boulanger, 1906) larvae fished between 22:00 and 06:00 h.

In many vertebrates, a positive relationship has been demonstrated between the length of the gut and the nature of the food they consume (Grassé and Devillers, 1965; Kramer and Bryant, 1965; Paugy, 1994). Thus, the intestine appears to be longer in herbivores, shorter in carnivores and of intermediate length in omnivores. Paugy (1994) had classified fish as follows: ichthyophagous (CI) less than 0.85, invertivorous, CI between 0.32 and 2.18, omnivorous, CI between 0.8 and 3.01 and phytophagous, CI between 4.71 and 6.78.

Table 2. General diet composition of male (n=193) and female (n=359) of *N. stewarti*.

Group/taxons	IN (%)	IN (%)	F_{fi} (%)	F_{fi} (%)	IV	IV	IP	IP	IRI	IRI
Sex	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**
Zooplanktons	**72.7**	**95.3**	**87.0**	**98.3**	**67.3**	**94.0**	**87.7**	**99.7**	**88.5**	**99.7**
Cladoceras	39.1	49.5	51.7	55.0	43.0	51.1	73.3	73.4	69.8	73.0
Copepodas	3.7	27.6	13.3	25.0	10.9	32.7	4.8	21.4	3.2	19.9
Rotiferas	29.8	18.1	21.8	18.3	13.3	10.1	9.5	4.8	15.4	6.8
Daphnidae	0.002	-	0.083	-						
Phytoplanktons	**27.2**	**4.6**	**12.5**	**1.6**	**32.0**	**5.9**	**12.2**	**0.2**	**11.4**	**0.2**
Cyanophyceae	0.02	-	0.6	-	0.8	-	0.01	-	0.009	-
Diatomés	27.2	4.6	11.8	1.6	31.2	5.9	12.2	0.2	11.4	0.2
Euglénophyceae (*Oscillatoria spp.*)					0.2					
Insects	**0.008**		**0.4**		**0.3**		**0.004**		**0.002**	
Chaoborus larvae	0.008	-	0.4	-	0.3	-	0.004	-	0.002	-
Σ	100	100	100	100	100	100	100	100	100	100

%IN: Numerical index; % Ffi: occurrence index; %IV: volumetric index; %IP: index of preponderance; %IRI: index of relative importance.
Source: Analysis from 667 stomachs diet of *N. stewarti*

Table 3. Size classes of *N. stewarti* determined from the Sturge rule.

Class	Limit of size (mm)	n	Group
I	[9 ; 12.95]	6	1
II	[13 ; 16.82]	55	
III	[17 ; 20.95]	58	2b
IV	[21 ; 24.95]	81	2a
V	[25 ; 28.95]	154	
VI	[29 ; 32.95]	130	2b
VII	[33 ; 36.95]	129	
VIII	[37.02 ; 53.79]	54	

n = Number of individuals in each size class.
Source: Scherrer (1984).

During the present investigation, the intestinal coefficient of *N. stewarti* specimens ranged from 0.5 to 1.0 with an average of 0.69 ± 0.03, which classifies it as an invertivore species.

In Lake Mai-Ndombe, *N. sterwarti* feeds on plankton (zooplankton and phytoplankton), insects, and worms. Of the 19 food items inventoried, we find copepods (Calanoides, *Tropodiaptomus* species, Cyclopoide, *Thermocyclops* species, *Nauplis*), Cladocerans (*Bosminopsis*, *Bosmina*, *Diaphanosoma*, *Alona*, and *Daphnia* species), Rotifera (*Keratela cochlearis, Keratela serulata, Keratela tecta, Trichocera marina*), Phytoplankton (Diatoms, *Phacus*, *Pinnularia*, *Plectonema* species), (*Oscillatoria* species, Euglenophyceae), insects (Grasshopper, *Chaoborus larva*), and worms (Nemathelminthe). Indeed, Paulsen (1993), Mandima (1999), Isumbisho et al. (2004), Isumbisho et al. (2006), and Mandima (2017) reported that in the stomach contents of clupeidae a microplankton slurry based on copepods and insects is observed. Variations in air temperature, rainfall and the presence of mineral salts in the water are factors that cause the proliferation of plankton that are prey to this fish in Lake Mai-Ndombe. The present results are in line with those of Otobo (1977)

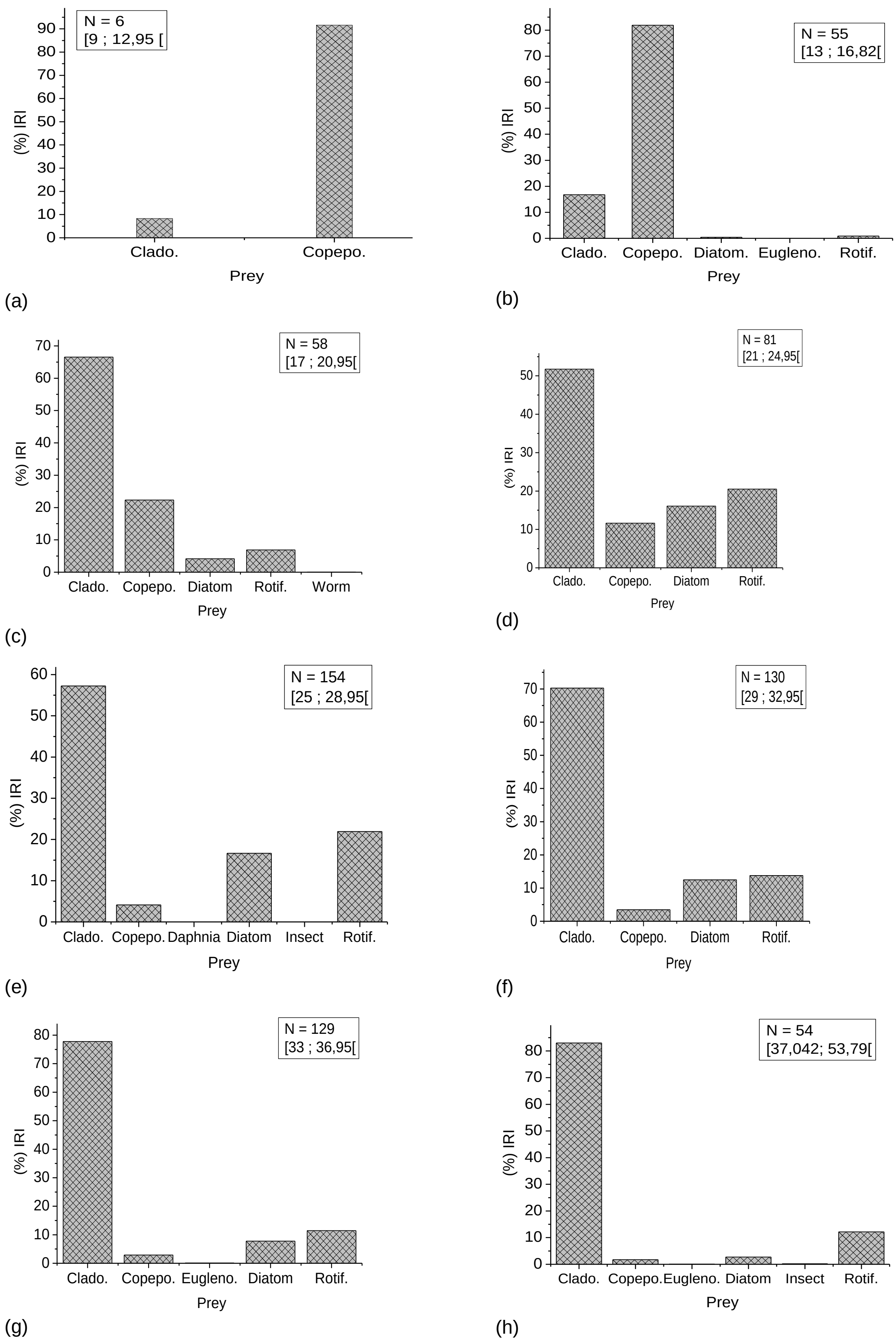

Figure 6. Diet by size class. Clado = Cladocera, Copepo = Copepoda, Daphnia = Daphnia, Diatom = Diatom, Eugleno. = Euglenophyceae, Insect = Insect, Rotif = Rotifera, Worm = Worm.
Source: Analysis from 667 stomachs diet of *N. stewarti*

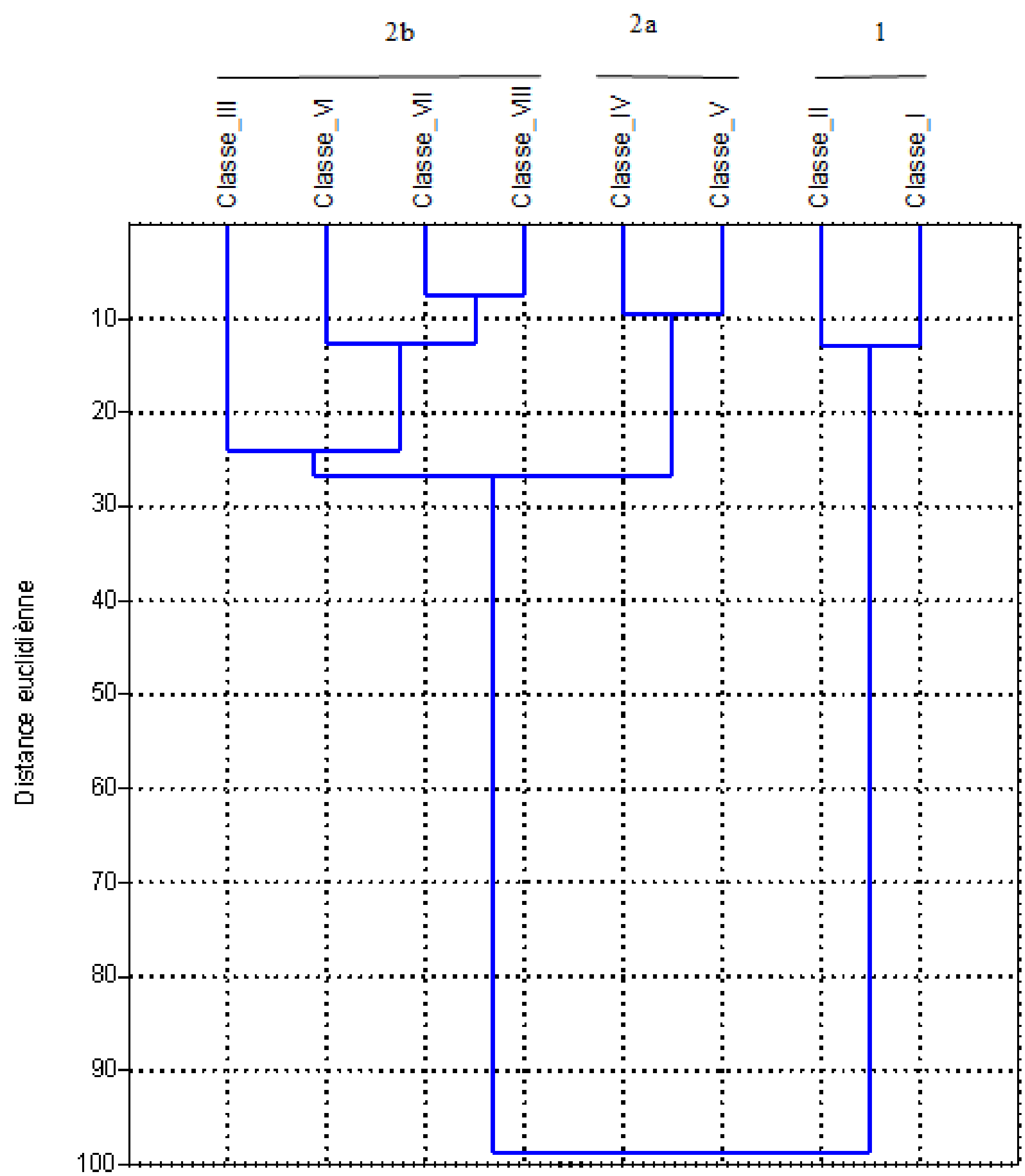

Figure 7. Dietary similarity dendrogram of *N. stewarti* by size classes.
Source: Analysis from 667 stomachs diet of *N. stewarti*

and Kolding et al. (2019) who report that the clupeidae *Stolothrissa tanganicae* feeds mainly on Copepods zooplankton, Cladocerans and some phytoplankton for reproductive activities (Mulimbwa et al., 2022).

No qualitative diet differences were observed between male and female *N. stewarti* specimens studied in Lake Mai-Ndombe. Spearman's rank correlation coefficient (rs) indicates that there is similarity in diet between the two sexes (rs = 0.83; p = 0.01).

Cladocerans and copepods were the preferred foods of individuals regardless of size. Larvae and juveniles feed on Copepods (Nauplius) and some Cladocerans while sub-adults add Rotifers, Diatoms and worms to their food bowl (Števove and Kováč, 2016).

According to Matthes (1968), Otobo (1977) and Muvengwi et al. (2012), a number of genera of Clupeidae have adapted to African fresh waters and some species can really be considered pelagic. This is the case for example of *Stolothrissa tanganicae* and *Limnothrissa miodon* from Lake Tanganyika. *S. tanganicae* is a planktivorous species feeding on tiny pelagic shrimps (*Limnocaridina*), copepods, cladocerans and some phytoplankton. *L. miodon* also consumes shrimps and zooplankton but also young stages of *Stolothrissa*. Some genera like *Pellonula, Cynothrissa,* and *Sierrathrissa* are fluviatile forms whose diet is mainly formed by insects (aquatic and terrestrial). However, they seem to adapt very well in dam lakes such as Lake Volta or Lake Kainji where they find an abundant food supply based on insects (Ephemera, Chaoborids) and zooplankton. The present results did not reveal the presence of shrimps.

Conclusion

The diet of the fish *N. stewarti* from Lake Mai-Ndombe was determined from the food indices calculated on 667 specimens fished according to a 24 h cycle.

This fish starts its feeding activity at dawn from 5 am where its stomach starts to fill and reaches the maximum around 1 pm to empty at 1 am. Its diet consists of plankton composed of Cladocerans, Copepods, Rotifers, Daphnia, Diatoms and Euglenophyceae.

No difference in qualitative diet was observed according to sex. Larvae consume especially copepods (*Nauplius*) while adults are both zooplanktonophagous (cladophagous, copepophagous, rotiphagous) and phytophagous. Insects are an accessory food.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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