OPEN ACCESS

African Journal of Environmental Science and Technology

October 2020
ISSN 1996-0786
DOI: 10.5897/AJEST
www.academicjournals.org

ACADEMIC JOURNALS
expand your knowledge

About AJEST

African Journal of Environmental Science and Technology (AJEST) provides rapid publication (monthly) of articles in all areas of the subject such as Biocidal activity of selected plant powders, evaluation of biomass gasifier, green energy, Food technology etc. The Journal welcomes the submission of manuscripts that meet the general criteria of significance and scientific excellence. Papers will be published shortly after acceptance. All articles are peer-reviewed

Indexing

The African Journal of Environmental Science and Technology is indexed in:
CAB Abstracts, CABI's Global Health Database, Chemical Abstracts (CAS Source Index), China National Knowledge Infrastructure (CNKI), Dimensions Database, Google Scholar, Matrix of Information for The Analysis of Journals (MIAR), Microsoft Academic

AJEST has an h5-index of 14 on Google Scholar Metrics

Open Access Policy

Open Access is a publication model that enables the dissemination of research articles to the global community without restriction through the internet. All articles published under open access can be accessed by anyone with internet connection.

The African Journal of Environmental Science and Technology is an Open Access journal. Abstracts and full texts of all articles published in this journal are freely accessible to everyone immediately after publication without any form of restriction.

Article License

All articles published by African Journal of Environmental Science and Technology are licensed under the Creative Commons Attribution 4.0 International License. This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited. Citation should include the article DOI. The article license is displayed on the abstract page the following statement:

This article is published under the terms of the Creative Commons Attribution License 4.0
Please refer to https://creativecommons.org/licenses/by/4.0/legalcode for details about Creative Commons Attribution License 4.0

Memberships and Standards

Academic Journals strongly supports the Open Access initiative. Abstracts and full texts of all articles published by Academic Journals are freely accessible to everyone immediately after publication.

All articles published by Academic Journals are licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0). This permits anyone to copy, redistribute, remix, transmit and adapt the work provided the original work and source is appropriately cited.

Crossref is an association of scholarly publishers that developed Digital Object Identification (DOI) system for the unique identification published materials. Academic Journals is a member of Crossref and uses the DOI system. All articles published by Academic Journals are issued DOI.

Similarity Check powered by iThenticate is an initiative started by CrossRef to help its members actively engage in efforts to prevent scholarly and professional plagiarism. Academic Journals is a member of Similarity Check.

CrossRef Cited-by Linking (formerly Forward Linking) is a service that allows you to discover how your publications are being cited and to incorporate that information into your online publication platform. Academic Journals is a member of CrossRef Cited-by.

Academic Journals is a member of the International Digital Publishing Forum (IDPF). The IDPF is the global trade and standards organization dedicated to the development and promotion of electronic publishing and content consumption.

Contact

Editorial Office: ajest@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/AJEST

Submit manuscript online http://ms.academicjournals.org

Academic Journals
73023 Victoria Island, Lagos, Nigeria
ICEA Building, 17th Floor,
Kenyatta Avenue, Nairobi, Kenya.

Table of Content

Vol. 14(10), pp. 290-300, October 2020
DOI: 10.5897/AJEST2020.2871
Article Number: 49296DD64805
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Bamboo diversity and carbon stocks of dominant species in different agro-ecological zones in Cameroon

Barnabas Neba Nfornkah[1*], Kaam Rene[2], Zapfack Louis[3], Tchamba Martin[1] and Chimi Djomo Cedric[4]

[1]Laboratory of Environmental Geomatics, Department of Forestry, Faculty of Agronomy and Agricultural Sciences, University of Dschang, Dschang, Cameroon, P. O. Box 222-Dschang, Cameroon.
[2]International Bamboo and Rattan Organisation, Behind Bastos Factory, P. O. BOX 17056, Yaounde, Cameroon.
[3]Plant Systematic and Ecology Laboratory, Department of Plant Biology, Faculty of Sciences, University of Yaounde I, Yaounde, Cameroon.
[4]Institute of Agricultural Research for Development (IRAD), Bertoua, P. O. Box. 203, Cameroon.

Received 4 June, 2020; Accepted 18 August, 2020

Bamboo is of ecological and socio-economic importance in the world. However, knowledge on its potential in climate change mitigation remains superficial in Cameroon. The present study identified bamboo diversity and estimated carbon stocks of the dominant species in Cameroon. Ground truth method and local informants were used for a bamboo species survey in five Agro-ecological zones (AEZs). Twenty-two circular plots of 100 m² each were utilized for biomass and density data collection in AEZ 2, AEZ 3 and AEZ 4. Destructive method was used to collect 5% of culms per plot sampled for bamboo biomass estimation. Culm density and carbon stocks for each bamboo species were extrapolated to hectares. A total of 8 bamboo species were recorded in the inventory. Three dominant bamboo species were identified (*Bambusa vulgaris, Oxytenanthera abyssinica* and *Phyllostachys aurea*) in different AEZs. For the three dominant bamboo species, biomass of culm was greater (76-84%), than those of branches (13-19%) and leaves (4-9%). Culm density varied significantly across the different bamboo species, that is, 2296, 4374 and 38017 culm/ha respectively for *B. vulgaris*, *O. abyssinica* and *P. aurea*. Carbon stocks varied from 13.13 tC ha^{-1} (*O. abyssinica*); 29.62 tC ha^{-1} (*B. vulgaris*) and 67.78 tC ha^{-1} (*P. aurea*), with significant variations (P< 0.05) across the different bamboo species. The fast growth rate of bamboo underpins its potential for climate change mitigation and could influence decisions and strategy for the fight against climate change in Cameroon.

Key words: Agro-ecological zone, climate change mitigation, culm density, REDD+ strategy, Cameroon.

INTRODUCTION

The bamboo plant is a perennial woody-stemmed grass which belongs to the Bambusoideae sub-family, Graminae (Poaceae) family. It can be classified into monopodial (running), sympodial (clumping) and

*Corresponding author. E-mail: barnabasneba@yahoo.com. Tel: +237675266617.

amphipodia (Arun et al., 2015). It is fast growing, widespread, and renewable (Lodovikov et al., 2007; Terefe et al., 2019). It easily adapts to an extreme and diverse range of climates and soil conditions (Xu et al., 2018). According to International world checklist Bamboos and Rattans (Maria et al., 2016), 1642 bamboo species have been identified in the world. Bamboo covers approximately 37 million hectares of forests across the tropical and subtropical world: Africa, Asia and Central and South America which is about 3.2% of the world's total forest area (FAO and INBAR, 2018). In Africa, there is an estimated 43 species of bamboo covering about 1.5 million hectares (Gurmessa et al., 2016). Madagascar alone counts 43 species including 32 native African species (INBAR, 2018). In Cameroon, the preliminary inventory done by Ingram et al. (2010) recorded a diversity of 5 bamboo species.

Bamboo plays an important role in ecosystem services, biodiversity conservation and socio-economic development (Ingram et al., 2010; Yuen et al., 2016, 2017; Terefe et al., 2019). In the context of climate change mitigation, it is recognized as an important carbon sink (Gurmessa et al., 2016; Li et al., 2016; Yuen et al., 2016; Xu et al., 2018; Xayalath et al., 2019). In Cameroon, bamboo is considered as a Non-Timber Forest Product (NTFP) by decision n° 0209/D/MINFOF/ CAB of 26 April 2019 of the Government of Cameroon. It has an important socio-economic value of Cameroonians (Ingram et al., 2010). Ecologically, it is used to preserve river banks, and to restore some degraded lands due to its extensive fibrous rhizome and root systems that can decrease surface soil erosion, lower the risk of shallow landslides, and stabilize river banks (Song et al., 2011). However, bamboo forests in Cameroon are today under threat by deforestation and degradation, because they have been historically criminalized as invasive species and increasingly discouraged, leaving it with no guarantee to continue its socio-economic and ecological function (Ingram et al., 2010; Yuen et al., 2017).

Global climate change has inspired and instilled an increasing interest of scientific and policy stakeholders in the study of global carbon storage in order to look for a way to mitigate the trends of increasing CO_2 concentration in the atmosphere. One important thing about bamboo here is that some major species are introduced and can be accepted in the context of degraded forests restoration in Cameroon, thus constituting one major carbon sinks in the Congo Basin forests. Nevertheless, knowledge on bamboo in Cameroon is still very limited and studies on carbon stocks potential of bamboo are few. Many authors have mentioned bamboo as a solution to climate change mitigation owing to its fast growing nature and high capacity to sequestrate and store carbon (Jyoti et al., 2009; Nath et al., 2012, 2015; Zhuang et al., 2015; Li et al., 2016; Yuen et al., 2017). Considering that Cameroon is involved in many initiatives related to landscape restoration and natural resource management, such as REDD+ mechanism, Afr100 and Nationally Determined Contribution (NDC) with the commitment to reduce emissions (32% by horizon 2035) as a contribution to the global effort of COP 21, it is important to measure the contribution of all potential carbon pools in order to orientate a climate change mitigation strategy. Within this context, bamboo forest ecosystem was a candidate for this study. This study was initiated to (1) investigate the number of bamboo species in Cameroon; (2) characterise the most common bamboo species in Cameroon, (3) estimate bamboo carbon storage capacity with the different agro-ecological zones in Cameroon.

MATERIALS AND METHODS

Study area

This study was carried out across the national territory of Cameroon which covers a total surface area of 475 000 km^2. Cameroon is located between latitudes 2° and 13° N and longitudes 8° 30' and 16° 10' E. It is divided into 5 AEZs. A summary of the climate and relief of these 5 AEZs is presented in Table 1. Four major types of soil are common across Cameroon; ferralitic soil essentially in the southern part of Cameroon, representing 67% of the soils in the country, volcanic soils within the Cameroon volcanic belt, ferruginous soil covering almost all of the Northern Regions (Adamawa, North and Far North) of the country and hydromorphic soils found especially in wetlands. The hydrographical network is dense in Cameroon (e.g. Sanaga, Benue, Wouri, Moungo, Kadey etc). More than 47% of Cameroon's national territory is forested (de Wasseige et al., 2009). The forest is mainly closed tropical broad-leaved rainforest with three predominant types: lowland evergreen, lowland semi-deciduous, and montane. The closed forests are concentrated in the south and along the coast. Concerning vegetation, Cameroon is characterized by both forest and grassland. From the southern part of Cameroon to the northern part, we can find humid forest, transition forest, savannah, etc. (Ingram et al., 2010). Climate of Cameroon is summarized in Table 1.

Cameroon's population was estimated at 19.4 million as of 1 January 2010, a projection derived from the Population and Housing Census of November 2005. This is based on an estimated annual growth rate of 2.6%. A little over half (50.5%) of the population is female, and 43.6% of the population is less than 15 years old (Ingram et al., 2010). The principal activities of the population are subsistence agriculture through slash and burn, gathering and marketing of NTFPs, hunting and fishing. Bamboo is one of the NTFPs exploited in Cameroon. They are exploited for socio-economic purposes as per listed uses: furniture; fencing and hedges; construction materials; utensils, baskets and containers; hunting implements; crop supports (climbers: bean, yams, tomatoes), musical instruments; ornamental and decorative planting; fuelwood paper and food etc (Ingram et al., 2010).

Selection of sample sites

This was done with the aid of literature reviews (Ingram et al., 2010; Ingram and Tieguhong, 2013; Ingram, 2017) on bamboo in Cameroon. Literature helped to identify the geographic location of bamboo production, processing and consumption zones in Cameroon. Local bamboo experts (informants) were identified within the bamboo primary stakeholders in the different AEZs of

Table 1. Precipitation, altitude, and temperature range in the different AEZ of Cameroon.

AEZs	Rainfall (mm)	Altitude (m.a.s.l.)	Mean annual temperature (range)
Sudano- Sahelian zone	500-900	250-500	28°C (7.7)
Sudano-Guinean high savannah zone	1500-1800	500-1500	23°C (6.4)
Western Highlands zone	1800-2400	1500-2500	21°C (2.2)
Monomodal rainfall forest zone	2000-11000	0-500	26°C (2.8)
Bimodal rainfall forest zone	1500-2000	400-1000	25°C (2.4)

Source: Toukam et al. (2009).

Cameroon. These informants were knowledgeable of bamboo production and different bamboo groves in order to lead field technical research teams for data collection. Five technical data collection teams were deployed to the different AEZs for ground truthing (field verification to ascertain truth) and data collection. Here the geographical coordinates of the bamboo groves were recorded (Figure 1). Bamboo specimen vouchers were collected to identity confirmation in the National Herbarium Obili at Yaounde. These data permitted us to complement and confirm the major bamboo species present in the AEZs in Cameroon. This survey in the 5 AEZs and literature permitted this study to count the number of bamboo species in the lineage of Bambuseae in Cameroon.

However, it is important to note that our study on bamboo carbon stocks estimation laid emphasis on *Oxytenanthera abyssinica* (A. Rich.) Munro; *Phyllostachys aurea* Riviére & C. Riviére., and *Bambusa vulgaris* Schrad. ex J.C.Wendl. in three AEZs where they were found in great quantities in Cameroon and was in AEZ 2, 3 and 4 respectively.

Data collection

Ecological factors

The three bamboo species were from three different ecological zones (Agroecological zones): *O. abyssinica* from (AEZ 2), *P. aurea* from AEZ 3 and *B. vulgaris* from AEZ 4. Since the environment upon which the plants grow affect the plants, the ecological factors of the plots were collected and presented in Table 2 (AEZ 2), Table 3 (AEZ 3) and Table 4 (AEZ 4).

Carbon stocks assessment

Bamboo density and biomass data were collected in a forest of bamboo, meeting the definition of a forest as defined by FAO (2010). The size and shape of the sample plots were consistent across the sample plot system. The circular plot of 100 m² was laid out for running bamboo (*P. aurea*) when the density of bamboo was 60-120 culms plot^{-1} and for clumping bamboo (*B. vulgaris* and *O. abyssinica*) when 1.5-2 clumps plot^{-1}(Huy and Trinh, 2019).

Bamboo culm density and biomass data were collected in a total of 22 circular plot of 100 m² (5.64 m radius): eight plots of *O. abyssinica*; 6 plots of *P. aurea* and 8 plots of *B. vulgaris*. Bamboo culm densities and biomass plots designed for clumping bamboo (*O. abyssinica*; and *B. vulgaris*) were as follows: at a GPS waypoint placed by convenience in the plot on arrival, the nearest bamboo clump was determined; from there five distances of six nearest bamboo clumps sequentially were measured (Huy and Trinh, 2019). From the average distance between the bamboo clumps, the number of bamboo clumps per hectare was calculated. The number of culms (N_{culms}) per clump was also counted.

Bamboo biomass estimation was done using the destructive approach because, allometric equations developed for these species elsewhere did not have the same environmental factors (e.g. edaphic factor, climatic variables, etc.). According to this context and in each circular plot, 5 % of bamboo with respect to age group was felled for sampling; for each clump present (sympodial bamboo *B. vulgaris* or *O. abyssinica*) and for *P. aurea* (running bamboo) in the plot. In all, 5 % of all total culms in circular plots were sampled. It is important to note that for each plot sampled, three age classes were considered. The age class was divided into 1 year, 2 year and ≥ 3 year old culms (Devi et al., 2018). Bamboo morphology and color change aided in identifying different age groups (Huy et al., 2013; Li et al., 2016). For each culm sampled, in addition to specimen collection for bamboo species identity confirmation, dendrometric variables were the height, the diameter at 1.50 cm (Huy and Trinh, 2019) and age class. For sympodial bamboo, additional data like girth (m) and number of culms (N_{culm}) were also collected. Then, the harvested bamboo was sorted out into components (e.g. culms, branches and leaves), weighed with an electronic suspension scale (capacity 300 kg) separately for total fresh biomass of the bamboo. Subsamples of the different bamboo components: culm (at 3 positions on the culm: root collar, middle and top); branches and leaves with approximately 100-300 g (using electronic scale of precision 0.1 g) were collected for each bamboo sampled. These subsamples were oven dried at 105°C until constant weight, in the laboratory of Rural Engineering of the University of Dschang, Cameroon; in order to obtain the biomass ratio.

Data analysis

Data analysis was done using R software version 3.4.1. Descriptive analysis was done for measurement variables and bamboo biomass of components.

Bamboo density estimation

The estimation of the number of clumps and culms per hectare of sympodial bamboo *B. vulgaris* and *O. abyssinica* was done using respectively the following formulae (Huy andTrinh, 2019):

$$\mathrm{N_{clumps}\ ha^{-1}} = \mathrm{N_{clump}} \times \frac{10^4}{\text{plot area } (\mathrm{m^2})} \quad (1)$$

$$\mathrm{N_{i\ culms}\ ha^{-1}} = \mathrm{N_{i\ culm}} \times \mathrm{N_{clump}\ ha^{-1}} \quad (2)$$

For running bamboo (*P. aurea*), the number of culms was determined using the formulae:

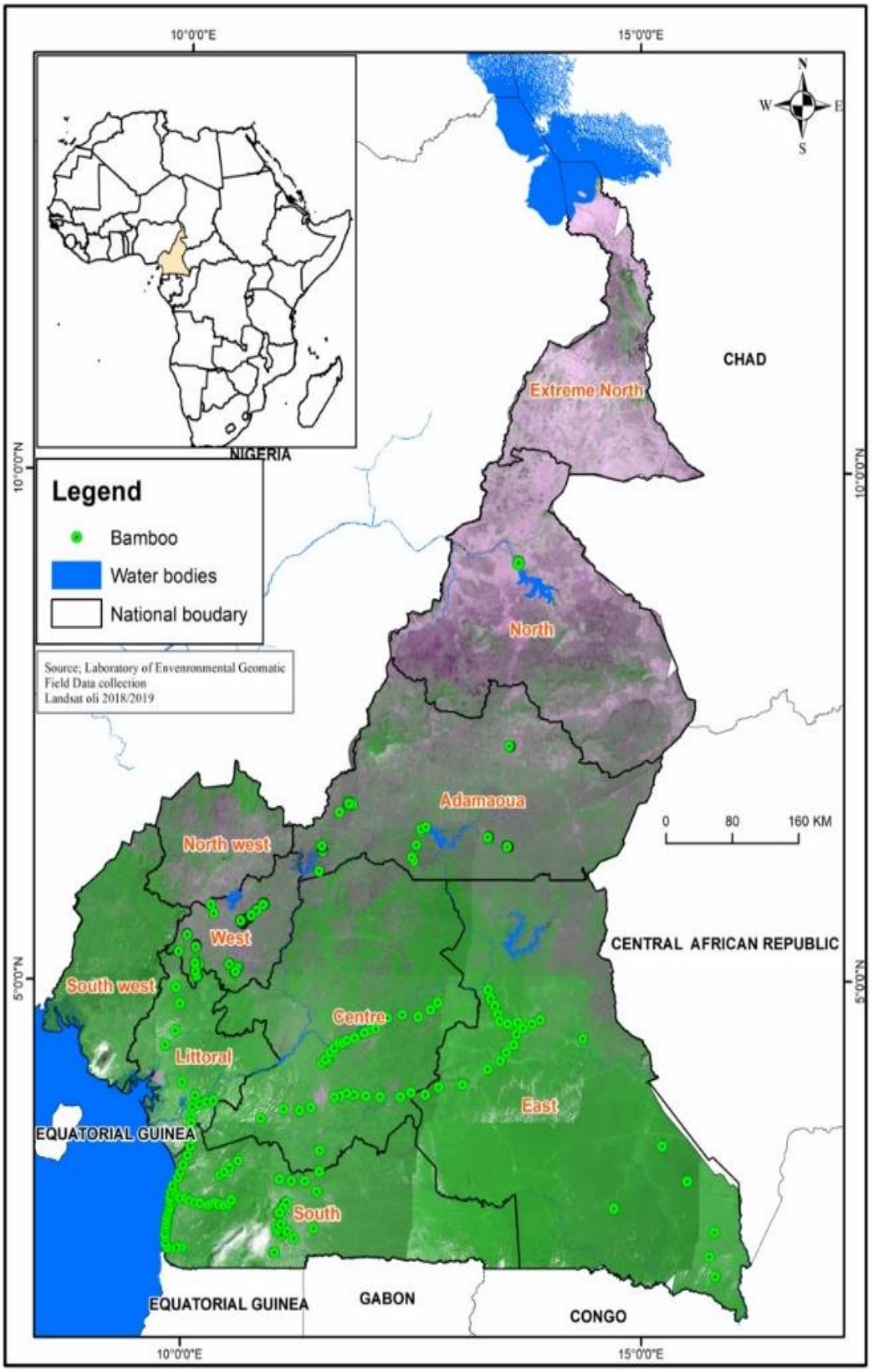


Figure 1. Map of ground truthing in the national territory of Cameroon.

Table 2. Summary of ecological factors affecting *Oxytenanthera abyssinica* in AEZ 2.

Factors/variable	Value
Mean annual rainfall (mm)	1200
Mean annual temperature (°C)	23
Source : Toukam et al. (2009); Institut de Recherche Agricole pour le Développement (I.R.A.D.) (2005)	
Bedrock	Metamorphic rocks
Soil colour	Red
Soil type	Ferruginous soils
Source: Yerima and Van Ranst (2005); CIRAD, 2000).	
Altitude range (m.a.s.l.)	778 to 1038
Soil layer depth range (cm)	25 to 40
Slope gradient range (°)	10 to 20
Source: Sample plots	

Table 3. Summary of ecological factors affecting *Phyllostachys aurea* in AEZ 3.

Factors/variable	Value
Mean annual rainfall (mm)	2000
Mean annual temperature (°C)	21
Source : Toukam et al. (2009) ; IRAD (2005)	
Bedrock	Igneous rocks
Soil colour	Red, grey, dark
Soil type	Volcanic soils (clay, rocky)
Source : Yerima and Van Ranst (2005); Jiotsa et al. (2015)	
Altitude range (m.a.s.l.)	1124 to 1349
Soil layer depth range (cm)	5 to 70
Slope gradient range	10 to 40
H_{culm} (m)	9.9 to 11.2
Source: Sample plots	

$$\mathrm{N_{culms}}\ ha^{-1} = \mathrm{N_{culm}} \times \frac{10^4}{\text{plot area } (\mathrm{m^2})} \quad (3)$$

Bamboo biomass and carbon stocks estimation

Total dry-weight of each component (for each culm bamboo sampled) was determined using the following formulae (Gurmessa et al., 2016):

$$\mathrm{TDW} = \frac{SDW}{SFW} \times \mathrm{TFW} \quad (4)$$

Where; TDW= total component dry weight; SDW= subsample dry weight; SFW= subsample fresh weight; and TFW=total component fresh weight.

Culm bamboo above ground biomass (AGB_{bamboo}) corresponds to the sum of the total dry bamboo biomass of the culm (AGB_{cl}, kg), branches (AGB_{br}, kg) and leaves (AGB_{le}, kg):

$$AGB_{bamboo} = AGB_{cl} + AGB_{br} + AGB_{le} \quad (5)$$

For sympodial bamboo, aboveground clump biomass (AGB_{clump}) was estimated by the formulae:

$$\mathrm{AGB_{clump}} = AGB_{bamboo} \times \mathrm{N_{i\ culm}} \quad (6)$$

For culm and/or clump aboveground biomass estimation for each plot, the extrapolation at the hectare was done using the following extrapolation factor,

$$\text{(EF); EF=}\ \mathrm{AGB\ (t\ ha^{-1})} = \frac{10^4}{\text{plot area } (\mathrm{m^2})} \quad (7)$$

AGB corresponds to the bamboo aboveground biomass (culm or clump) in 100 m².

Table 4. Summary of ecological factors affecting *Bambusa vulgaris* in AEZ 4.

Factors/variable	Value
Mean annual rainfall (mm)	3000
Mean annual temperature °C)	26
Source: Toukam et al. (2009); IRAD (2005)	
Bedrock	Metamorphic, Igneous rocks
Soil colour	Greyish dark, brown red to dark, dark
Soil type	Ferralitic soils (Silty, hydromorphic and Sandy) and Volcanic soils (rich in organic matter)
Source: Yerima and Van Ranst (2005); Jiotsa et al. (2015)	
Altitude range (m.a.s.l.)	-7 to 755
Soil layer depth range (cm)	5 to 60
Slope gradient range (°)	2 to 8
H_{culm} (m)	12.3 to 19.3
Source: Sample plots	

According to Jyoti et al. (2009), Huy and Trinh (2019) and Huy et al. (2019), the carbon content in bamboo represents 47% of it biomass. Like that, bamboo carbon stocks at the hectare were estimated by the following formulae:

$$\text{Carbon stock (t C ha}^{-1}\text{)} = \text{biomasses (t ha}^{-1}\text{)} \times 47\% \quad (8)$$

With respect to the fact that 1 tC = 3.67tCO_{2eq}, the following formulae was used for bamboo CO_2 stocks.

$$\text{Stock } CO_2 \text{ (t}CO_2\text{eq.ha}^{-1}\text{)} = \text{Carbon stock (t Cha}^{-1}\text{)} \times 3.67 \quad (9)$$

Comparative carbon analysis

For the comparison of culm density, biomass and carbon stocks amongst 3 bamboo species, firstly, the Shapiro-Wilk normality test was used to test data for normality test. ANOVA and Turkeys tests (parametric test) were used for data which follow a normal distribution and the non-parametric tests (Kruskal-Wallis and Wilcoxon) used for data do not follow a normal distribution; were performed to test for significant difference amongst these bamboos. In this study, Kruskal-Wallis and Wilcoxon tests were used for bamboo culm density comparison and ANOVA and Turkey tests were used to compare biomass of the different bamboo species.

RESULTS

Bamboo species in Cameroon

Bamboo species inventoried nationwide permit the identification of eight (8) bamboo species in the lineage of Bambuseae (tropical woody). These bamboo species were: *Bambusa vulgaris* Schrad. ex J. C. Wendl., *Oxytenanthera abyssinica* (A. Rich.) Munro, *Bambusa sp. longinternode, Phyllostachys aurea* Riviére & C. Riviére., *Phyllostachys* sp*., Ochlandra travancorica* (Bedd.) Gamble, *Phyllostachys atrovaginata* C. S. Chao & H. Y. Chou and *Dendrocalamus strictus* (Roxb.) Nees*.* Out of these bamboo species in Cameroon, only *Oxytenanthera abyssinica* (A. Rich.) Munro is endemic in Africa. *B. vulgaris* was found represented in all the different AEZs. They were in great quantities (abundant) as the dominant bamboo species in AEZ4 and AEZ5. Some bamboo species like *Dendrocalamus strictus* and *Ochlandra travancorica.* were less common in Cameroon. Bamboo species like *Phyllostachys aurea* and *Dendrocalamus strictus* were found in AEZ3 and AEZ4, respectively (Table 4).

Literature however, provided the following bamboo species in Cameroon: *Dendrocalamus aurea* (MINFOF 2018), *Puelia atractocarpa* and O*reobambos buchwaldi* (Bystriakova et al., 2002; Ohrnberger and Goerrings 1988); *Yushania alpina* (Ingram et al., 2010), making a total of 12 bamboos of the lineage of Bambuseae. Data from the National Herbarium, Yaounde identifies 11 bamboos to species level and 4 species to sp. level; giving a total of 15 bamboo species in Cameroon.

Characteristics variables of the three bamboo species

According to our observation in the field, three bamboo species appeared dominant in Cameroon (study area). Their characteristics are presented in Table 5. Considering the fact that *P. aurea* is not a sympodial species, data like girth (m) and N_{culms} were not available for this bamboo species. *B. vulgaris* had the largest diameter with main diameter of 7.62±1.21 and the highest height with mean 15.95±2.96. For girth, *B. vulgaris* was still the largest with mean value of 20.75±9.76. Therefore, *B. vulgaris* > *O. abyssinica* > *P. aurea* in diameter. Comparing height, *B. vulgaris* > *P. aurea* > *O. abyssinica.* For girth of clump and number of culms per clump: *B. vulgaris* > *P. aurea.* $N_{culms.clump}^{-1}$:

Table 5. Bamboo species identified in different AEZs with respect to their abundance in Cameroon ("+" refer to the abundance of bamboo species with respect to other bamboo species in this area. Absence of "+" refer to the absence of bamboo species observed in this AEZ).

Bamboo species	Status	Area observed in Cameroon	Abundance in different agroecological zone				
			AEZ1	AEZ2	AEZ3	AEZ4	AEZ5
Bambusa vulgaris Schrad.ex. J.C.Wendl.	Introduced	South, Littoral, Centre, West, East and Adamoua	+	+	++	++++	++++
Bambusa longinternode		Centre; West			+		+
Dendrocalamus strictus (Roxb.)Nees	Introduced	Kribi				+	
Ochlandra travancorica (Bedd.) Gamble	Introduced	Kribi, Campo, Bafang			+	+	
Oxytenanthera abyssinica (A. Rich.) Munro	Native	Beyala, Tibati, Banyo, Bankim, North. etc.	+	++++			
Phyllostachys aurea Riviére & C. Riviére,	Introduced	Bafang, Baleck, Babou, Koupara, West Cameroon			++++		
Phyllostachys atrovaginata C. S. Chao & H. Y. Chou	Introduced	Bertoua, Tonga,			+	+	
Phyllostachys sp.	Introduced	Bafang, Bertoua, Menuoa etc.			+		+

Characteristic of biomass components (leaves, branches, culms and total AGB culm bamboo) of these three bamboo species

Summary of bamboo biomass of the three most abundant bamboo species in Cameroon is given in Table 6. Biomass of bamboo culm was higher than those of branches and leaves. Average biomass of bamboo leaves for the three bamboo species was: *B. vulgaris* > *P. aurea* > *O. abyssinica*. Those of branches and culm follow the gradient *B. vulgaris* > *O. abyssinica* > *P. aurea.* Concerning the percentage of biomass for the different bamboo components, aboveground biomass for bamboo was 84, 13 and 4% respectively for culms, branches and leaves of *B. vulgaris*. For *O. abyssinica*, it was 77, 19 and 4% respectively; and for *P. aurea,* bamboo biomass was 76, 14 and 9% respectively for the three components.

Culm density and carbon stocks of the three bamboo species on study

Since *P. aurea* is running bamboo, the N_{clump} ha^{-1} was not estimated. The arithmetic average with standard deviation and statistical analysis of density, biomass, carbon stocks and CO_2 stocks are summarized in Table 7. The results showed that average culm per hectare varied significantly with respect to the bamboo species (Kruskal-Wallis test, p<0.000). However, Wilcoxon test showed that this difference was not significant between culm number per ha of *B. vulgaris* and *O. abyssinica*. The high value of culm per ha was found for *P. aurea* which was significantly different from those of these two bamboo species (Figure 2A). The contrary was observed with average culm bamboo biomass (kg) which varied significantly with respect to the bamboo species (Figure 2B) where that of *P. aurea* was low and significantly different from those of *B. vulgaris* and *O. abyssinica* (Kruskal-Wallis and Wilcoxon tests, p <0.000). ANOVA test (p <0.000) showed a significant difference between the three bamboo species with respect to carbon stocks and CO_{2eq} (Figure 2C, D). Comparing the carbon stocks or CO_2 stocks of these bamboo species two by two, Turkey test showed a significant difference (p <0.000). Globally, average carbon stocks of the three (3) bamboo species significantly followed the gradient of: *P. aurea* (67.78 tC ha^{-1}) >*B. vulgaris* (29.62 tC ha^{-1}) > *O. abyssinica* (13.13 tC ha^{-1}) Table 8.

DISCUSSION

Bamboo species and characterization

The diversity of bamboo showed that, many species were small sized bamboo except of the pan-tropical species (*Bambusa* sp.) which are medium. Cameroon still need to have big sized bamboos and this will probably be introduced species. The medium and big sized bamboo shall be very important for industrial transformation into other utilities. Cameroon has 12 bamboo species and other studies reports Madagascar, Ethiopia and Ghana with 33, 25 and 8 bamboo species respectively (INBAR 2018, Mulatu et al., 2016; Amare and Shiferaw, 2020; Kwame et al., 2020).

Bamboo has 10 000 documented uses (INBAR, 2019)

Table 6. Summary of bamboo dendrometric parameters in the selected AEZs.

AEZs	Bamboo species	Predictive variables	Minimum	Maximum	Mean	Stand. dev.
AEZ 4	*B. vulgaris*	Diameter (cm)	4.33	10.66	7.62	1.21
		Height (m)	9.55	22.34	15.97	2.96
		Age (year)	1	≥ 3	-	-
		$Girth_{clump}$ (m)	7.18	40.00	20.75	9.76
		$N_{culm\ clump}^{-1}$	20	255	107	67
AEZ 2	*O. abyssinica*	Diameter (cm)	2.01	6.61	3.93	0.66
		Height (m)	2.00	11.02	8.40	0.36
		Age (year)	1	≥ 3	-	-
		$Girth_{clump}$ (m)	2.18	8.33	3.64	1.19
		$N_{culm\ clump}^{-1}$	9	61	23	11
AEZ 3	*P. aurea*	Diameter (cm)	1.69	4.39	3.40	0.51
		Height (m)	7.70	13.70	10.67	1.34
		Age (year)	1	≥ 3	-	-
		$Girth_{clump}$ (m)	-	-	-	-
		$N_{culms\ clump}^{-1}$	-	-	-	-

Table 7. Summary of the biomass of bamboo culms (kg) of the three (03) bamboo species.

Parameter	AEZ 4			AEZ 2			AEZ 3		
	B. vulgaris			*O. abyssinica*			*P. aurea*		
	leaves	branches	culms	leaves	branches	culms	leaves	branches	culms
Minimum	0.08	0.18	1.69	0.00	0.01	1.01	0.01	0.04	0.4
Maximum	4.07	14.57	55.03	1.29	7.62	18.44	0.95	0.99	6.02
Mean	0.82	2.65	17.61	0.22	1.14	4.67	0.36	0.54	2.9
Stand. Dev.	0.84	2.34	10.58	0.34	1.18	2.98	0.25	0.21	1.12

Table 8. Carbon stocks of the three bamboo species most abundant in Cameroon.

Descriptive statistic	AEZ 4	AEZ 2	AEZ 3
	B. vulgaris	*O. abyssinica*	*P. aurea*
$N_{culms.}$ ha^{-1}	2296±631[a]	4374±2604[a]	38017±4510[b]
$N_{clumps.}$ ha^{-1}	20±3[a]	184±83[a]	-
Average AGB_{culm} (kg)	29.80±6.96[b]	6.39±3.44[a]	3.79±0.54[a]
AGB_{clump} bamboo (t ha^{-1})	63.02±4.10	27.97±14.63	144.21±21.58
AGB_{clump} bamboo (t C ha^{-1})	29.62±1.93[b]	13.13±6.88[a]	67.78±10.14[c]
AGB_{clump} bamboo (t $CO_{2eq\ ha}^{-1}$)	108.70±7.07	48.19±25.24	248.75±37.22

Statistical analyses (parametric and non-parametric tests) are significant at 95% confidence interval.

and every part of the plant can be utilised. This knowledge on the number, diversity in species and characteristics (diameter, height, culm density and clump density per hectare) of bamboo are very important to inform policy makers and planners in the bamboo sector of the resources available, their ecological conditions and location. This information shall have an impact on the bamboo choices to be promoted for different transformation sectors. For the case of Cameroon, *O. abyssinica* (lowland bamboo) is best adapted to the semi-arid zones with mean annual rainfall of ≤1200 mm and temperature of ≤ 23°C (Guinea savannah and Sudano-

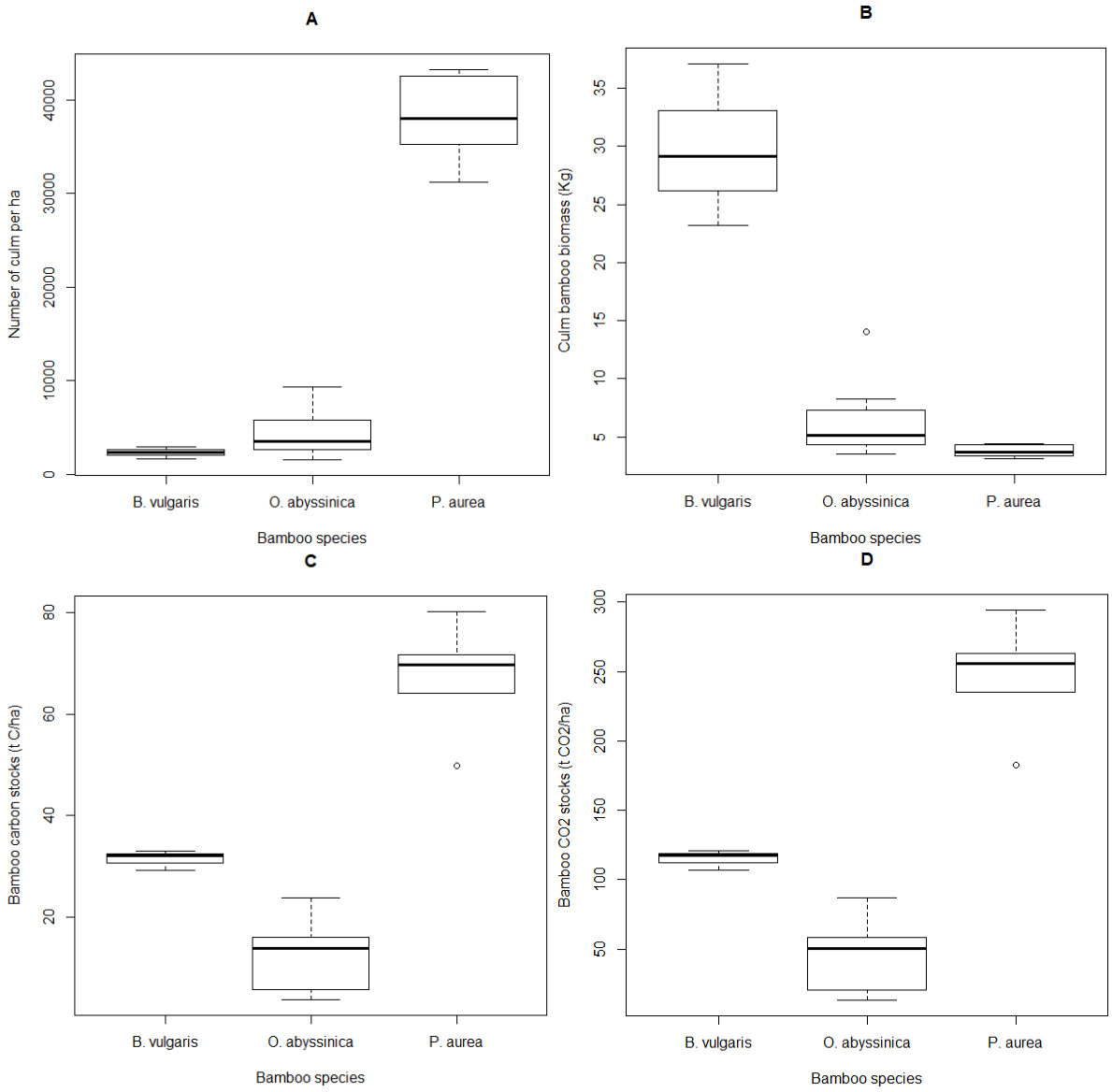


Figure 2. Culm density and carbon stocks per hectare of the three most abundant bamboo species in Cameroon.

Sahel zones). The planting of *O. abyssinica* can be promoted in degraded landscapes, marginal lands, plantations and even intercropped in agroforestry systems (Arun et al., 2015) in Guinea Savannah and Sudano-Sahel zones to mitigate climate change (FAO and INBAR, 2018; Terefe et al., 2019; Yuen et al., 2017), serve as bioenergy (fodder, animal feed, hay, firewood, Charcoal, pellet, biogas etc.) for both animals and the local population. Bamboo can be processed in various ways to become an important source of biomass energy for cooking, heating and electricity, and has important co-benefits for farmers (INBAR, 2019a). *B. vulgaris* strives perfectly well in tropical zones with high temperatures and rainfall. In fact, *B. vulgaris* recorded in all the agro-ecological zones of Cameroon, therefore, its plantations could be promoted to serve as feed stocks for industrial transformation of bamboo throughout the country. *P. aurea* and *Y. alpina* are western highlands species (volcanic soils) in Cameroon. The western highlands local population are known for using bamboo for handicrafts, culture, housing, beehive keeping, fishing, drying rags, crop staking (Neba et al., 2020; Ingram et al., 2010; Tchamba et al., 2020).

Bamboo carbon stocks in Cameroon

Average AGB_{culm} (kg) was significantly different with respect to the three bamboo species. *B. vulgaris* was the bamboo species with the highest significant AGB_{culm}

biomass compared to the two other bamboo species. In fact, we observed that similar to trees (Yuen et al., 2016), the AGB_{culm} increased with increase in culm diameter. For this reason, therefore, the diameter follows the gradient: *B. vulgaris* > *O. abyssinica* > *P. aurea*. The same gradient was found for total culm aboveground biomass. Nevertheless, concerning aboveground biomass proportions of the bamboo components, it was approximately similar for the three bamboo species. This has also been reported by several authors who studied these three bamboo species and other bamboo species in the world (Gurmessa et al., 2016; Li et al., 2016; Nath et al., 2012; Yuen et al., 2017; Zhuang et al., 2015). With respect to literature review, bamboo carbon stocks found in the world vary in function of bamboo species (Jyoti et al., 2009; Nath et al., 2012; Patricio and Dumago, 2014; Yuen et al., 2016, 2017). This observation was confirmed in the context of this study where the average carbon stocks of three bamboo species varied in relation to the bamboo species: 13.13; 29.62 and 67.78 t C. ha^{-1} respectively for *O. abyssinica, B. vulgaris* and *P. aurea*. In fact, the review of bamboo aboveground carbon (AGC) for seventy bamboo species by Yuen et al. (2017) showed a range of 16 to 128 Mg C ha^{-1} for the different bamboo species. Many things could explain the variation of carbon stocks between bamboo species. Despite the faster growing rate of bamboo than other trees, these differences may be explained by the fact that, different bamboo species seem to have a different capacity in terms of carbon stocks. The density of culm/ha seems also to explain the significant difference of carbon stocks found between these bamboo species. For example, though *P. aurea* has a low AGB_{culm} (kg) when compared to *B. Vulgaris* and *O. abyssinica*, its abundance per hectare may have a significant influence on its carbon stocks potential making it the bamboo species with the highest carbon stocks per hectare. Its abundance per hectare was 9 and 17 times greater than that of *B. vulgaris* and *O. abyssinica* respectively. In addition, ecological conditions (clump crowding, and culm position within a clump) and bamboo morphology (sympodial or running) may also influence the carbon storage potential (Xayalath et al., 2019; Yuen et al., 2017).

Importance of bamboo in restoration of forests and mitigation of climate change

Degradation and deforestation have a direct impact on forest cover. The reduction in forest cover aggravates climate change and global warming because the forest is one of the largest carbon sinks and plays an important role in the global carbon cycle and photosynthesis. Plants grow by CO_2 fixation through photosynthetic processes and decrease the concentration of CO_2 gases from the atmosphere. Therefore, reforestation with fast growing plants like bamboos (*P. aurea*) (Arun et al., 2015; Terefe et al., 2019; Yuen et al., 2017) could be recommended in the national strategy, to fight against climate change. To attain the climate change mitigation objective and the fact that *P. aurea* has the highest carbon storage capacity in Cameroon; this bamboo species is a solution to combat global warming effect. This bamboo species could be recommended in the context of the Bonn Challenge landscape restoration, and Africa 100 000 ha landscape restoration initiatives. The REDD+ mechanism in reducing emissions from deforestation and forest degradation in conserving forest carbon stocks, sustainably managing of forests, and enhancing forest carbon stocks is an initiative to bamboo for its high carbon storage capacity in Cameroon.Yuen et al. (2017) carried out a study on the carbon storage capacity of 70 bamboo species demonstrating that the total bamboo ecosystem carbon storage capacity is lower than that of most types of forests, as it is on a par with that of rubber plantations and tree orchards, but greater than agroforests, oil palm, various types of swidden fallows, grasslands, shrublands, and pastures. This means that bamboo can successfully substitute degraded lands (e.g. agroforestry systems, oil palm plantations, various types of swidden fallows, grasslands, shrublands, and pastures; especially in the Guinea Savannah and Sudano Sahel Regions) and marginal lands, and contribute significantly towards mitigating climate change in Cameroon. It is also feared that bamboo's rapid growth could modify the original or local biodiversity of an area.

Conclusion

The results of this study on bamboo species, complemented with the literature review confirmed the diversity of 15 bamboo species and data from National Herbarium, Yaounde Cameroon; among which are three native African species. However, three of these bamboo species were more abundant and each in a specific AEZ. Concerning their capacity to mitigate climate change, we found that carbon stocks varied significantly ($p < 0.5$) with respect to the different bamboo species. *P. aurea* was the bamboo species with the highest value of carbon stocks (67.78 tC ha^{-1}) and *O. abyssinica* with the least carbon stocks (13.13 tC ha^{-1}).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to the International Bamboo and Rattan Organization (INBAR), under its Inter-Africa bamboo smallholder livelihood Development Programme

for funding this study; the University of Dschang for providing laboratories and all laboratory collaborators for collecting field data; and the local experts. The reviewers who assured the quality of this study are also appreciated.

REFERENCES

Amare SM, Shiferaw A (2020). Bamboo policy Integration Analysis, Ethiopia. INBAR working paper N° 84. 33 p.

Arun JN, Lal R, Das AK (2015). Ethnopedology and soil quality of bamboo (Bambusa sp.) based agroforestry system. Science of the Total Environment 521-522:372-379.

Bystriakova N, Kapos V, Lysenko I (2002). Potential distribution of woody bamboos in Africa and America. In: Working Paper 43, United Nations Environment Program-World Conservation Monitoring Centre (UNEP-WCMC),Cambridge, UK.

Devi AS, Singh KS, Lalramnghinglova H (2018). Aboveground biomass production of Melocanna baccifera and Bambusa tulda in a sub-tropical tropical bamboo forest in Lengpui, North East India 7(7):23-28.

de Wasseige C, Devers D, Marcken P, Eba'a Atyi R, Nasi R, Mayaux P (2009). The forests of the Congo Basin, State of the Forest 2008. Office des publications de l'Union Europeenne, Congo Basin Forest Partnership, Yaounde, Cameroon.

CIRAD (2000). Variations in Soil Fertility Under Cotton Crops in The Bénoué Cotton-Growing Area In Northern Cameroon. Beltwide Cotton Conferences, Nashville, Tennessee. Pp 1635-1641. http://agritrop.cirad.fr/551709/

FAO (2010). Global forest resources assessment 2010 terms and definitions', Forest Resources Assessment Working Paper 144/E. Rome: Forestry Department, FAO, p.27.

FAO and INBAR (2018). Bamboo for land restoration. INBAR Policy Synthesis Report 4. INBAR: Beijing, China 67 p. http://www.inbar.int/sites/default/files/resources/

Gurmessa F, Gemechu T, Soromessa T, Kelbessa E (2016). Allometric Equations to Estimate the Biomass of Oxytenanthera Abyssinica (A. Rich.) Munro. (Ethiopian Lowland Bamboo) in Dicho Forest, Oromia Region, Western Ethiopia. International Journal of Research Studies in Biosciences 4(12):

Huy B, Thanh GT, Poudel KP, Temesgen H (2019). Individual plant allometric equations for estimating aboveground biomass and its components for a common bamboo species (Bambusa procera A. Chev. and A. Camus) in tropical forests. Forest. 10(4): https://doi.org/10.3390/f10040316.

Huy B, Trinh TL (2019). A manual for Bamboo Forest Biomass and Carbon Assessment; INBAR. 155 p.

International Bamboo and Rattan Organisation (INBAR) (2019). Trade Overview 2018 Bamboo and Rattan Commodities in China, 15 p.

International Bamboo and Rattan Organisation (INBAR) (2019a). Bamboo as a source of bioenergy 2 p.

International Bamboo and Rattan Organisation (INBAR) (2018). Remote Sensing-Based Regional Bamboo Resource Assessment Report of Madagascar; Tsinghua University of China.

Ingram VJ (2017). Shifting global development discourses : Implications for forests and livelihoods Changing governance ... Shifting global development discourses : Implications for forests and livelihoods Changing governance arrangements : NTFP value chains in the Congo B. International Forestry Review 19(S1): 1-18.

Ingram V, Tieguhong JC, Nkamgnia EM, Eyebe JP, Ngawe M (2010). The bamboo production to consumption system in Cameroon. CIFOR Working Paper, 50, x-pp. http://www.cifor.org/nc/online-library/browse/view-publication/publication/3312.html

Ingram V, Tieguhong JC (2013). Bars to jars: Bamboo value chains in Cameroon. Ambio 42(3): 320-333.

IRAD (2005). République du Cameroun Institut de Recherche Agricole pour le Zones Agro-écologiques , Centres , Stations et Antennes. 237, 2123.

Jiotsa A. Timothy MO, Yambene H (2015). Cooperative Movements in the Western Highlands of Cameroon, http://journals.openedition.org/rga/2764 retrieve on the 2/10/2019.

Jyoti NA, Das G, Das AK (2009). Above ground standing biomass and carbon storage in village bamboos in North East India. Biomass and Bioenergy 33(9):1188-1196.

Kwame A, Oduro EA, Obeng HA, Sarah P (2020). Bamboo policy Integration Analysis, West Africa, Ghana. INBAR working paper N° 83. 44 p.

Li LE, Lin YJ, Yen TM (2016). Using allometric models to predict the aboveground biomass of thorny bamboo (Bambusa stenostachya) and estimate its carbon storage. Taiwan Journal of Forest Science 31(1):37-47.

MINFOF (2018). Programme National de Développement de la filière du Bambou de Chine au Cameroun.

Maria SV, Lynn GC, Dransfield J, Govaerts R, Baker WJ (2016). World Checklist of Bamboo and Rattans. INBAR Technical Report No. 37. 454 p.

Mulatu Y, Alemayehu A, Tadesse Z. (2016). Biology and Management of Indigenous Bamboo Species of Ethiopia. Ethiopian Environment and Forest Research Institute (EEFRI), Addis Ababa.

Nath AJ, Franklin DC, Lawes MJ, Das MC, Das AK (2012). Impact of Culm Harvest on Seed Production in a Monocarpic Bamboo. Biotropical 4(5):699-704.

Nath AJ, Lal R, Das AK (2015). Managing woody bamboos for carbon farming and carbon trading. Global Ecology and Conservation 3:654-663.

Neba B, Chimi C, Gadinga W, Kaam R (2020). Bamboo policy integration analysis, Cameroon. INBAR Working Paper.

Ohrnberger D (1999). The bamboos of the world. Elsevier, Amsterdam the Netherlands.

Patricio JH, Dumago SW (2014). Comparing aboveground carbon sequestration of three economically important bamboo species grown in Bukidnon, Philippines. Journal of Multidisciplinary Studies 3(1):1-15.

Song X, Zhou G, Jiang H, Yu S, Fu J, Li W (2011). Carbon sequestration by Chinese bamboo forests and their ecological benefits : assessment of potential , problems , and future challenges. https://doi.org/10.1139/a11-015

Tchamba M., Rene K., Neba B., Chimi C., Tanoungong A (2020). Remote Sensing-Based Bamboo Mapping and Bamboo Stock Assessment in Cameroon. INBAR working Paper.

Terefe R, Jian L, Kunyong Y (2019). Role of Bamboo Forest for Mitigation and Adaptation to Climate Change Challenges in China. Journal of Scientific Research and Reports 20:1-7.

Toukam MG, Cellier G, Wicker E, Kahane R (2009) Broad diversity of ralstonia solanacearum strains in Cameroon 8 p.

Xayalath S, Hirota I, Tomita S, Nakagawa M (2019). Allometric equations for estimating the aboveground biomass of bamboos in northern Laos. Journal of Forest Research 24(2):115-119.

Xu M, Ji H, Zhuang S. (2018). Carbon stock of Moso bamboo (Phyllostachys pubescens) forests along a latitude gradient in the subtropical region of China pp. 1-11.

Yerima BPK, Van Ranst E (2005). Major Soil Classification Systems used in the Tropics: Soils of Cameroon. Trafford Publishing, Canada.

Yuen JQ, Fung T, Ziegler AD (2016). Review of allometric equations for major land covers in SE Asia: Uncertainty and implications for above- and below-ground carbon estimates. Forest Ecology and Management 360:323-340.

Yuen JQ, FungT, Ziegler AD (2017). Carbon stocks in bamboo ecosystems worldwide: Estimates and uncertainties. Forest Ecology and Management 393: 113-138.

Zhuang S, Ji H, Zhang H, Sun B (2015). Carbon storage estimation of moso bamboo (Phyllostachys pubescens) forest stands in Fujian, China. Tropical Ecology 56(3):383-391.

Vol. 14(10), pp. 301-310, October 2020
DOI: 10.5897/AJEST2020.2857
Article Number: 65E00F764852
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Advancing climate change adaptation in Uganda's agricultural programming for sustainable development: Key milestones and constraints

Fred Alinda[1], David Ssekamatte[1*], Ezekiel Kisambira[2] and Anthony Kagoro[3]

[1]Uganda Management Institute, Uganda.
[2]Climate Change Research Group, Uganda.
[3]Ministry of water and Environment, Uganda.

Received 6 May, 2020; Accepted 6 August, 2020

Climate change remains a crucial threat to sustainable development, particularly to the farming communities, which are more vulnerable to climate impacts. Uganda has made commendable steps in building an institutional framework for addressing climate change. However, the framework remains scattered in several documents making it difficult to track and conceptualize. This paper provides a one-stop center for understanding how effectively climate change is institutionalized in the agricultural sector and identifies the critical issues for future actions towards effective mainstreaming of climate change in agricultural programming. Findings in this paper are based on data collected through document review and a case study of Bududa district, representing the local governance of climate change adaptation mainstreaming. The paper observes that significant steps have been taken to mainstream climate change adaptation in agricultural programming, but adoption of adaptation measures will necessitate robust institutionalization of agricultural insurance as a climate change adaptation strategy particularly in the context of the rural, resource-constrained farming communities which are also more vulnerable to climate change hazards. Secondly, effective mainstreaming of climate change adaptation in agricultural programming in local governments will necessitate increased budget support from the central government towards addressing the critical institutional capacity gaps which hinder climate change adaptation programming and implementation of adaptation measures in local governments of Uganda.

Key words: Climate change adaptation, agricultural programming, institutional frameworks for adaptation, Uganda regulatory frameworks for adaptation.

INTRODUCTION

Global and regional context of climate change adaptation

Climate change remains a global issue associated with extreme conditions like floods and droughts, which constrain development, particularly in emerging and developing economies (UNDP, 2018). There is a long history of the world's commitment to addressing climate change reflected in the climate change discourse and the key milestones. These include the 1979 first World Climate Conference held in Geneva, the 1985 United Nations Environmental Program on greenhouse emissions, the 1988 Intergovernmental Panel on Climate (IPCC) established by United Nations Environmental

Program, the 1994 United Nations Framework Convention on Climate Change (UNFCC), the 2005 Kyoto Protocol, the 2006 Asia-Pacific Partnership for Clean Development, the 2007-Stern report highlighting the economic rationale and implication for climate change published and the thirteenth conference of parties in Bali, which drew a roadmap towards Copenhagen. Key stakeholders at all levels including local leaders, government, development partners, civil society, policy makers, political leaders, private sector, academia, research institutions, cultural and faith-based leaders and communities have weighed in climate change issues (Environmental Alert, 2010).

The African sub-regional initiatives demonstrate commitment by governments and civil society towards addressing climate change. Such initiatives include the African Ministers Conference on Environment (AMCEN) held towards building a common position and voice as Africa, which is taken in the global discussion and negotiations on climate change; the Pan African Climate Justice Alliance (PACJA) a network of African CSOs which advocate for climate justice and influence the African position on climate change; the East African Community Climate Change Policy responding to the increasing threats of the impacts of climate change to the development of set targets and goals in the region (Environmental Alert, 2010).

There is a general consensus that climate change is here to stay and is predicted to worsen. What matters is the degree to which systems can adapt to ensure they survive and sustain a high degree of performance. Consequently, development and research approaches to the problem of climate change are getting more focused to climate change adaptation. This is based on the general notion that climate change poses adverse impacts which in the absence of effective adaptation mechanisms, affects systems' performance (Adger, 2010; IPCC, 2007; Isoard et al., 2008; Smit and Wandel, 2006).

Uganda's Climate change vulnerability and impact

Uganda is a landlocked nation with substantial natural resources, including fertile soil and regular rainfall conducive for farming. The country is mainly agrarian, depending on primary production and natural resources. The agricultural sector remains a significant contributor to GDP (24%), export revenues (about 48%), and a source of livelihood for over 70% of the population (Uganda Irrigation Master Plan, 2010). However, Uganda is highly vulnerable to climate change (Thornton et al., 2006). Uganda carbon (CO_2) emissions is on the rise. Available statistics indicate that CO_2 increased by 7.8% (4,407.73 metric tons) from 2012 to 2013, by 8.32% (4,774.43 metric tons) from 2013 to 2014 and by 11.9% (5,342.82 metric tons) from 2014 to 2015 (Macro Trends, 2020). In fact, the total GHG emission is estimated to increase from 3.2 million mt CO_2 in the base year (2000) to 24.9 million mt CO_2 by the year 2035 and could double by 2090 (MWE, 2014). Due to the rising carbon (CO_2) emissions, human-induced climate change in Uganda has been predicted to increase average temperatures by up to 1.5°C in the next 20 years and by up to 4.3°C by the 2080s. Such changes bear a detrimental impact on the country's natural resource base, agricultural production, and productivity potential and ultimately curtail sustainable development (MWE, 2015b). Consequently, addressing the climate change issue is critical to the realization of the country's development aspirations.

Floods and landslides remain among the major climate change risks in Uganda (USAID, 2013). The ministerial statement by members of the Parliamentary Forum on Disaster Risk Reduction and Mitigation in partnership with the Civil Society Budget Advocacy Group and OXFAM, Uganda's National Humanitarian Actors (LNHAs) on floods paint a picture of the intensity, frequencies and adverse impacts of foods in Uganda between the period 2015 and 2018. According to the statement, Uganda is not flood-resistant and experiences catastrophic floods annually. In July 2015, River Nyamwamba, in Kasese district, western Uganda, burst its banks for the fourth time in just over three years. In August 2017, heavy rain caused a river to overflow, causing flooding in the town of Elegu in Amuru district, which depleted the economic livelihoods of 3000 households. In September 2017, about fifteen (15) people died and eight (8) others remained missing after heavy rain triggered floods and landslides in the district of Rubanda. In addition, a short period of torrential rain in March 2018 caused severe flash floods in Mbarara district, western Uganda. Notably, the poor rural farmers remain more vulnerable with minimal or no adaptation. Such shocks deplete economic assets such as crops, livestock, and property (OXFAM, 2018).

The impact of climate change to agriculture productivity and growth is quite evident. Significant crop losses were reported at the farm level in 2016 and attributed to climate-related shocks. The growth of the agricultural sector is reported to have declined from 3.8 to 1.5% between the period 2004 and 2015. The impact of climate change to the declining performance of Uganda's agriculture has also been underscored by the UNFCCC report (MWE, 2015b). In fact, climate-induced yield losses are predicted to increase to a range of 50 to 75% by 2050. The potential impact of climate change on the economy cannot be overemphasized given that the

*Corresponding author. E-mail: dmssekamatte@gmail.com.

affected agricultural produce, such as coffee, accounts for 18% of Uganda's export earnings. Similar impacts are felt on tea and cotton.

According to the Uganda climate change vulnerability assessment report (2013), more vulnerable households are those with the lower proportion of able-bodied (working) members; less educated; headed by females; less likely to sell a portion of their crops or livestock; less access to loans; and minimal participation in community groups (USAID, 2013). The most affected sub-counties include Bukigai, Nalwanza, Buwali Bukalasi, Bubiita, Bulucheke, Bushiyi, Bushiribo, Bushika, and Bududa town council being more vulnerable (Irish Aid, 2016). The communities face difficulties adapting despite the availability of a range of adaptation options, including the use of climate-smart farming practices and technologies such as shifting planting dates, crop rotation, mixed farming, mixed cropping regimes, soil and water conservation and migration as the long-term strategy (USAID, 2013).

Climate change adaptation is inevitable. It is costly, but though not to the extent of the cost of none-adaptation. For example, the economic assessment of the impacts of climate change in Uganda estimates the cost of climate change adaptation at 3.2% of total government revenues (excluding grants). The cost of no adaptation is 24 to 46 times greater. Thus, in the absence of adaptation actions, climate factors could compromise the Uganda Vision 2040 target of an 8% annual growth rate (MWE, 2015a). A vicious circle could be evidenced in the absence of effective climate change adaptation. Slow economic growth and increased poverty in the face of limited climate change adaptation will mean reduced low adaption capacity and limited adaptation.

The Government of Uganda has demonstrated commitment to addressing the climate change problem through climate change policies, strategies, action plans, structures, and programs. However, the framework remains scattered in several documents making it difficult to track and conceptualize. Consequently, it is imperative to consolidate the framework and understand how effectively climate change is addressed in the agricultural sector and identify the critical issues for future actions into framing and advancing the climate change agenda in the context of the agricultural sector. Against this background, this paper addressed the following questions:

(1) How is climate change mainstreamed in Uganda's development programming?
(2) How is climate change adaptation mainstreamed in the regulatory environment for climate change adaptation in the agricultural sector?
(3) How is the implementation of climate change adaptation structured in the context of the agricultural sector?
(4) What gaps prevail in the institutional terrain for the advancement of climate change adaption in the agricultural sector?

METHODOLOGY

Findings in this paper are based on data collected through document review and findings of a qualitative case study of Bududa district, representing the local governance of climate change adaptation mainstreaming. A critical review of documents highlighting the context of climate change and the adaptation framework in Uganda in the context of the agricultural sector was done. Categorically, the relevant documents accessed and reviewed included climate change policies, plans and adaptation framework at national and district levels.

A qualitative case study of Bududa district was undertaken to understand how climate change adaptation is mainstreamed in the agricultural sector programming. Bududa district is located in the eastern region of Uganda and is most vulnerable to climate change shock of floods and landslides in the country. It lies between the longitudes of 340 16' 18" and 340 32' 6.69" East, and latitudes 000 58' 45.63" to 10 7' 22.07". The district lies at an average of 1800 m above sea level on the slopes of Mt. Elgon with most vegetation (40%) tropical forests followed by alpine vegetation towards the mountain summit (Figure 1).

The district experiences a bimodal type of rainfall with the highest in the first season of March to June and the second normally light, from September to November. The average rainfall is 1800 mm per annum, highly supportive of intensive agriculture, which forms the backbone of the district economy. The district has a total population of 211,683 and 44,861 households, of which 96.8% is rural (Uganda Bureau Of Statistics, 2014). Most households are poor (33%), and 86% depend on subsistence farming for a livelihood. Due to the high amount of rainfall averaging at 91.2 mm, the steep slopes and valleys are vulnerable to hazardous landslides, which are recurrently characterized by high intensity and severe impacts on agriculture and rural livelihoods of the farming communities (Figure 2).

According to the district multi-hazard, risk, and vulnerability profile (UNDP, 2018), Bududa district is highly vulnerable to landslides, and floods reported as the major disasters in the area. There is a high likeliness of occurrence of floods and landslides estimated at 0.3 and 0.2.

Face-to-face interviews were applied to collect qualitative data from 12 key informants. The key informants were selected using purposive sampling with care taken to represent the most relevant stakeholders across diverse categories of key informants or organizations. Consequently, the analysis was able to tap into the diversity of stakeholders in mainstreaming climate change adaptation, particularly in local governments and in the agricultural sector. The stakeholders included: Political leaders-Local Council V and Local Council III officials, Technocrats in administration units, sub-county officials and agricultural extension workers. Environment and Natural Resources Officers, Technical Committees (District Technical Planning Committee, District Environmental Committees, Disaster Management Committees and Environmental Committees) and Local NGOs and CBOs-Red Cross, Shelters International.

The politicians LCV and LCIII officials oversee implementation of government programs, climate change adaptation inclusive. The technocrats agricultural extension officers manage implementation on agricultural programs, including those related to climate change adaptation. The Environment and Natural Resources officers manage the environmental and natural resource function or programs. The disaster management committees at district and sub-county levels support the implementation of climate change programs. Non-Governmental Organizations (NGOs) and Community Based Organizations implement climate change

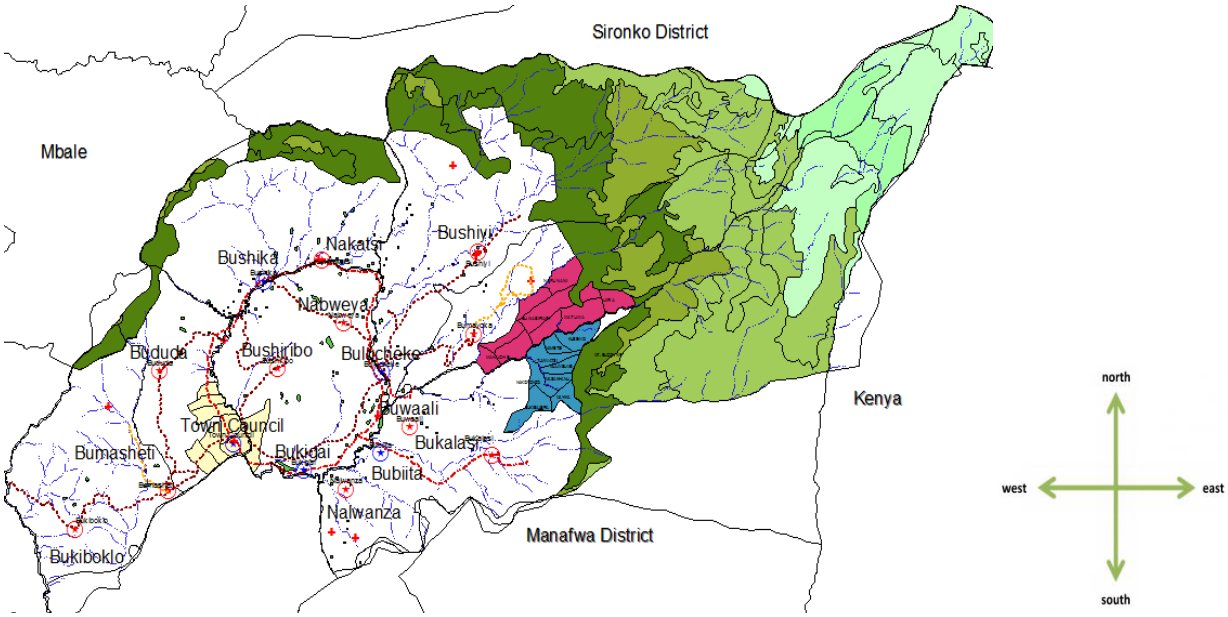


Figure 1. Map of Bududa district.
Source: www.gou.go.ug.

programs and project interventions as well as support the local government climate change structures in functions like planning for and evaluation of climate change interventions.

The interviews were standardized using an interview guide, which was designed with open-ended questions. This ensured the probing of respondents to gain a deeper understanding of the issues under study, as supported by Creswell (2014). The data was analyzed using content analysis.

FINDINGS AND DISCUSSION

The institutional framework for climate change in Uganda

The regulatory environment for climate change

Uganda has made commendable steps in building an institutional framework for addressing climate change. Uganda ratified the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol demonstrating a commitment to the adoption and implementation of policies and measures designed to mitigate climate change and adapt to its impacts. Uganda is also a member of the East African Community and therefore bound by the EAC climate change policy, which urges partner states to develop consistent national policies to ensure harmonized action. This demonstrates commitment and obligation to develop and implement strategies at local and national levels to contribute to the overall goal of combating climate change. This leverages the current national framework to address climate change and its impacts.

At the country level, addressing climate change is flagged off in the country's National Development agenda; vision 2040 and the National Development Plan 2015-2020 (GOU, 2012). This framework is the blueprint for long-term development towards the realization of sustainable economic and social development. The development agenda identifies agriculture among the sectors which are likely to be more affected by climate change impacts and consequently provides for the integration of climate change adaptation measures in agriculture programming at sectoral and local government levels. The development agenda provides strategies for management of climate change, including addressing the legal and institutional frameworks necessary for the implementation of the UNFCCC; multi-stakeholder involvement in tackling the climate change issue; ensuring adequate resources for effective implementation of the committed strategies, mainstreaming climate change adaptation in agricultural programs and projects, including the National Agricultural Advisory Services, among others.

In 2015, the National Climate Change Policy (NCCP) was developed to ensure a harmonized and coordinated approach towards a climate-resilient and low-carbon development path for sustainable development in Uganda. The NCCP sets to address key concerns of climate change adaptation and mitigation, giving priority to adaptation over mitigation. It provides a clearly defined pathway for dealing with the challenges of climate change within the socio-economic context of Uganda.

Uganda's NCCP provides for a decentralized framework for the implementation of the climate change agenda. The local governments are to address climate change

Figure 2. Water run-offs after heavy rainfall on steep slopes of Bududa district.
Source: www.gou.go.ug.

as an urgent issue of district interests as it is at the national level (MWE, 2015a). The policy charges district local governments with the role of implementing climate change programs at all levels of local governance. This framework is entrenched in the legislative framework of decentralization as provided by the local government statute of 1993, the 1995 Constitution, the Local Government Act 1997 and the NCCP 2015, devolves the responsibility for providing services from central ministries to the district level (MWE, 2015b).

In 2016, the National Adaptation Plan (NAP) framework was developed with adaptation strategies contextualized into different agro-ecological zones. A Budget Circular Call (BCC) was issued by the Ministry of Finance, Planning and Economic Development (MoFPED), requiring the mandatory mainstreaming of climate change into all sectoral budget framework papers and district local government plans, starting with the fiscal year of 2017/2018 (FAO, 2011, 2016). In 2018, the Uganda National Climate Change Communication Strategy (UNCCCS) 2017-2021 was developed. The strategy outlines a comprehensive action plan that should be followed while communicating about climate change issues in Uganda. It addresses existing gaps in communication, coordination, and dissemination of climate change adaptation and mitigation information (FAO, 2016).

Uganda's Land Use Policy 2011 recognizes the impact of climate change, especially in exacerbating the already degraded, fragile natural ecosystem. Through the policy, the government intends to address climate change mitigation and adaptation by (a) mainstreaming sustainable management of the environment and natural resources in its plans and programs; (b) putting in place climatic change adaptation strategies to reduce the impact on people and the economy and (c) developing a framework for compliance with all international climate change commitments. These activities are expected to be spearheaded by the Ministry of Lands, Housing and Urban Development (MLHUD). However, most of the Local Governments rarely plan for climate change adaptation, and where these plans exist, they are hardly monitored, implemented or evaluated as required by the national policy framework on climate change adaptation (Sridharan et al, 2019).

Climate change management and implementation structures

Management and implementation of the climate change agenda engage structures at national and local levels. A summary of the structures is outlined in Table 1.

The Ministry of Water and Environment is the national coordinating body for climate change issues in Uganda. It manages the implementation of climate change adaptation and mitigation interventions. It is supported by five ministries, the MOFPED finances and monitors climate change implementation interventions funded through the ministry. MAAIF manages the implementation of climate change adaptation interventions related to agriculture since the sector is among the most vulnerable to climate change shocks. Under the decentralized model of governance in Uganda, the MOLG provides oversight to climate change programs within the local governments, Bududa district inclusive. NARO is a mother research organization that conducts research, develops, disseminates and supports the adoption of modern agricultural technologies, including those which are climate-smart or climate-resistant. The Ministry of Lands, Housing and Urban Development (MLHUD) implements and oversees interventions towards the soil and

Table 1. Management and implementation of the climate change agenda: key structures.

Category of research participants	Institution/Unit where paricipants were selected
Stakeholders in subsidiary ministries and supporting institutions	Ministry of Water and Environment (MOWE) Ministry of Finance Planning and Economic Development (MOFPED) Ministry of Agriculture Animal Industry and Fisheries (MAAIF) Ministry of Local Government (MOLG) Ministry of Lands, Housing and Urban Development (MLHUD) National Agriculture Research Organization (NARO)
Lead Government Departments' staff	MWE Climate change unit Climate change policy committee, The Climate Change Task Force of MAAIF Climate Change Policy Committee
Supporting International Development Agencies	Food Agriculture Organization (FAO) United States Agency for International Development (USAID) United Nations Development Program (UNDP) Federal Department of International Development (DFID)
Local Government climate change stakeholders	Political leaders – Local Council V, Local Council III Chairperson Technocrats Chief Administrative (CAO), Sub-county Chiefs & Agricultural Extension Officers (AEOs), Environment and Natural Resources Officer Technical Committees (District Technical Planning Committee, District Environmental Committee, Disaster Management Committees & Environmental Committees)
	Local NGOs and CBOs- Red Cross, Shelters International, Office of the Prime Minister (OPM)

environmental conservation in the sectors of land management and urban development.

The key international development agencies which have mainstreamed climate change adaptation into their Uganda country programs include UNDP, FAO, USAID, and DFID. For example, UNDP coordinates inter-agency responses to climate change adaptation. Funds from the Global Environmental Facility (GEF) are channeled through UNDP. The agency also pioneered and supported the implementation of the climate change National Adaptation Policy Actions (NAPA). It also takes the lead on the implementation of the Sustainable Development Goal (SDG) 13 on climate change. FAO provides implementation support to national and local projects designed specifically to address climate change adaptation, climate-related disaster risk management, or a combination of adaptation and mitigation. Specifically, FAO supported development of the institutional framework for climate change adaptation in agriculture in Uganda and led the preparation of the country's National Adaptation Plan (NAP) framework. USAID funds research on climate change adaptation, the latest being the 2013 Uganda Climate Change Vulnerability Assessment. Together with DFID, USAID also funded a study on the costs of climate change in Uganda. USAID also funds capacity building interventions for climate change adaptation through programs such as the enabling environment for agriculture activity. DFID is implementing a project called the Northern Uganda-Transforming the Economy through Climate-smart agriculture (NUTEC), which is also implemented in Bududa district.

Notably, the mentioned ministries and international agencies have designated person-in-charge of climate change adaptation. For instance, the climate change advisor at DFID; the Team leader-Climate change and energy at UNDP; the Program Manager for Climate Change at FAO; the Commissioner for climate change within the climate change department at the MWE; and the Climate desk officer at the MOFEPD.

At the local government level, climate change stakeholders include political leaders (Local Council V and Local Council III Chairpersons); technocrats including the Chief Administrative (CAO), sub-county chiefs, agricultural extension officers (AEOs), and environment and natural resources officer. In addition, there are technical committees, including the District

Technical Planning Committee, the Environmental Committee as well as the Disaster Management Committee at district and sub-county levels.

The LCV and LCIII chairpersons oversee the implementation of government programs, including climate change adaptation. The Environment and Natural Resources Officer manage the environmental and natural resources function or programs. The Agricultural Extension Officers manage implementation on agricultural programs, including those related with climate change adaptation. The disaster management committees at district and sub county levels supports the the implementation of climate change programs. Non-Governmental Organizations (NGOs) and Community Based Organizations implement climate change programs and project interventions as well as support the local government climate change structures in functions like planning for and evaluation of climate change interventions.

Climate change mainstreaming in the agricultural sector

Mainstreaming climate change adaptation in the agricultural sector is flagged off in the Uganda's climate change policy which identifies agriculture among the priority sectors given its high vulnerability to climate change and significance to the country's development. Specific emphasis is put on climate change adaptation strategies that enhance resilient, productive and sustainable agricultural systems; and promoting value addition, improving food storage and management systems in order to ensure food security at all times as a factor of resilience. The policy underscores the need to support research and development, transfer and diffusion of climate-smart technology and information to better understand the impacts of climate change (MWE, 2015a).

The policy recognizes agriculture among the key priority sectors in addressing climate change adaptation and sets out agricultural sector climate change adaptation priorities. They are expanding extension services, climate-smart agriculture, livestock and crop enterprise diversification, value-addition post-harvest handling and storage, markets and access to finance, rangeland management, research on climate resilient crops and animal breeds, as well as value addition and irrigation infrastructure. The key players supporting implementation of these sector priorities include the National Agricultural Research Organization (NARO), universities and private research organizations, national programs such as the National Agricultural Advisory Service (NAADS) and Operation Wealth Creation, NGOs and CBOs (USAID, 2013). MAAIF is charged with management of climate change adaptation interventions in the agricultural sector. Notably, however, the interventions towards climate change adaptation necessitate financial investment yet farmers have limited access to finance. Agricultural insurance which would potentially promote financing of adaptation measures (Acosta-Diaz et al., 2009), is loosely advanced as a climate change mitigation strategy particularly in the context of farming communities which are more vulnerable to climate risk hazards. Institutionalization of agricultural insurance in climate change adaptation and its advancement in the climate change vulnerable communities necessitates empirical exploration. Limited advancement of agricultural insurance in climate change adaptation will compromise efforts to create resilient communities in the face of climate change.

Institutional structures for climate change adaptation

Among the stakeholders supporting national efforts include Climate Action Network Uganda (CAN-U), a coalition of non-governmental organizations advocating for climate adaptation justice in Uganda; the department of meteorology within the Ministry of Water and Environment which coordinates climate change activity, in its capacity as the national focal point for climate change under the UNFCCC; the Ministry of Health and Ministry of Finance, Planning and Economic Development which finances climate change adaptation budgets across ministries and sectors; the Commission on Disaster Management and Refugees (CDMR) under the Office of the Prime Minister coordinating an effective response to climate induced disasters such as droughts and floods; the Directorate of Water Resources Management and Directorate of Water Development within the Ministry of Water and Environment.

Specific to the agricultural sector, the National Agricultural Research Organization and universities such as Makerere conduct research developing climate-smart technologies such as risk resistant varieties and water resources management technologies. Agricultural extension organizations particularly the Ministry of Agriculture Animal Industry and Fisheries, the National Agricultural Advisory Service (NAADS) and Operation Wealth Creation work with the local government agricultural extension structures and NGOs to institutionalize, promote adoption and replicate the technologies. They also extend information, credit services, agricultural financing and agricultural insurance services to farmers (USAID, 2013). However, how the technologies and services are being accessed by farmers, how they influence farmers' adaptive capacity and emerging constraints in the context of adaptation to climate change induced floods and landslides in Bududa district is yet to be understood. In addition, there is paucity of knowledge regarding the coordination and interactions between agricultural extension, research organizations and local communities to tap into local knowledge, innovations and technologies towards

building more sustainable adaptive capacity.

Case study findings: Mainstreaming climate change adaptation agricultural programming at local government level

Results of the study showed that Bududa district local government does not periodically undertake periodic planning of climate change adaptation. Climate change adaptation is loosely mainstreamed into the district programming. Climate change adaptation was underscored in the vision of Bududa District Local Government "to have a prosperous and democratic society in a sustainable environment" though on the contrary stakeholders did not perceive climate change adaptation as central to the vision. This variance signifies insufficient knowledge of the district strategic positioning regarding climate among some stakeholders. The other gap was that the institutional programming was adhoc and focused more on disaster management in times of disasters like landslides rather than the required integrated/institutionalized processes of planning, implementing and evaluation. In addition, there are no specific and stand-alone policies, plans and byelaws towards promoting climate change adaptation. Further to note, there was no evidence of mainstreaming climate change adaptation programming across the different district departments and at the relevant lower level local government structures. While effective climate change programming would necessitate an institutionalized framework for developing abilities of staff in climate change, the district had no institutionalized training plan specific for stakeholders in climate change. The district-level intended actions on staffing, budget and policy frameworks were not responsive to climate change adaptation processes contrary to the requirement under the Uganda Climate Change Policy, 2015 and the Uganda Climate Change Plan of Action. In confirmation, one of the respondents had this to say:

"One of the problems is that the budget process is often guided by the indicative planning figures yet as a district, we do not have special budget codes or the authority to include critical climate change adaptation that the community would have identified" (Participant C).

Though the identified institutional capacity gaps can be explained by many factors, low level of budget support from the central government, the rural and hard to reach nature of the district appeared more critical. Interviews revealed that the district does not make sufficient budget allocation for climate change adaptation and quite often the budget does not address key priorities of the district for climate change adaptation. The district budget formulation process rarely picks out critical areas of support needed towards climate change adaptation. Arguably, funding is critical to support efforts towards building a competent human resource and institutional framework for effective climate change programming.

Notably, however, positive signs of improvement towards strengthening the institutional capacity for climate change adaptation programming were noticed. It was evident that the district leadership team was committed to creating an enabling environment that could galvanize district intended actions that support local climate change adaptation. The district developed a contingency plan for disaster risk reduction (DRR) to major challenges of unreliable weather pattern caused by global weather change. Further interviews revealed that the district in close collaboration and coordination with the Office of the Prime Minister (OPM) and the District Disaster Management Focal Persons routinely collects data using GIS with the aim of identifying the various hazards ranging from drought, floods, landslides, human, animal and crop diseases, pests, wildlife animal attacks, earthquakes, fires and conflicts among others. It was through this process that the district developed the district Multi-Hazard, Risk and Vulnerability Profile in 2016. These documents provide vital evidence to inform periodic programming for climate change adaptation.

In addition, the five-year District Development Plan (DDP) mirrors the strategic alignment of the district local government programs to the intended district level actions as provided for within the provisions of the law. A case in point is the participatory process for the integration of climate change adaptation plans for the lower local governments and other development partners into the district strategic plan which was being followed as required by the broader National Adaptation Policy and Actions (NAPA). This provides an opportunity for stakeholders' engagement as well as justifies any potential initiatives to support capacity building towards effective stakeholder engagement in climate change programming.

The significance of strategic positioning to climate change adaptation at local government level is consistent with Matthews et al. (2012) who consider strategic alignment as a key success factor for climate change adaptation because it enables local authorities to access a wider range of resources and to develop mutual benefits with other local projects that address climate change challenges. Burton et al. (2006) shared a similar view that adaptation efforts and activities need to be well directed, they must be guided and supported by policies and strategies developed by the leadership teams of affected areas.

Conclusions

Significant steps have been taken to mainstream climate change adaptation in agricultural programming and interventions are geared towards expanding extension

services, climate-smart agriculture, livestock and crop enterprise diversification, value-addition post-harvest handling and storage, markets and access to finance, rangeland management, research on climate resilient crops and animal breeds, as well as value addition and irrigation infrastructure. Notably, however, adoption of such interventions necessitates capital resources, yet farmers are poor with limited access to agricultural finance/credit. Agricultural insurance which would foster access to finance is loosely advanced as a climate change mitigation strategy particularly in the context of farming communities which are more vulnerable to climate risk hazards.

Climate change adaptation is loosely mainstreamed in local government programming despite the policy provisions. There are critical institutional capacity gaps which are hinged on low level of budget support from the central government towards climate change adaption in local governments. In the context of agricultural programming, the budget allocation towards expanding extension services, climate-smart agriculture, livestock and crop enterprise diversification, value-addition post-harvest handling and storage, markets and access to finance is quite limited. Generally, district local governments were observed to make insufficient budget allocation for climate change adaptation in terms of addressing the key priorities.

PRACTICAL IMPLICATIONS

The Ministry of Agriculture, Animal and Fisheries in collaboration with Ministry of Water and Environment as well as Ministry of Finance Planning and Economic Development need to institutionalize agricultural insurance in climate change adaptation with focus on the farming communities which are more vulnerable to climate change hazards. However effective institutionalization of agricultural insurance will necessitate further research to identify the potential, opportunities and challenges of advancing agriculture as a robust climate change adaptation strategy in Uganda.

Effective mainstreaming of climate change adaptation in agricultural programming in local governments will necessitate increased budget support from the central government towards capacity building of local government climate change structures for effective climate change adaptation programming. The budget should be targeted to finance key priorities areas for climate change adaptation in the specific contexts on local governments. Capacity building will foster districts' ability to plan, monitor and evaluate climate change adaptation initiatives.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Adger WN (2010). Social capital, collective action, and adaptation to climate change. In Der klimawandel VS Verlag für Sozialwissenschaften pp. 327-345.

Burton I, Diringer E, Smith J (2006). Adaptation to climate change: International Policy Options. Pew Centre on Global Climate Change, Arlington, USA.

Acosta-Díaz E, Acosta-Gallegos JA, Trejo-López C, Padilla-Ramírez JS, Amador-Ramírez MD (2009). Adaptation traits in dry bean cultivars grown under drought stress. Agricultura Technica en Mexico 35(4):419-428.

Creswell J (2014). Research design: Qualitative, quantitative, and mixed methods approaches 2nd ed. Thousand Oaks, CA: Sage Publications.

Environmental Alert (2010). Climate Change in Uganda: Insights for Long Term Adaptation and Building Community Resilience. http://envalert.org/wp-content/uploads/2016/06/Climate-Change-Issues-paper.pdf

Food and Agricultural Organization of the United Nations (FAO) (2011). FAO-Adapt Framework Programme on Climate Change Adaptation. http://www.fao.org/resilience/resources/resources-detail/en/c/1114449/

Food and Agricultural Organization of the United Nations (FAO) (2016). Integrating Agriculture in National Adaptation Plans (NAP-Ag) Inception Report, Kampala, Uganda. https://www.adaptation-undp.org/sites/default/files/resources/nap-ag-highlights-2015-2017.pdf

Government of the Republic of Uganda (GOU) (2012). Uganda Vision 2040. (Available at: http://npa.ug/wpcontent/themes/npatheme/documents/vision2040.pdf) (Accessed, April 2019).

Isoard S, Grothmann T, Zebisch M (2008). Climate Change Impacts, Vulnerability and Adaptation: Theory and Concepts. Workshop 'Climate Change Impacts and Adaptation in the European Alps: Focus Water. Vienna. https://eve.cranfield.ac.uk/urd/sits.urd/run/siw_ipp_cgi.start

Irish Aid (2016). Uganda Climate Action Report for 2016. www.irishaid,ie

OXFAM (2018). OXFAM Annual Report 2018-2019. OXFAM, Kampala Uganda. https://uganda.oxfam.org/latest/policy-paper/oxfam-uganda-annual-report-2018-2019

Macro trends (2020). Uganda Carbon (CO2) Emissions 1960-2020. Available at https://www.macrotrends.net/countries/UGA/uganda/carbon-co2-emissions

Matthews HD, Solomon S, Pierrehumbert R (2012). Cumulative Carbon as a policy framework for achieving climate stabilization. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 370:4365-4379.

Ministry of Water and Environment (MWE) (2014). Uganda Second National Communication to the United Nations Framework Convention on Climate Change October 2014. https://unfccc.int/resource/docs/natc/uganc2.pdf

Ministry of Water and Environment (MWE) (2015a). Uganda National Climate Change Policy. https://www.mwe.go.ug/sites/default/files/library/National%20Climate%20Change%20Policy%20April%202015%20final.pdf

Ministry of Water and Environment (MWE) (2015b). Economic Assessment of the Impacts of Climate Change in Uganda, Final Study Report, Kampala, Uganda. https://cdkn.org/wp-content/uploads/2015/12/Uganda_CC-economics_Final-Report2.pdf

Smit B, Wandel J (2006). Adaptation, Adaptive Capacity and Vulnerability. Global Environmental Change 16:282-292.

Sridharan V, Pereira R, Zepeda E, Boehlert B, Shivakumar A, Tailotis C, Howells M (2019). The Impact of Climate Change on Crop Production with Water and Energy Implications. Water 11(1805):1-24.

United Nations Development Programme (UNDP) (2018). Climate Change Adaptation in Africa: UNDP Synthesis of Experiences and Recommendations, Bangkok, Thailand. https://www.thegef.org/sites/default/files/publications/CCA-Africa-

Final.pdf
United States Agency for international development (USAID) (2013). Uganda Climate Change Vulnerability Assessment, Report August, Kampala, Uganda. file:///C:/Users/DELL/Desktop/Articles/doc%2013%20USAID%20Uganda%20Vulnerability%20Assesment%20Report%202013.pdf
Uganda Bureau of Statistics (2014). The National Population and Housing Census 2014 Main Report, Kampala, Uganda. https://www.ubos.org/wp-content/uploads/publications/03_20182014_National_Census_Main_Report.pdf

Vol. 14(10), pp. 311-328, October 2020
DOI: 10.5897/AJEST2020.2882
Article Number: 1833B5764870
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Assessment of air pollutant emissions from healthcare waste incinerators of different design features

Anicetus Honest[1]*, Samwel Manyele[2], Josephat Saria[3] and Julius Mbuna[4]

[1]Ministry of Health, Community Development, Gender, Elderly and Children, P. O. Box 743, Dodoma, Tanzania.
[2]Department of Chemical and Mining Engineering, University of Dar es Salaam, P. O. Box 35131, Dar es Salaam, Tanzania.
[3]Department of Environmental Studies, The Open University of Tanzania, P. O. Box 23409, Dar es Salaam, Tanzania.
[4]Dar es Salaam College of Education, P. O. Box Private Bag, Dar es Salaam, Tanzania.

Received 9 July, 2020; Accepted 11 August, 2020

The aim of this paper was to e valuate the levels of gaseous emissions from four different healthcare wastes incinerators in three regional hospitals and one national hospital in Dar es Salaam, Tanzania. The incinerators studied differ in terms of capacity (kg/h) and design features. Five gaseous air pollutants (CO, CO_2, NO_x, and SO_2) were analyzed in the sampled flue gases using a portable desktop combustion gas analyzer (model KANE900 Plus). About 29, 30, 34 and 40 consecutive runs were conducted for each incinerator at Amana, Temeke, Mwananyamala, and Muhimbili National Hospital (MNH), respectively. Other properties of the flue gas analyzed include temperature (FT), combustion efficiency (CE), percent excess air, and CO/CO_2 ratio. Results showed lower CE range (lowest at Ilala regional hospital (51.4%) and highest at MNH (60.0%). The highest flue temperature was detected at MNH (911°C). The CE and pollutants concentration increased with FT and decreased with percent excess air. Results indicated poor performance of the incinerators, due to higher gaseous emissions above US-EPA standards, putting communities around these hospitals at occupational and public health risks. Installation of various air pollution control devices (APCDs) as well as monitoring and inspection programs is strongly recommended.

Key words: Incinerator, combustion efficiency, healthcare waste, flue gas, acidic gaseous emissions, excess air, flue gas temperature.

INTRODUCTION

Of all the available technologies for disposal of healthcare waste, incineration has been found to be the most effective method overall for destroying infectious and toxic material, in the healthcare waste stream with high volume and weight reduction (Singh and Prakash, 2007). However, poor performance of incinerators may result into release of many toxic substances necessitating research. According to World Health Organization (WHO,

*Corresponding author. E-mail: hanicetus@gmail.com. Tel: +255 754311115.

2014), healthcare waste is defined as any waste, which consists wholly or partly of human and animal tissue, blood or any other body fluids, excretions, drugs or pharmaceutical products, swabs or dressings, syringes, needles or sharp instruments, being waste which unless rendered safe may prove hazardous to any person coming into contact with it (Baharun et al., 2005; Manyele and Anicetus, 2006; Manyele and Mujuni, 2010). Hazardous waste is treated almost exclusively by incineration. Incineration must be understood as an element of comprehensive logistics for the treatment of those wastes which due to their harmful nature have to be managed separately from municipal waste. Hazardous waste is waste requiring particular supervision, which by its nature, condition or amount poses a particular hazard to health, air and/or water pollution (Gitonga, 2017). Currently, there is a rapid increase in the use of incineration and burning structures, especially in healthcare waste instead of landfilling as means of disposal of healthcare waste in Tanzania and elsewhere. Incinerators are widely used due to their waste volume and weight reduction potential, and efficacy in destroying pathogens and toxic chemicals in the waste (ICRC, 2011). Another advantage is the ability of incineration method to suit most types of waste. These incinerators are however, known to release good number of toxic chemicals into the atmosphere as well as to produce ashes and other solid waste residues. Undesirable health effects due to mass burn incineration of healthcare waste are of great concern as large population groups and workers may be exposed to the emitted toxic substances (WHO, 2018). Many of these substances such as dioxins, and heavy metals are known to be persistent, bioaccumulative, carcinogenic or endocrine disruptors. Waste generated by healthcare activities includes a broad range of materials from used needles and syringes to soiled dressings, hypodermic needles, intravenous set needles, broken vials and ampoules, dressings, bandages, gauze, and cotton contaminated with blood or other body fluids; and many other including diagnostic samples from laboratories and mixed or absolute chemicals (World Bank, 1999; Gitonga, 2017; Manyele and Anicetus, 2006).

Incineration is a waste treatment process that involves combustion of organic substances contained in waste materials (Batterman, 2004). Incineration of waste materials converts the waste into ash, flue gas, and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulate matter (PM) carried by the flue gas (Wiles and Shepherd, 1999). The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into atmosphere. In some cases, the heat generated by incineration can be used to generate electric power or heat the water for use in the hospital (Batterman, 2004), leading to energy saving.

In several countries, there are still concerns about the environmental impact of incinerator wastes (Batterman, 2004). Many of these incinerator wastes especially from poor countries were built few decades ago and did not include systems for materials separation to remove hazardous, bulky or recyclable materials before combustion (Batterman, 2004; Manyele et al., 2011). These facilities tend to risk the health of the community around due to inadequate levels of gas cleaning and combustion process control (Batterman, 2004).

To minimize the hazards, incineration of healthcare waste is a significant alternative way for disposal of this category of waste. Emissions of heavy metals and organic pollutants from these facilities cause significant environmental harm (Anamul et al., 2012). People living near incinerators are similar to those living near landfill sites or dump sites in which they are potentially exposed to chemicals by way of inhalation of contaminated air, consumption of contaminated foods, water or dermal contact with contaminated soil (Allsopp et al., 2001). Incinerator operators can also be occupationally exposed to chemicals emitted from incinerators, which are generally of higher intensity and duration compared with environmental exposures; quantitative levels of compounds can be more easily ascertained and defined. According to Goren et al. (1999) determination of occupational exposure to the general population needs care since workers differ from the general population in terms of sex, age, and lifestyle, and are also self-selected to be relatively healthy (healthy worker effect).

Tanzania like many other developing countries still faces the problem of healthcare waste management (HCWM). The unsafe disposal of health-care waste (for example, contaminated syringes and needles) poses public health risks (Baharun et al*.,* 2005; Manyele and Mujuni, 2010). Contaminated needles and syringes represent a particular threat as the failure to dispose of them safely may lead to dangerous recycling and repackaging, which lead to unsafe reuse. Contaminated injection equipment may be scavenged from waste collection and storage areas and dumpsites and either are reused or sold to be used again (Ferronato and Torretta, 2019).

The use of healthcare waste incinerators appears to be rapidly expanding in developing countries whereas it discharges hundreds of pollutants into atmosphere (Ferronato and Torretta, 2019). Many of these chemicals are both toxic and bio accumulative, building up over time in the body in an insidious fashion with the risk of chronic effects at much lower exposures (Takata, 2003). In Tanzania, very little attention has been paid to the concentrations of the major chemicals emitted in an effort to avoid acute local toxic effects.

The combustion process in the incinerator is an exothermic reaction between organic matter in the waste acting as a fuel and oxygen. During incineration process, the fuel is predominantly waste loaded and the oxygen source is air. During this process of combustion, many of

the end products are stable whether the material burned is healthcare waste, municipal solid waste, natural gas, coal, gasoline, wood or hazardous waste (Hettiarachchi et al., 2018). The flame zone in the incinerator is sufficiently hot to break down all organic and many inorganic molecules, allowing reactions between most volatile components of the waste and the oxygen and nitrogen in air. Because the dominant element is carbon and hydrogen, therefore the predominant reactions are between carbon and oxygen, producing carbon dioxide (CO_2), and between hydrogen and oxygen, producing water vapor. When there is insufficient air supply, incomplete combustion of organic compounds in the waste feed stream produces some carbon monoxide and carbon-containing particles. Hydrogen also reacts with organically-bound chlorine to produce hydrogen chloride (HCl). In addition, many other reactions occur, producing sulfur oxides (SO_x) from sulfur compounds, nitrogen oxides (NO_x) from nitrogen compounds (and, a little, from the nitrogen in the air), metal oxides from compounds of some metals, and metallic vapors such as mercury and lead (Wiedinmyer et al., 2014).

The exact composition of emissions from incinerators will vary with type of waste loaded at given time, the efficiency of the installation and the pollution control measures in place (Takata, 2003). During incineration more toxic forms of some of heavy metals and man-made organic chemicals can be created. The three most important constituents of the emissions, in terms of health effects, are particulates, heavy metals, and combustion products of man-made chemicals (Wiedinmyer et al., 2014). The latter two can be adsorbed onto the smaller particulates making them especially hazardous. In Tanzania, most hospitals had low incineration capacity, with few of them made of fire brick and other refractory materials (Baharun et al., 2005; Manyele and Anicetus, 2006). On the other hand, poor management of healthcare waste potentially exposes health care workers, waste handlers, patients and the community at large to infection, toxic effects and injuries, and risks of polluting the environment. It is essential that all healthcare waste materials are segregated at the point of generation, appropriately treated and disposed of safely (WHO, 2011). The United States Environmental Protection Agency (US-EPA) recommended standards for CO, SO_2, and NO_x are 97.9, 88.1 and 411.2 mg/m^3, respectively.

Over the last three decades there has been increasing global concern over the public health impacts attributed to environmental pollution, in particular, the global burden of disease. The World Health Organization (WHO, 2014) estimated that about a quarter of the diseases facing mankind today occur due to prolonged exposure to environmental pollution. Most of these environment-related diseases are, however, not easily detected and may be acquired during childhood and manifested later in adulthood due to long latency periods of toxins in the human body.

The impact of waste incinerators on health and their releases of hazardous combustion products, such as dioxins and PAHs are of great public concern (Ernesto and Savino, 2019). Research has identified numerous toxic compounds, which are emitted in stack gases and in ashes, as well as many unidentified substances of unknown toxicity (Ardevol et al., 1999). Individuals who are exposed to the hazardous substances resulting from incineration, and whose health can, therefore, be potentially affected by such exposure, include workers connected with incinerator facilities and populations living within their local vicinity.

The potential effects of metals and other pollutants that are very persistent in the environment may extend well beyond the area close to the incinerator. Persistent pollutants can be carried long distances from their emission sources, go through various chemical and physical transformations, and pass numerous times through soil, water or food. Dioxins, furans, and mercury are examples of persistent pollutants for which incinerators have contributed a substantial portion of the total national emissions (Parry and Stevens, 2001).

Persistent air pollutants, such as dioxins, furans and mercury, can be dispersed over large regions well beyond the local areas and even the countries from which the sources first emanate. Food contaminated near an incineration facility might be consumed by people close to the facility or far away from it. Thus, local deposition on food might result in some exposure of populations at great distances, due to transport of food to the markets. However, distant populations are likely to be more exposed through long-range transport of pollutants and low-level, widespread deposition on food crops at locations remote from the incineration facility (Demirezen and Aksoy, 2006).

Waste products resulting from incineration take the form of stack gas emissions to the atmosphere, bottom ashes (slag) and fly ashes (caught in filters in the incinerator stack) which ultimately are disposed of to landfill sites. Where water is used for cleaning processes in an incinerator, there are also releases of waste products to water (Allsopp et al., 2001), which is easier to manage than when emitted into atmosphere such systems include water operated wet scrubbers.

The weight and volume of the original raw waste are normally reduced during incineration. It is often stated that the solid residues (ashes) remaining are less than one quarter to one-tenth of the initial weight of the raw waste (Pluss et al., 1991; Matee and Manyele, 2015a) and volume reduction of about 90-95% is achieved (Pluss et al., 1991; Baharun et al., 2005). Higher weight reduction of up to 94.6% has been reported (Matee and Manyele, 2015a). If the entire pollutants load in the output from an incinerator is summed up, then the output will exceed the original waste input in terms of mg/kg, indicating that the pollutants become concentrated in the

small volume or weight of ashes. This is true for heavy metals, which would otherwise be widely spread in the environment. Given the small amount of ashes generated, it is easy to control the pollutants (Matee and Manyele, 2015a).

The gases present in the stack result from the combination of carbon-based materials with oxygen and are usually ignored in calculating the mass of residues. The combination with oxygen to form CO_2 increases actual weight of the gas. Aeration during incineration also contributes to the volume of flue gas. Residues from wet gas cleaning systems can generate appreciable volumes of contaminated water and solids. However, the resulting liquid waste can be easily controlled than when the pollutants are dispersed into atmosphere (Enviros Consulting Ltd., 2004). In the case of the statistic concerning volume reduction, this is usually generated by reference to the volume of un-compacted wastes (Pluss et al., 1991). However, experience based on handling HCW, will support the volume reduction concept. Landfilled municipal solid waste MSW, however, is generally compacted to increase stability and prevent water infiltration as well as reduce the volume of the wastes. Such compaction is, however, minimal compared to volume and weight reduction via generation of ashes after combustion incineration (Wiles and Shepherd, 1999).

The exact nature of the substances released during incineration depends on the composition of the waste that is incinerated. For instance, incineration of chlorinated organic compounds will cause the formation of hydrogen chloride (HCl) and this in turn can contribute to the formation of dioxins (Allsopp et al., 2001). Technical standards that are applied both to the incineration process and to pollution control equipment will also influence the final products of incineration (Oppelt, 1987). However, whatever control technology is applied, all types of incineration result in releases of toxic substances in ashes and in the form of gases and particulate matter. It is also ascertained that the products of compounds that contain sulfur, nitrogen and halogens have a potential effect on human health and the environment. Specific compounds of concern which are generated include CO, NO_x, SO_x, and HCl.

Nitrogen oxides, sulphur dioxide and carbon monoxide are among pollutants emitted from incinerators. Apart from contribution to the formation of ozone and acidic aerosols, the oxides of nitrogen and sulphur dioxide are associated with respiratory short-term effects especially in individuals with a particular susceptibility (Goren et al., 1999). Carbon monoxide is likely to increase the onset of heart disease.

According to Baharun et al. (2005), for the perfect working incinerator the combustion efficiency is assured by operating the secondary combustion chamber at temperature ≥ 1000°C at the same time maintaining an oxygen rich environment. The burners will re-ignite the partial products of combustion emitted from the primary chamber and raise the temperature of the gases in the excess of 1000°C (Matee and Manyele, 2015b). Baharun et al. (2005) indicated that the combustion efficiency in the secondary chamber is necessary to minimize emissions of byproducts of incomplete combustion and is capable of achieving combustion efficiency of up to 99.99% if the temperature is ≥ 1000°C. The combustion air is supplied by the fan controlled to maintain an oxygen level of not less than 7% (Baharun et al., 2005).

The aim of the present work was to evaluate the levels of emissions of four healthcare waste incinerators in four hospitals (Ilala Regional Hospital, Temeke Regional Hospital, Mwananyamala Regional Hospital, and MNH) all of which are in Dar es Salaam Region. Five air pollutants (CO, CO_2, NO_x, and SO_2) were sampled and analyzed in the emissions. Further analysis involved experimental determination of CE expressed as a percentage and CO/CO_2 ratio.

MATERIALS AND METHODS

Sample collection sites

The study was conducted at three municipal regional hospitals (Ilala, Temeke and Mwananyamala) and one National Hospital (MNH). All these hospitals have double-chamber high-tech incinerator. In this type of incinerator, there are two burners of similar specifications, the primary and secondary combustion chamber. The chambers' fire-walls are made of refractory bricks, with secondary chambers about 1/3 of the primary chambers in size. The primary and secondary chambers for Temeke Hospital incinerator are supplied with excess air from a 1.1 kW blower, while all other incinerators use burners with high blowing capacity. According to Manyele et al. (2011), the burners at Temeke Hospital are made to use 7 L of oil per cycle and are designed to return the un-used oil to the tank. The specification of the burners: Rielo 40 G series, 230 V, 50 Hz, capacity of 95-213 kW, and fuel maximum viscosity is 6 mm^2/s at 20°C are fitted on both chambers and able to burn waste at high temperature more than 1000°C. The control panel contains all switches for timer, primary burner, blower, and temperature displays. Healthcare waste was collected from different sections of the hospital and weighed. The healthcare waste was loaded manually after identifying the content in the waste. The incinerated materials were not sorted and contain mostly pampers, gloves, needles, infusion, swabs, packing materials, syringes, blood, paper, and drugs remains. The wastes were then mixed in the primary chamber in order to facilitate good combustion followed by tightly closing the loading door ready to start combustion. The incineration time was set and the secondary burner switched on in order to pre-heat the chamber up to a temperature of about 250 to 300°C, followed by switching on the primary burner and air blower.

Determination of gaseous emissions

The gaseous emissions concentration from incinerator stack was determined using a portable desktop combustion gas analyzer type KANE900 Plus manufactured by KANE International Limited, UK. The combustion gas analyzer undergoes automatic calibration once switched ON by pumping in fresh air into the sensors to allow toxic sensors to be set to zero and the oxygen sensor to be set to 20.9% or above, which is normally found in ambient air. As per combustion

analyzer emission measuring specifications, the sampling hole should be located and drilled at the length of two times the internal diameter (ID) of the stack from the incinerator chimney or where the stack starts which was almost 2 ft from the base of the stuck. Also the probe with thermocouple (temperature detecting sensor with a range from 0 to 1200°C) was connected to the analyzer and then inserted to the drilled hole at the center of the stack or exhaust diameter. The hole measures 17 mm. The analyzer established the air composition characteristics in combustion exhaust/stack by recording the proportions of oxygen (%O_2), and carbon dioxide (%CO_2), carbon monoxide (CO in mg/m^3), nitrogen oxides (NO_x in mg/m^3), sulfur dioxide (SO_2 in mg/m^3), carbon monoxide/carbon dioxide ratio (CO/CO_2). It also determines flue and ambient temperatures (FT and AT in °C), excess air (X Air in %), combustion efficiency (CE in %), and draft (mbar) reading time or residence time. The combustion efficiency, describes how good or poor fuel (mostly hydrocarbon) is burning in the presence of oxygen, producing carbon dioxide and water.

RESULTS AND DISCUSSION

Design features and performance of incinerators studies

Table 1 shows the design features in capacity and maximum observed temperatures of the incinerators in different hospitals.

Table 1 indicates the type and capacity of the incinerators operated in the study area and the highest temperature observed during the study. The highest was Incinerator at MNH with a temperature of 914°C and the lowest was Ilala with a temperature of 711°C. Only one (1) (MNH incinerator) operated earlier required temperature of 850°C and above. This indicates that majority 75% of incinerator operate below required standard of 850°C. In this study, the maximum combustion efficiency was detected at MNH state average, that is, 65.9% and the lowest was at Mwananyamala Regional Hospital with CE of 54.2%.

In developed countries operation of the incinerators is governed by regulating board, such that to qualify for a process of the thermal treatment of healthcare waste, that possess infectious and non-infectious properties, requires that the temperature of the flue gas, measured near the inside wall of the combustion chamber, after the last air supply is at least 850°C for the non-infectious waste, and at least 1100°C for the waste with the infectious properties (Wajs et al., 2019). This temperature must be maintained for at least two seconds, even under the most adverse conditions (for example unstable work of the burners). This is not the case for the present study as the highest temperature was detected at MNH with 914°C followed by Temeke Regional Hospital with 842°C, Mwananyamala Regional Hospital 792°C and the lowest was at Ilala Regional Hospital with 711°C. The results observed concur with the values obtained earlier where the average maximum temperatures achieved in the primary chamber was 397.8 and 839°C for secondary chamber. These temperatures were lower compared to the design temperatures of 850 and 950°C as a result of loading wet waste. The healthcare waste materials from these hospitals are characteristically heterogeneous. Its material composition is diverse hence these lower temperatures observed indicate poor performance, which may lead to release of toxic gases harmful to community residing near the incinerator.

Temperature is a key factor to the emissions of NO_x and SO_2 as well as CO and CO_2. The results in this study showed that high temperature leads to high NO_x concentration while low temperature corresponding with low concentration of NO_x (Figures 2 and 3). At the beginning of reaction, the bottom of gasifier exits a dense phase area with sufficient oxygen where fuel was burned sufficiently and nitrogen in the fuel can be oxidized easily, whereas in the upper thin phase area NO_x did not have proper reductive reaction condition. Especially, without plenty of reductive radical of OH and CH, which results in more production of NO in a short time, the maximum amount of NO_x reached approximate 632 mg/m^3 at Mwananyamala Regional Referral Hospital. Subsequently, the concentration of NO_x decreased and run to stable due to formation of NO_x. It can be predicted that higher temperature prefers NO_x forming and lower temperature may restrain its production.

Temperature profile during incineration and emission testing

Figure 1 shows the flue gas temperature profiles during emissions testing for the four incinerators.

The Figure 1 shows trend and performance of the four incinerator temperature observed during the study in different run. The highest (914°C) observed temperature was at MNH followed by Temeke Regional Referral Hospital (842°C), Mwananyamala Regional Referral Hospital (792°C) and the lowest was at Ilala Regional Hospital Incinerator (711°C). The normal required incinerator temperature is between 850 and 1100°C. Matee and Manyele (2015b) studied the temperature profiles in the primary and secondary chambers of the MNH incinerator, which were observed to increase to the maximum peak value before dropping again.

Combustion efficiency of incinerators

Combustion efficiency, defined as the ratio of heat released by the fuel (healthcare waste in this case) to the heat input by the fuel. Combustion efficiency is affected by type and composition of waste loaded into the incinerator (sharps waste, pathological waste, pharmaceutical waste, blood bags, etc.), bed temperature, air or gas flow rate, and excess air levels. Combustion efficiency increases with fuel volatile matter content and bed temperature, and decreases with increasing superficial gas velocity. Combustion efficiency initially

Table 1. Description of hospital incinerators.

Name of facility	No. of beds	Waste generation rate (kg/day)	Type of incinerator	Combustion design	Capacity (kg/h)	Observed max. temperature (°C)
MNH	1500	325	Diesel burner operated	Vertical Double Chamber	100	914
Mwananyamala Regional Hospital	210	299	Diesel burner operated	Horizontal-Double Chamber	80	792
Ilala Regional Hospital	170	143.4	Diesel burner operated	Horizontal Double Chamber	80	711
Temeke Regional Hospital	190	232	Diesel burner operated	Horizontal Double Chamber	150	842

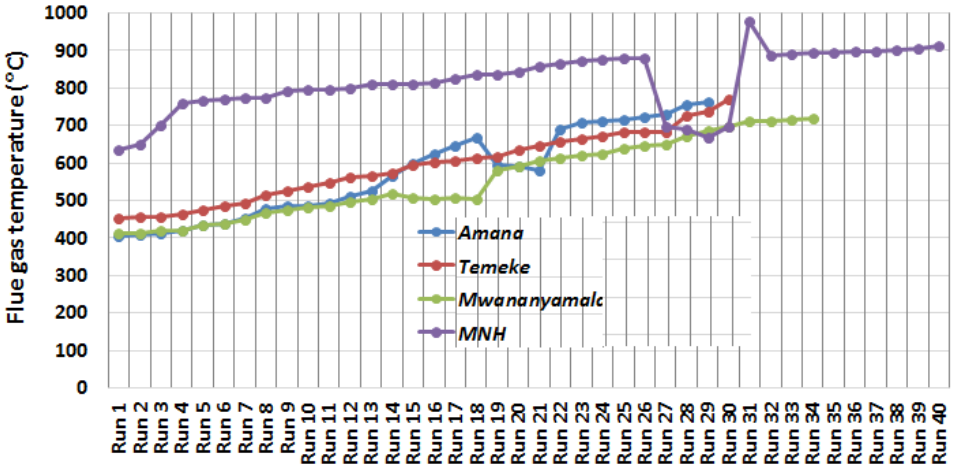


Figure 1. Flue gas temperature during emission testing in the four incinerators.

increases with increasing excess air level and then decreases. This is believed to be due to an increase in CO and hydrocarbon emissions as the excess air level increases to higher levels. Table 2

Combustion efficiency is a measurement of how well the fuel being burned is being utilized in the combustion process. This is different from the efficiency number produced on the analyzer, which is reflective of the total amount of heat available from the fuel minus the losses from the gasses going up the stack. The combustion efficiency calculation considers both the stack temperature and the net heat and moisture losses. Figure 2 shows the effect of incineration temperature/based on the flue gas temperature in the secondary chamber on combustion efficiency for the four incinerators studied. In general, CE increases with increasing temperature.

The CE data from Temeke shows two different linear relationships with flue gas temperature for the intervals from 400 to 600 and 600 to 800°C, the latter having at higher CE values (Figure 2). On the other hand, data from MNH shows increasingly higher values from 600 to 1000°C.

The linear dependency of CE on temperature of the flue gas was approximated by a generalized Equation 1 with $R^2 = 0.899$.

$$y = 0.037x + 30.278 \quad (1)$$

Pollutants concentration profiles for different acid gaseous pollutants in the incinerator flue gas

Profiles of carbon monoxide, CO

Carbon monoxide emissions result when carbon in the waste is not oxidized to carbon dioxide (CO_2). High levels of CO indicate that the combustion gases were not held at a sufficiently high temperature in the presence of

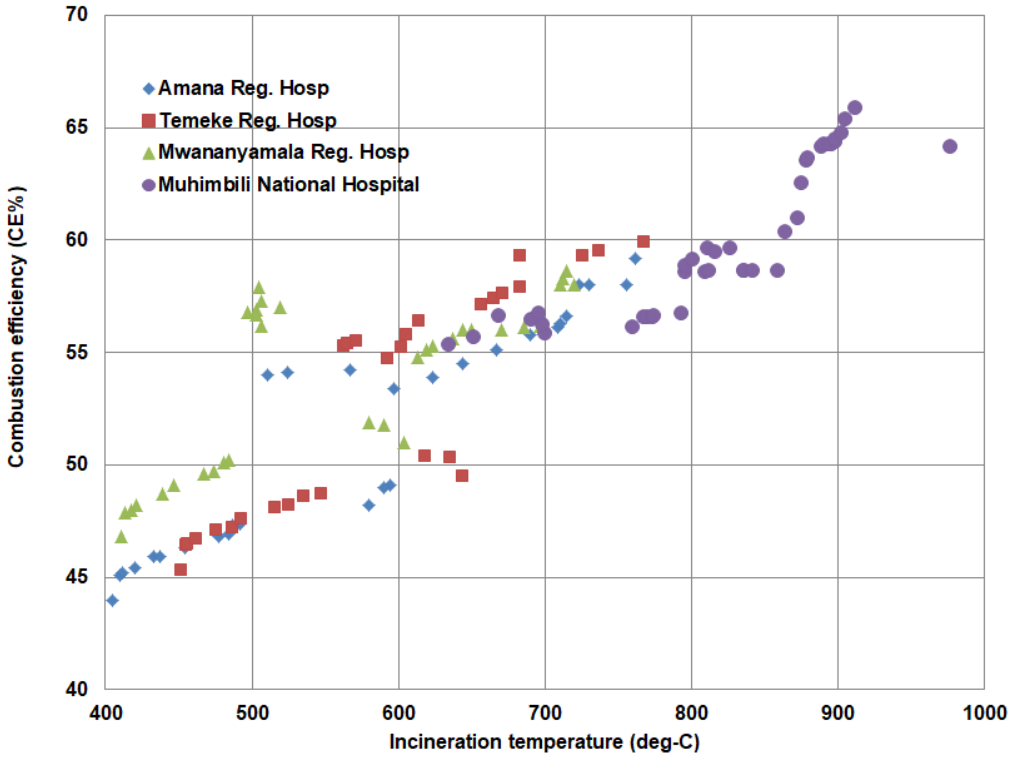


Figure 2. Comparison of performance of incinerator at Amana, Mwananyamala and Temeke regional hospitals and MN.

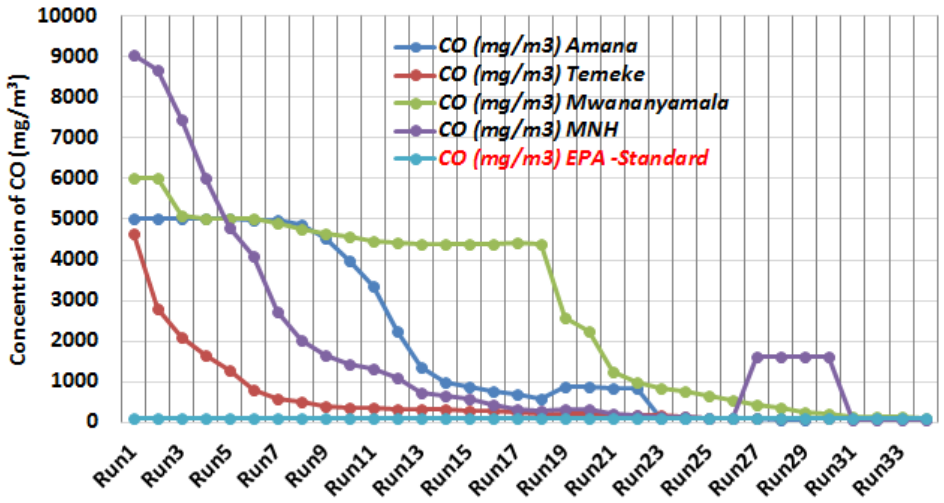


Figure 3. Levels of carbon monoxide concentration in the flue gas during test runs for the different incinerators.

oxygen (O_2) for a long enough time to convert CO to CO_2. Because O_2 levels and air distributions vary among combustor types, CO levels also vary among combustor types. Carbon monoxide concentration is a good indicator of combustion efficiency, and is an important criterion for indicating instabilities and non-uniformities in the combustion process (Baharun et al., 2005).

The greater the amount of air present and the higher degree of turbulence, the less CO will be formed. Unfortunately, turbulence as a combustion parameter

Table 2. Average values of combustion efficiency and temperature in different incinerators.

Statistics	Amana Reg. Hospital		Temeke Reg. Hospital		Mwananyamala Reg. Hospital		Muhimbili National Hospital	
	FT (ºC)	CE (%)	FT (ºC)	CE (%)	FT (ºC)	CE (%)	FT (ºC)	CE (%)
Minimum	405	44.0	452	45.3	411	46.8	634	55.4
Mean	572.5	51.4	589.6	53	555.8	52.3	815.5	60
Maximum	762	59.2	768	59.9	720	58	911	65.9
Std. dev.	119.4	5.0	91.3	5.0	103.3	9.7	81.5	3.4

cannot be easily quantified. Hence, only the amount of air present (indicated by the amount of O_2 emitted), and the combustion temperatures affecting the equilibrium constant and the relationship of CO and CO_2 produced is being considered.

During the incineration of municipal solid waste (MSW) in incinerators, the carbon monoxide is formed as the product of incomplete combustion. CO is an indicator substance for the combustion process and an important quality criterion for the level of combustion of the gases. As a rule, CO is measured continuously in the plants. Average CO emissions, as daily means, are below 50 mg/m^3. Plants reflecting best available techniques (BAT) have daily means in the range of <10 mg/m^3 (Wang, 2002).

Generation of CO is due to limited air supply and temperature leading to incomplete combustion. Figure 3 indicates variation of the carbon monoxide concentration in the flue gas from different incinerator in different runs. The concentration was highest initially when the temperatures are also lower and decreased with time. High levels of CO indicate that the combustion gases were not held at a high temperature in the presence of oxygen for a long enough time to convert CO to CO_2. The variation depends on the level of temperature during operation of incinerator which determines the extent of combustion of organic matter to CO_2. The trend shows the lower the temperature the higher the release of carbon monoxide. This explain that low combustion result into incomplete combustion, thus result into high release of CO, which also indicated poor performance of the incinerator.

Figure 3 indicates variation of the carbon monoxide concentration in the flue gas from different incinerators sampled in different runs. The concentration was highest initially when the temperatures are also lower and decreased with time. High levels of CO indicate that the combustion gases were not held at a sufficiently high temperature in the presence of oxygen for a long time to convert CO to CO_2. The variation depends on the level of temperature during operation of incinerator, which determines the extent of combustion of organic matter to CO_2. Generation of CO is due to limited air supply and temperature leading to incomplete combustion. The trend shows the lower the temperature the higher the release for carbon monoxide. This explain that low combustion result into incomplete combustion thus result into high release of CO which also indicated poor performance of the incinerators (La Fond et al., 1985; Anamul et al., 2012).

The highest concentration was observed for Muhimbili incinerator (9054 mg/m^3), corresponding to a temperature of 634°C and the lowest was at Temeke Hospital (4653 mg/m^3), corresponding to a temperature of 452°C. The variation might also be factored by the amount of waste per circle and type of waste materials put for incineration. The high pick observed at the end of the run was due to shutdown of secondary chamber for the purpose of saving fuel, which resulted in a drop up of temperature and as a result sharp increase of CO concentration level. Further to that the levels of carbon monoxide (CO) vary widely from one incinerator to the other presumably due to the variations in healthcare waste incinerator operations and waste composition, which affect the degree of combustion.

Profiles of carbon dioxide, CO_2

In this study, CO_2 concentration in the flue gas was determined as a %CO_2 in the stack, that is, carbon dioxide percent by volume, based on a dry basis. Figure 4 shows the variation of CO_2 concentration in different incinerators with time or runs. The CO_2 concentration decreases with time indicating that the charged waste load also goes to completion, with low remaining amount of carbon and monoxide capable of converting to CO_2. Initially, the amount of CO_2 is high for all incinerators, depending on type of waste and percent excess air supplied. More CO_2 was observed for MNH and Temeke that indicates good combustion efficiency for these incinerators, but also could indicate undiluted flue gas for these two incinerators. Muhimbili National Hospital had more run due to huge amount of waste generated per day and also varied characteristics of waste compared to other three hospitals under the study. Results indicated that complete combustion was being attained and continued aeration or supply air led to dilution of the flue gas, as time progresses. Similar trends were observed for all incinerators, indicating similar incinerator operation mode that is batch destruction, since waste is loaded after a batch is runs indicate longer cycle times to

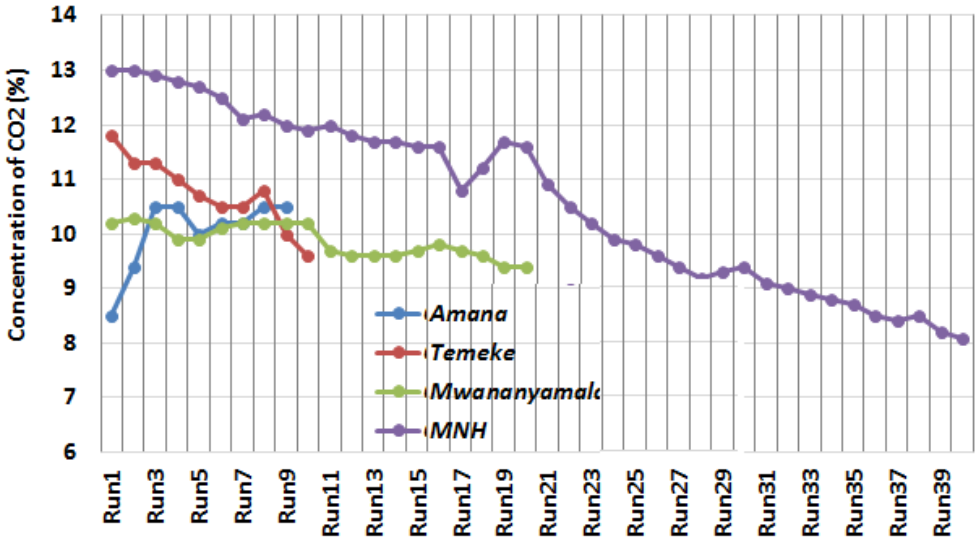


Figure 4. Profiles of the carbon dioxide concentration in the flue gas from different incinerators.

complete the combustion process per batch, such Temeke Hospital incinerator.

CO/CO_2 ratio in the flue gas

Carbon monoxide (CO) is a poisonous, colourless, odourless gas produced by the incorrect or incomplete combustion of healthcare waste, while carbon dioxide (CO_2), although a problematic greenhouse gas, is not toxic to the same degree and is a product of correct or complete combustion. When the CO produced by incineration in parts per million (ppm or mg/m^3) is divided by the CO_2 produced also in ppm we get the CO/CO_2 ratio. Dividing CO by CO_2 effectively cancels the effect of flue gas dilution by air blower and gives a value proportional to the true amount of CO being produced. CO/CO_2 ratio gives a more reliable picture of combustion process than CO (ppm) alone.

Figure 5 shows the variation of the CO/CO_2 ratio with residence time during healthcare waste incineration for the four incinerators studied. The data from Temeke Hospital shows that the ratio falls immediately to minimum after the combustion process is started with the values being lowest compared to other incinerators. At MNH, on the other hand, the CO/CO_2 ratio starts at a highest value, and decreases continuously to zero. While the data from MNH and Temeke shows higher initial values followed by faster decrease in CO/CO_2 ratio with time, the ratio remained constant and lowest for Amana and Mwananyamala Regional Hospital incinerators. This shows that the secondary chambers of the incinerators at MNH and Temeke have good performance in terms of raising temperature and providing enough residence time in order to burn the CO to CO_2 as incineration cycle time proceeds. On the other hand, the situation observed at Amana and Mwananyamala Regional Hospitals can be attributed to low amount of waste feed and excess air supply (Table 1), since combustion efficiency was observed to be lower for these two incinerators.

Although CO/CO_2 testing has not been widely utilized in the waste combustion sector, it may provide a quick and effective additional method of ensuring the performance of healthcare waste incinerators (La Fond et al., 2012). In Figure 6, the values of the CO/CO_2 ratio were initially highest (for Temeke and MNH), which decreased from 0.065 and 0.032 to about 0.001, in about 20 and 9 runs for MNH and Temeke incinerators, respectively, which is about two orders of magnitude change in the ratio. The ratio of CO/CO_2 reflects the completeness of waste combustion and its decrease is accompanied by a decrease in the heat generated by waste combustion, indicating that the incinerators at MNH and Temeke are loaded with larger quantities of waste which is destroyed faster.

The lower values of the ratio CO/CO_2 can be described by the fact that the heat of reaction for the formation of CO_2 is a factor of 3.5 higher than for CO. Thus, formation of CO instead of CO_2 will be favoured by the combustion process. But instead, results showed that CO_2 formation is favoured despite the energy barrier. The fact that CO/CO_2 ratio is lower than 0.1, shows that the combustion processes in the incinerators were efficient leading to higher generation rate of CO_2 compared to CO as the incineration cycle proceeds. The terms excess air and excess oxygen are commonly and synonymously used to define combustion. The percentage of excess air is the amount of air above the stoichiometric requirement

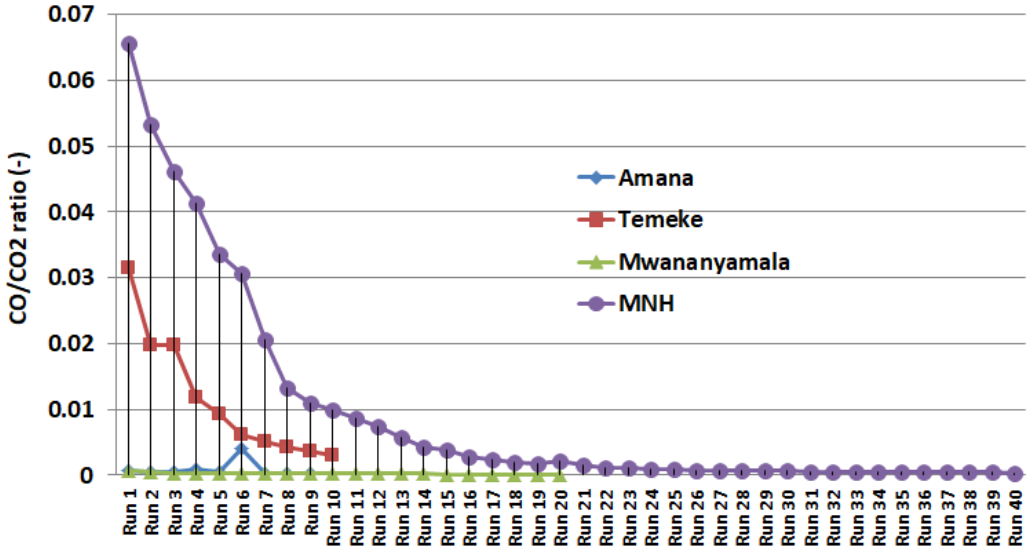


Figure 5. Variation of the CO/CO_2 ratio with time during healthcare waste incineration for the four incinerators studied.

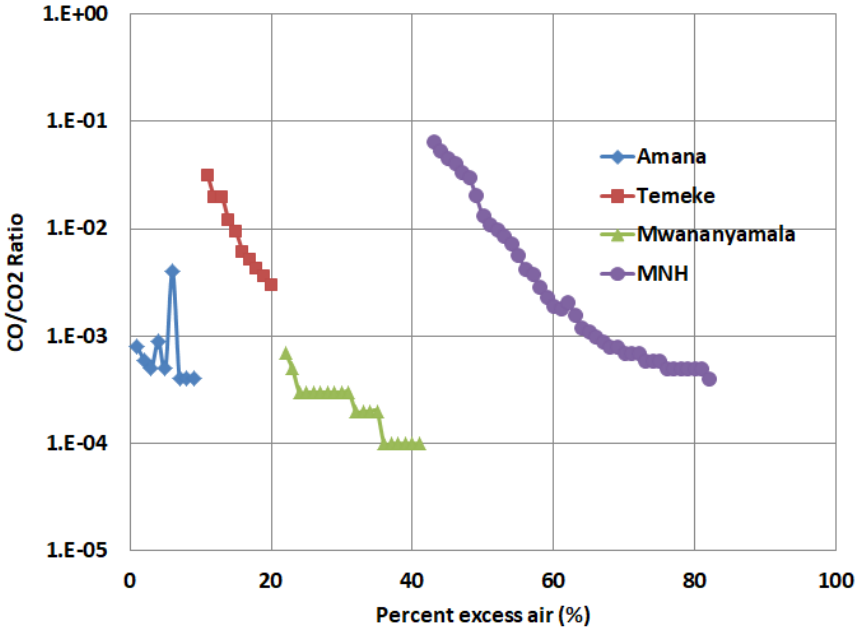


Figure 6. Effect of increasing percent excess air on CO/CO_2 ratio during healthcare waste incineration.

for complete combustion. To avoid products of incomplete combustion (PICs), especially carbon monoxide (CO), excess air is usually added.

Variation of NOx concentration with incineration time

Among the major environmental concerns related to incineration are the emissions of nitrogen oxides (NO_x), which have been shown to strongly contribute to the formation of acid rain and photochemical smog. During the incineration of municipal solid waste in grid furnace incinerators for instance, NO is the major component of the NO_x formed, representing 95% of those emissions (Abbas et al., 1997). In those conditions, past research

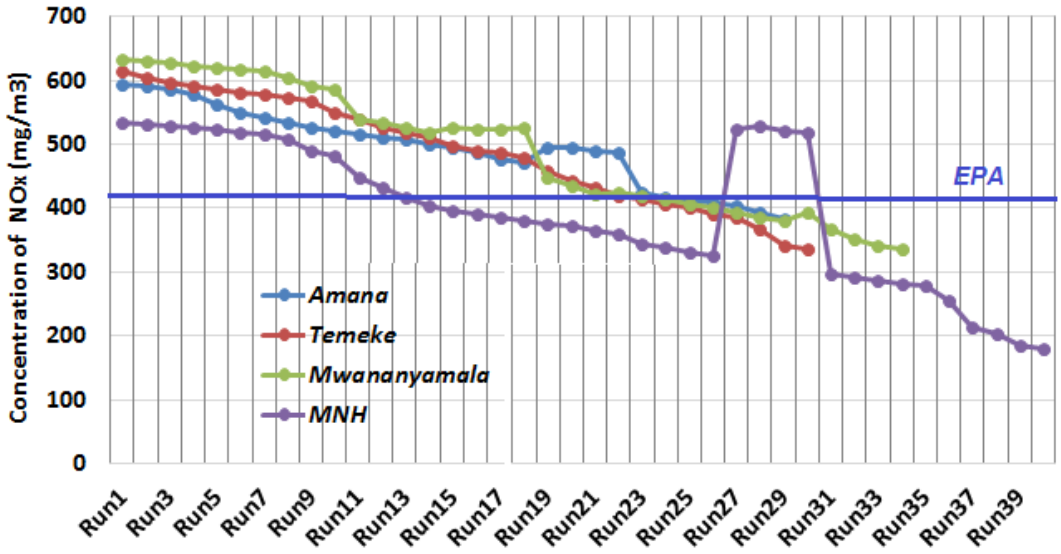


Figure 7. Profiles of the NO_x concentration in the flue gas from different incinerators.

(Sorum et al., 2001) showed that more than 95% of the NO is formed from the fuel-NO mechanism. Moreover, past studies have demonstrated that no NO_2 and N_2O are emitted during similar tests, so that the only NO_x is NO (Rogaume et al., 2002). Therefore, it is justifiable to concentrate only on the establishment of the main variables controlling NO. Also, past studies have shown that NO is generated from three sources: thermal NO, prompt NO and fuel NO (Miller and Bowman, 1989; Rogaume et al., 2002).

In the incineration of healthcare waste, nitrogen oxides NO_x (NO, NO_2) arise, which are formed essentially from the nitrogen contained in the waste, from the combustion process itself and from spontaneous reaction (so-called prompt NO_x). As a rule, nitrogen oxide concentrations in the flue gas were measured continuously at these plants. To avoid damage of the KANE9000 probe, NO_x measurement we conducted by sampling the gas at short intervals of time, covering the whole incineration cycle time. Figure 7 shows the levels of NO_x concentration in the four incinerators with time during test runs, compared to the EPA standard. Initially, all incinerators emitted higher levels of NO_x, which decreased with time, until the concentration level was below acceptable the limit (411 mg/m^3). This can be attributed to the decrease in materials in the healthcare waste leading to NO_x formation as combustion proceeds in a batch operated incinerator (Wang, 2002).

Thus, types of measures have been recommended in order to reduce NO emissions, the optimization of combustion parameters and the introduction of secondary reduction techniques or flue gas treatment using APCDs. Since the cost imposed by secondary reduction techniques is high, optimization of the combustion process is therefore the preferred approach.

Profiles of SO_2 emissions in different incinerators during burning process

Figure 8 shows the variation of SO_2 concentration with time for the four incinerators studied, which were also compared to the EPA standard ⟨set at 88.1 mg/m^3⟩. In all cases the SO_2 concentration decreased with time to the maximum allowable level. Figure 8 indicates that sulfur dioxide is released from incinerators during incineration of healthcare waste. The concentration levels varied between the studied incinerators. The highest level (2208 mg/m^3) was observed to MNH incinerator, while the lowest values were observed at Mwananyamala hospital incinerator.

At some point between run new load of waste is added and depending on the constituent of the waste materials (some are too wet) usually there is a fall of temperature but still there is increase of SO_2 due to new load of waste materials.

Effect of temperature on pollutant concentration in the flue gas

Effect of temperature on CO_2 concentration in the flue gas

Results showed further that maintaining high temperature increases the release of CO_2, as depicted in Figure 9, which shows the variation of CO_2 concentration with temperature for the four incinerators studies. The CO_2

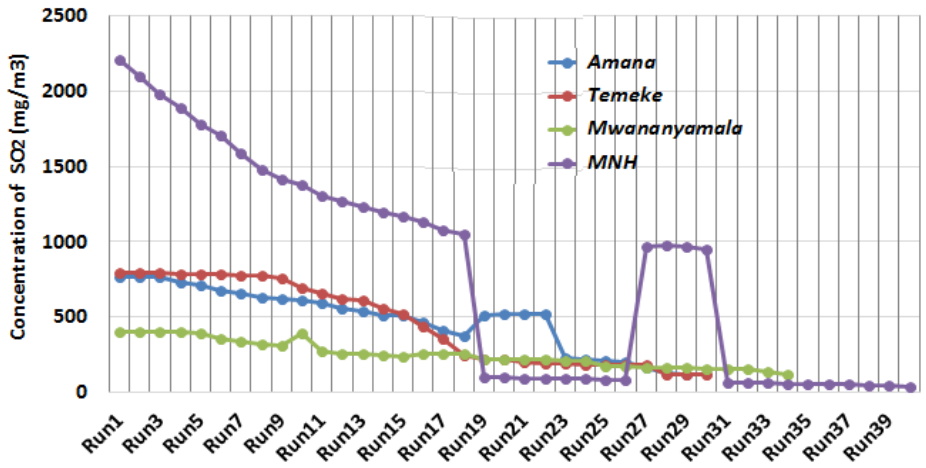


Figure 8. Profiles of the sulfur dioxide concentration in the flue gas from different incinerator.

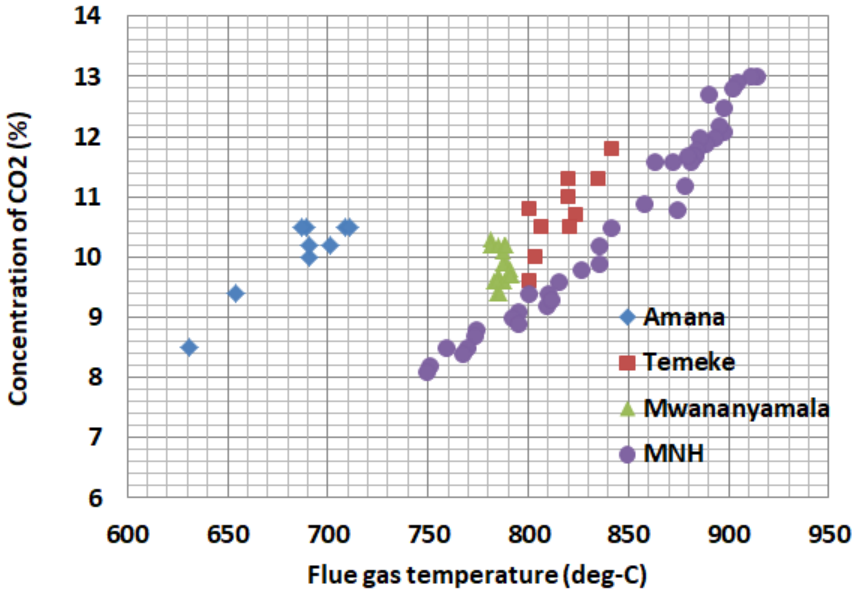


Figure 9. Effect of flue temperature on flue gas (CO_2) concentration.

concentration increased with temperature for all incinerators, which agrees with the fact that at higher temperature, organic matter and CO are converted completely to CO_2 in presence of oxygen (La Fond et al., 2012). The results showed similar correlation of CO_2 concentration with temperature for all studied incinerators, indicating that temperature is one of the key factors, which determine the time variation of CO_2 during operation of incinerators. The highest and lowest releases were observed at MNH incinerator, that is, 13 and 8%, respectively. The lowest CO_2 concentration at MNH corresponds to the low temperature about 750°C, which indicates further that the data was taken at the beginning of the cycle when the incinerator was fully loaded with the waste, while the highest CO_2% corresponds to the final incineration data where the temperature is also high as shown in Figure 1.

Figure 9 shows also the incineration temperature ranges for each incinerator as a span of data on the horizontal axis, which is widest for MNH, from 740 to 920°C as compared to Amana Hospital incinerator from 630 to 710°C only, which is shifted towards the left in Figure 5. The Mwananyamala incinerator, however was operated in a very narrow temperature range of 780 to

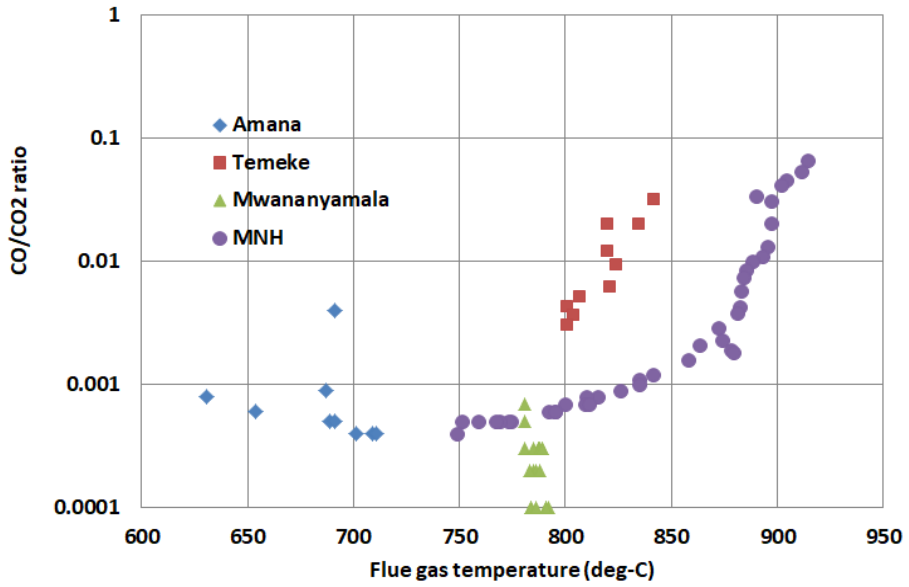


Figure 10. Variation of CO/CO_2 ratio with temperature in the studied incinerators.

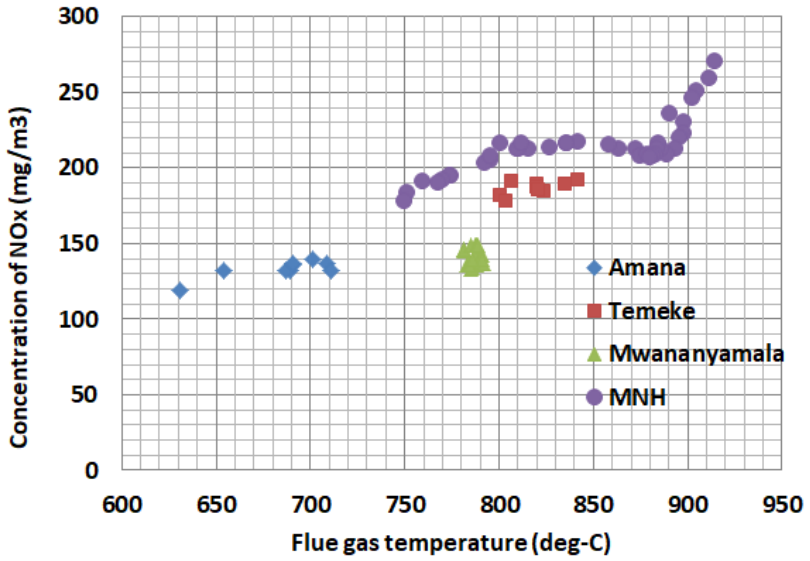


Figure 11. Effect of flue temperature on flue gas NO_x concentration.

790°C only.

Effect of temperature on CO/CO2 ratio in the flue gas

Figure 10 shows the relationship between temperature and the CO/CO_2 ratio for the four incinerators studied. The CO/CO_2 ratio was observed to increase with flue gas temperature for MNH and Temeke incinerators. The CO/CO_2 ratio produced by the carbon-oxygen reaction is assumed or inferred from the waste particle temperature during combustion, which is also a measure of the flue gas temperature, and secondary chamber temperature.

Effect of temperature on NOx ratio in the flue gas

Figure 11 shows the variation of NO_x concentration with temperature in the four different incinerators studied. The NO_x concentration was observed to be temperature dependent such that at low temperature, NO_x levels did not increase strongly with temperature. The highest NO_x

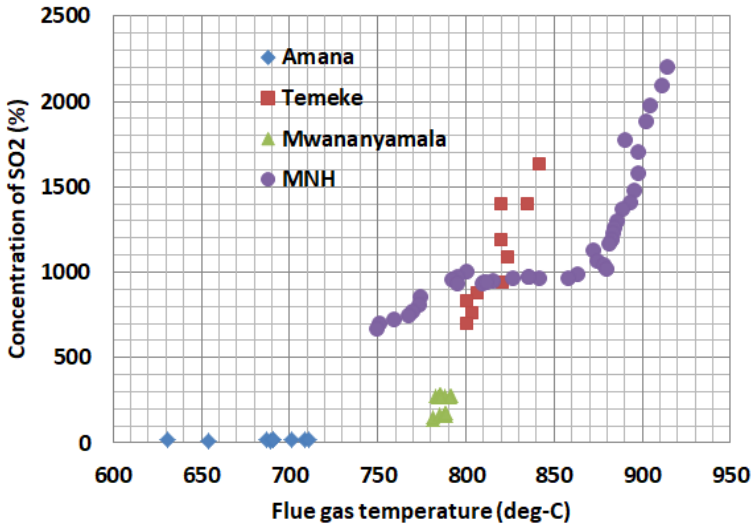


Figure 12. Effect of flue temperature on SO_2 concentration in the flue gas.

level (270 mg/m^3) concentration was observed at MNH at a higher temperature of 910°C and the lowest level (120 mg/m^3) was recorded at Amana hospitals corresponding to a low temperature of 634°C. Thus, high temperature slightly increases the NOx concentration in the flue gas. The NOx levels in the flue gas depend also on the nitrogen content or in organic compounds in the healthcare waste and also nitrogen from the air can be converted to NOx when conditions are favorable, including high temperature (Allen et al., 1986; Tezanou et al., 2009).

Effect of temperature on SO_2 concentration in the flue gas

Figure 12 shows the variation of SO_2 concentration in the flue gas with temperature for the two incinerators studies. Results for (MNH and Temeke) incinerators showed stronger dependency of SO_2 emissions on temperature. Result from both incinerators revealed that SO_2 concentration increases with temperature, indicating high combustion efficiency of the incinerators in destroying sulfur containing compounds at higher temperature. With elevated temperatures, the levels of SO_2 increased dramatically. This necessitates application of air APCDs which can trap SO_2, such as fixed-bed or wet-scrubbers. Again, despite other factors temperature is a key factor to the variation of SO_2 level in the flue gas during incineration of healthcare waste a case depicted strongly for MNH and Temeke hospital incinerators. As reaction time increases, the concentration of SO_2 showed a decreasing trend. This may be due to the amount of sulfur in organic solid waste diminishing as incineration cycle proceeds towards the end. Influence on the production of SO_2. Higher temperature leads to sufficient gasification reaction, that is, high conversion of sulfur in the waste to SO_2. Some inorganic sulfur and sulfur chain may produce more SO, which reacts further with oxygen to yield SO_2.

Effect of percent excess air on combustion efficiency and pollutant concentration in the flue gas

In order to have the most efficient combustion during incineration process, the quantity of fuel and air would be in a perfect ratio to provide perfect combustion with no unused fuel or air, that is, theoretical perfect combustion or stoichiometric combustion. In practice, however, for safety and maintenance needs, additional air beyond the theoretical amount needs to be added to the combustion process, referred to as “excess air” (Abbas et al., 1997). With incineration, if some excess air is not added to the combustion process, unburned fuel, soot, smoke, and carbon monoxide exhaust will create additional emissions and fouling of chambers and chimney surfaces. Although, excess air is needed from a practical standpoint, too much excess air can lower combustion efficiency during incineration, so that a balance must be found between providing the optimal amount of excess air to achieve ideal combustion and prevent combustion problems associated with too little excess air (such as higher emissions concentration), while not providing too much excess air to reduce combustion efficiency (CE) (Rogaume et al., 2002).

Significant amounts of energy can be lost because of too much air entering the incinerator, resulting in heat loss through flue gases and cooling of chambers. The excess air results in oxygen that is not consumed during

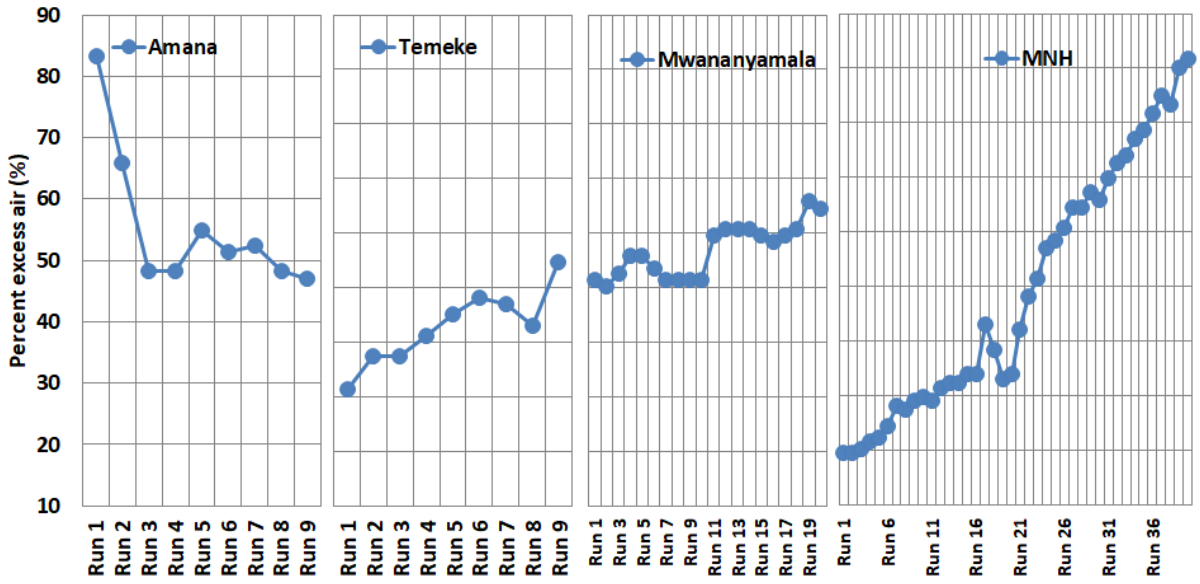


Figure 13. Range of values of percent excess air observed in the four incinerators during test runs.

combustion, and this oxygen and the accompanying nitrogen absorbs otherwise usable heat and carries it out of the stack. However, this ideal (known as the stoichiometric air-to-fuel ratio) is difficult to reach because health waste and air don't completely mix, meaning that a certain amount of excess air will always be necessary for complete combustion. Another challenge leading to uncertainty in supplying excess air is the composition variation in the healthcare waste.

Figure 13 shows the series of values of percent excess air observed during incineration test runs from four incinerators studied. While the results from Amana regional hospital showed a decrease in percent excess as incineration proceeded, the observation from other sites shows increase in percent excess. This can be attributed to poor aeration via burner or blower caused by blockage of air supply pipes due to arches. On the other hand, Temeke, and Mwananyamala hospital incinerators showed slight increase in percent excess air with time, due to constant aeration, while the waste load diminishes in the primary chamber, and also the flow of pyrolytic gases into the secondary chamber decreases with time. Data from MNH showed a faster increase in percent excess attributable to both high CE and temperature, as well as, blower capacity, and portioning of secondary chamber (that is, at the top of the primary chamber).

Figure 14 shows the variation of CE with percent excess air for the four incinerators studies. There is a clear observation that the four incinerators were operated at different percent excess ranges, starting with a low range at Amana, Temeke, Mwananyamala and a highest range at MNH.

In general, most incinerators indicated that initially set air flow rate from a blower becomes highly excess towards the end of the incineration cycle, when the fired load becomes smaller as shown in Figure 14. Thus, increasing excess air requirements as the firing rate of the incinerator decreases (towards the end of the cycle) leads to lower efficiency at the end of the cycle. Initially, the CE was high for Amana and MNH, which dropped later as percent excess, was increasing. The values of percent excess air corresponding to the maximum values of CE are shown also as an insert to Figure 14.

Figure 15 shows the variation of emissions concentration (CO, CO_2 SO_2, and NO_x) in the flue gas with percent excess air for the four incinerators studies. In general, the concentration of these gases in the flue gas decreased with percent excess air. The data from MNH forms a base case, where by the percent excess air varied from 20 to 91.7%, while other incinerators were operated using percent excess within this range. The decrease in concentration with percent excess air can be attributed to dilution of the flue gas rather than improved combustion, since this contradicts the trend for CO_2 which should increase at higher percent excess if the improved combustion was the controlling factor. Moreover, SO_2 concentration should also increase if improved combustion was the controlling factor, but it decreased with percent excess air similar to NO_2, and CO. The fact that CO concentration decreased with percent excess is linked to both improved combustion and dilution of the flue gas.

Rogaume et al. (2009) studied the effect of increasing percent excess air on NO_x formation (as NO) and observed that NO emissions in a fixed bed combustor for municipal solid waste increased with percent excess air,

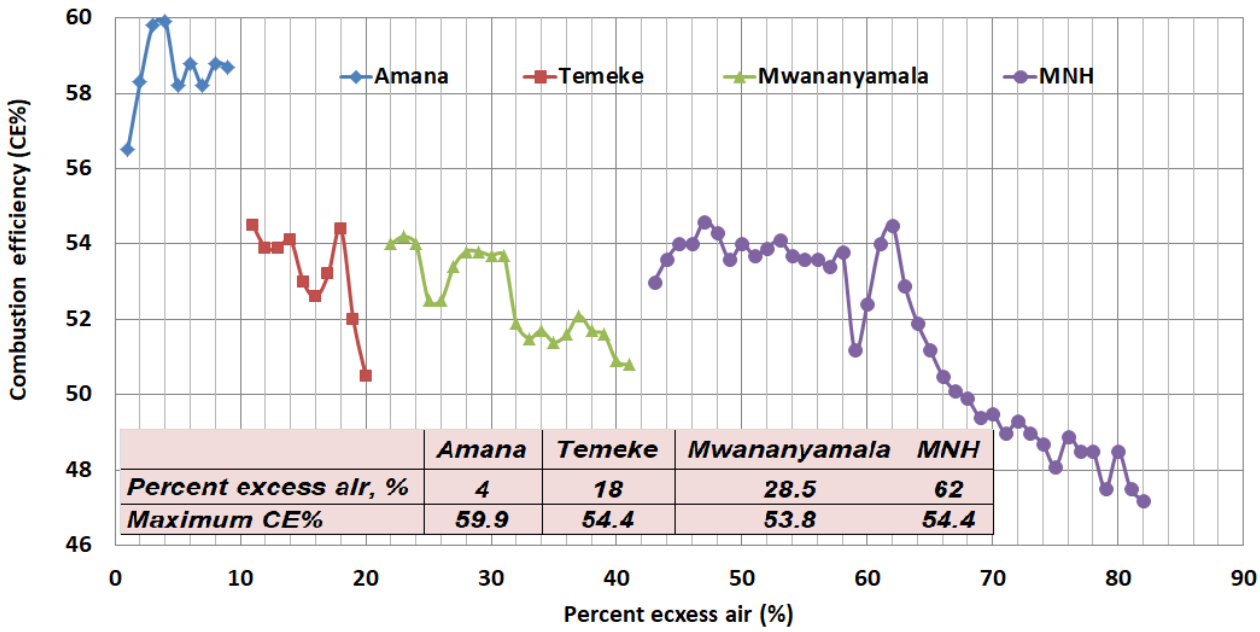


Figure 14. Effect of increasing percent excess air on combustion efficiency during incineration.

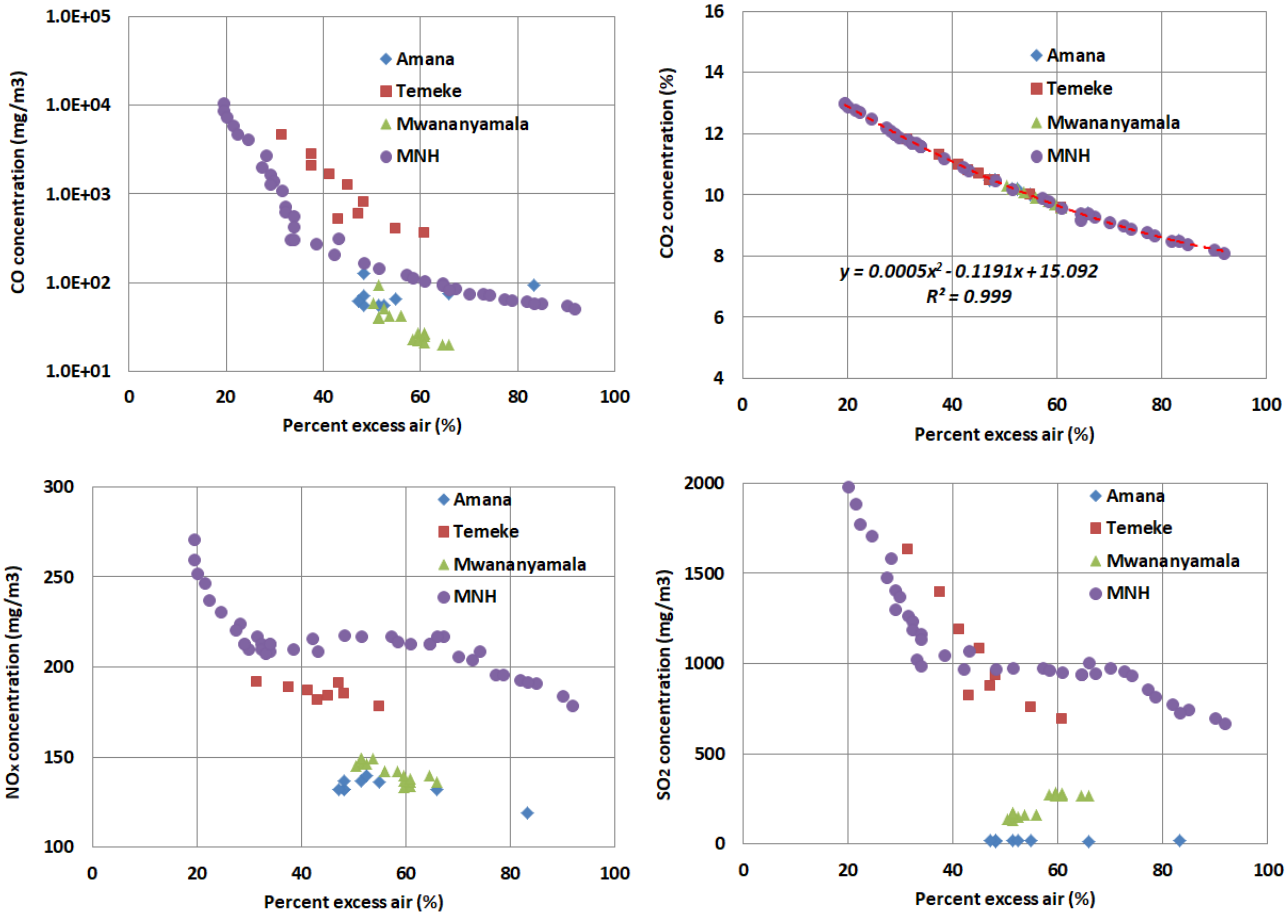


Figure 15. Effect of percent excess air on emissions concentration in the flue gas.

different from results shown in Figure 15 (from fixed grate double chamber incinerators for healthcare waste). The NO emissions were, however, measured in mg/g of waste incinerated, while data in Figure 15 is presented based on mg/m^3 of flue gas, which is subject to dilution challenges at higher excess air supply.

DISCUSSION

Waste are produced everywhere in the world and tones of healthcare waste production are no exception. Healthcare waste can be infectious, contain toxic chemicals and pose contamination risks to both people and the environment. If patients are to receive healthcare and recover in safe surroundings, healthcare waste must be disposed of safely. One of the healthcare waste treatments methods used worldwide is healthcare waste incineration.

During incineration process different pollutants from healthcare waste are dispersed into air, which may have adverse health effects associated with mass burn incineration are of great concern as large population groups and workers may be exposed to derived toxic substances. These effects can be exposed directly through inhalation or indirectly through consumption of food or water contaminated by deposition of the pollutants from air to soil, vegetation, and water.

Apart from toxic heavy metals, which may be present, there are different oxides of non-metals the NO_x and SO_2 emissions will contribute, respectively, for the formation of acidic aerosols. It should be noted that SO_x and NO_x emissions as a result of incineration of waste is can be minimize by flue gas treatment like scrubbing medical waste cannot be a good comporting candidate due to pathogens content, elimination of which leads to SO_2 and NO_x. The nitrogen and sulphur dioxide, which are associated to respiratory short-term effects especially to individuals with a particular susceptibility should be removed from the gas. Carbon monoxide emissions result when carbon in the waste is not completely oxidized to carbon dioxide (CO_2). High levels of CO normally indicate that the combustion gases were not held at a sufficiently high temperature and long enough residence time. In the presence of oxygen (O_2) for a long enough time converts CO to CO_2, or that quenching has occurred.

It is hereby recommended to set country standards for the emission, which requires use of various air pollution control devices as well as monitoring and inspection and permitting programs. To meet the required standard effective waste reduction and waste segregation should be promoted ensuring that only the smallest quantity of appropriate waste types is incinerated. Future studies on the levels of dioxin and furan emissions from these incinerators is required as these deadly compounds may resulted into public health risks due to persistent and bio-accumulative nature of these compounds.

Conclusions

(1) In all incineration cycles the temperature of the flue gas increased with time, as recorded in time intervals to the end of the batch or cycle.
(2) CO, SO_2, and NO_x levels were initially above the recommended EPA-standard for all incinerators, except at the end of cycles.
(3) CO_2 levels were higher in the flue gas, but decreased with the time attributable to completion of organic matter in the primary/secondary chambers.
(4) The NO_x, SO_2 and CO_2 increased slightly with temperature, indicating high combustion efficiency at high temperature.
(5) Higher levels of NO_x, SO_2 and CO necessitate use of APCDs for the gas treatment.

The study has indicated that majority of incinerators operate, while emitting pollutants above recommended standards by EPA, which decreases to allowable levels within a cycle time. A concern on the danger of toxin gas emission, e.g., SO_2 and NO_x from incinerators can be minimized by use of APCDs. Emissions may be controlled by modification of process techniques and physical parameters to optimize combustion conditions, or by employment of abatement techniques. The level of abatement at an incinerator plant varies, depending on the size of the plant, age and emission regulations. In order to address the problem of toxic gas emission, authorities must set new standards for incinerators and recommend for a better environmental friendly technologies for the management of healthcare waste.

Recommendations

(1) Incinerators should be located away from health facility vicinity and residential areas and in a reward direction to avoid direct exposure to emission from incinerators.
(2) Scaling up program for improving HCWM in Tanzania should be supported with consideration of promoting other alternative methods of waste management, especially in urban area where space for sitting up incinerator is a problem.
(3) Regular monitoring and maintenance of the incinerators should be done to rectify structural defects, which result in emission of unacceptable levels of smoke, which is likely to affect first the health of the incinerator operators and the entire community.
(4) Further investigations on other toxic organic pollutants, such as dioxins and furans are recommended in the future.

ACKNOWLEDGEMENT

The completion of this study has been the results of assistance received from all management teams of the hospitals involved in the study (Temeke, Mwananyamala and Ilala Regional hospitals, and MNH).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abbas T, Costen P, Lockwood FC (1997). A review of current NO_x control methodologies for municipal solid waste combustion process. 4th European Conference on Industrial Furnaces and Boilers, London.

Allen RJ, Brenniman GR, Darling C (1986). Air Pollution Emissions from the Incineration of Hospital Waste. Journal of the Air Pollution Control Association 36(7):829-831.

Allsopp M, Costner P, Johnston P (2001). Incineration and Human Health: State of Knowledge of the Impact of Waste Incinerators on Human Health - Executive Summary. Environmental Science and Pollution Research 8:141-145.

Anamul H, Tanvir M, Rahman J (2012). Zinc and Nickel of bottom ash as a potential diffuse pollutant and their application as fine aggregate. Journal of Civil Engineering Research 2(6):64-72.

Ardevol E, Minguilon C, Garcia G, Serra ME, Gonzalez CA, Alvarez L, Elitja R, Lafuente A (1999). Environmental tobacco smoke interference in the assessment of the health Impact of a municipal waste incinerator on children through urinary thioether assay. Public Health 113:295-298.

Baharun S, Robiah A, Khairili M, Arshad A, Tahir A, Rashid M, Zamri I (2005). Variables affecting the combustion efficiency of a clinical waste incineration process. Jurnal Teknologi 42(F):11-24.

Batterman S (2004). Findings on assessment of small-scale incinerators for healthcare waste, World Health Organization, Geneva pp.1-65.

Demirezen D, Aksoy A (2006).Heavy metal levels in vegetables in Turkey are within safe limits for Cu, Zn, Ni and exceeded for Cd and Pb. Journal of Food Quality 29:252-265.

Enviros Consulting Ltd (2004) Review of environmental and health effects of waste management: Municipal solid waste and similar wastes. London: Department for Environment, Food and Rural Affairs (19) (PDF) environmental and health risks related to waste incineration. Available from: https://www.researchgate.net/publication/334563514_Environmental_and_health_risks_related_to_waste_incineration [accessed Aug 03 2020].

Ernesto T, Savino A (2019). Environmental and health risks related to waste incineration, Waste Management and Research 37(10):0734242X1985970.

Ferronato N, Torretta V (2019). Waste mismanagement in developing countries: A review of global issues. International Journal of Environmental Research and Public Health 16(6):1060:1-28.

Gitonga LK (2017), Factors influencing waste segregation among staff in Chuka level four hospital. Rehabilitation Science 2(4):91.

Goren A, Hellmann S, Gabbay Y, Brenner S (1999). Respiratory problems associated with exposure to airborne particles in the community. Archives of Environmental Health: An International Journal 54(3):165-171.

Hettiarachchi H, Meegoda JN, Ryu S (2018). Organic waste buyback as a viable method to enhance sustainable municipal solid waste management in developing countries. International Journal of Environmental Research and Public Health 15:2483.

International Committee of the Red Cross (ICRC) (2011). International Committee of the Red Cross, Healthcare Waste Management, Geneva, Switzerland.

La Fond RK, Kramlich JC, Randall S, Gary SS (1985) Evaluation of continuous performance monitoring techniques for hazardous waste incinerators. Journal of the Air Pollution Control Association, 35(6):658-663.

La Fond RK, Kramlich JC, Randall S, Samuelsen GS (2012). Evaluation of continuous performance monitoring techniques for hazardous waste incinerators. Journal of the Air Pollution Control Association 35(6):658-663.

Manyele S, Kagonji IS, Mrisho J (2011). Assessment of healthcare waste incinerator performance based on physical characteristics of ashes. Engineering 3(10):1045-1053.

Manyele SV, Anicetus H (2006). Management of healthcare waste in Tanzanian hospitals. Tanzania Health Research Bulletin 8(3):177-182.

Manyele SV, Mujuni CM (2010). Current status of sharps waste management in lower level health facilities in Tanzania. Tanzania Health Research Journal 12(4):257-264.

Matee V, Manyele SV (2015a). Performance of a large-scale medical waste incinerator in a referral hospital. Engineering 7: 676-690.

Matee V, Manyele SV (2015b). Analysis of temperature profiles and cycle time in a large-scale medical waste incinerator. Engineering 7:717-732.

Miller JA, Bowman CT (1989). Mechanism and modeling of nitrogen chemistry in combustion. Progress Energy Combustion Science 15:287-338.

Oppelt ET (1987).Incineration of hazardous waste: A critical review. Journal of Air and Waste Management 37(5):558-586.

Parry J Stevens A (2001). Prospective health impact assessment: pitfalls, problems, and possible ways forward. British Medical Journal 323:177-1182.

Pluss A, Pirkle JL, Kaufman RB, Brody DJ, Hickman T, Ferrell R (1991).Characterization of lead and other heavy metals in fly Ash from municipal waste incinerators. Hazardous Waste and Hazardous Waste Materials 8(4):275-292.

Rogaume T, Auzanneau M, Jabouille F, Goudeau JC, Torero JL (2002). The effects of different airflows on the formation of pollutants during waste incineration. Fuel 81:2277-2288.

Singh S, Prakash, V (2007). Toxic environmental releases from medical waste incineration: A review. Environmental Monitoring and Assessment 132(1-3):67-81.

Sorum L, Skreiberg O, Glarborg P, Jensen A, Dam Johansen K (2001). Formation of NO from combustion of volatiles from municipal solid wastes. Combustion and Flame 124(1-2):195-212.

Takata T (2003). Survey on the health effects of chronic exposure to dioxins and Its accumulation on workers of a municipal solid waste incinerator, rural part of Osaka prefecture, and the results of extended survey afterwards. Industrial Health 41(3):189-96.

Tezanou J, Rogaume T, Richard F, Andzi Barhé T, Jabouille F (2009). Influence of waste composition on NOx emissions from incinerators. International Journal of Heat and Technology 27:1-8.

Wajs J, Bochniak R, Golabek A (2019). Proposal of a mobile healthcare waste incinerator with application of automatic waste feeder and heat recovery system as a novelty in Poland. Sustainability11:4980-4998.

Wang Y (2002). A combustion test facility for testing low NOx combustion systems', ASME Turbo Expo 2002: Power for land, sea, and air, Amsterdam, The Netherlands.

World Health Organization (WHO) (2011). Healthcare and its safe management, World Health Organization, Geneva, Switzerland.

World Health Organization (WHO) (2014), Safe management of wastes from healthcare activities, Geneva: World Health Organization World Health Organization, Geneva, Switzerland.

World Health Organization (WHO) (2018). Healthcare Waste. World Health Organization Geneva, Switzerland.

Wiedinmyer C, Yokelson RJ, Gullett BK (2014). Global emissions of trace gases, particulate matter, and hazardous air pollutants from open burning of domestic waste. Environmental Science and Technology 48:9523-9530.

Wiles C, Shepherd P (1999). Beneficial use and recycling of municipal waste combustion residues. A comprehensive resource document national renewable energy laboratory, USA.

World Bank (1999). Technical guidance on municipal solid waste incineration. The International Bank for Reconstruction and Development the World Bank.

Vol. 14(10), pp. 329-335, October 2020
DOI: 10.5897/AJEST2020.2885
Article Number: 744363864912
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

ACADEMIC JOURNALS
expand your knowledge

African Journal of Environmental Science and Technology

Full Length Research Paper

Occurrence dynamics of nitrogen compounds in faecal sludge stabilisation ponds in the Tamale Metropolis, Ghana

Abagale Felix K.[1]*, Osei Richard A.[2] and Kranjac-Berisavljevic G.[1]

[1]Department of Environment, Water and Waste Engineering, School of Engineering, University for Development Studies, Tamale, Ghana.
[2]Laboratoire Eaux-Hydro Systèmes et Agriculture (LEHSA), Institut International d'Ingénierie de l'Eau et de l'Environnement (2iE) Ouagadougou, Burkina Faso.

Received 13 July, 2020; Accepted 1 September, 2020

Faecal sludge, with richness in soil nutrients represents an important resource for enhancing soil productivity. In this study, the occurrence dynamics of nitrogen compounds NH_3, NO_2^- and NO_3^- in engineered waste stabilisation ponds in the Tamale metropolis was monitored for 5 months in the dry season. Four treatment ponds were divided into three units: Influent point, midpoint and effluent point for sampling purposes. Faecal sludge sampling was simultaneously carried out for each of the ponds at marked points and approximate depth of 30 to 50 cm using 500 ml sample collection bottles. Using the Nessler method and Powder Pillows NH_3, NO_3^- and NO_2^- levels were determined through direct reading with a DR 2800 Spectrophotometer. Mean concentrations of NH_3, NO_3^-, and NO_2^- were determined to be 42.65, 57.99 and 0.15 mg/l, respectively. The anaerobic pond on average, recorded the maximum concentration levels of all three compounds. The primary facultative pond recorded the average minimum concentration of NO_2^- while the maturation pond recorded the minimum for both NH_3 and NO_3. Variation in concentration of nitrogen compounds was statistically highly insignificant by ANOVA at 5% significance level, except NH_3. Average NH_3 concentrations in stabilisation ponds were observed to be higher than the allowable limit of EPA Ghana for effluent discharge or reuse for agriculture while NO_3^- was lower aside concentration in the anaerobic pond. The effluent should further be treated to reduce NH_3 concentration using different treatment options such as the filter beds or constructed wetland prior to reuse for agriculture.

Key words: Faecal sludge, stabilisation pond, nitrogen compounds, nitrification, denitrification.

INTRODUCTION

Management of faecal sludge in urban centres of most developing countries is generally characterised by indiscriminate disposal in the environment, notwithstanding the consequent health and environmental

*Corresponding author. E-mail: fabagale@uds.edu.gh.

implications (Ingallinella et al., 2002). However, faecal sludge is rich in plant nutrients and organic matter constituents, which contribute to replenishing the humus layer, soil nutrient reservoir, and improvement of the soil structure. It thus represents an important resource for enhancing soil productivity on a sustainable basis (Koné et al., 2010). According to Kuffour (2010), treatment options for faecal sludge should allow for optimum recovery of nutrients to support agriculture. Over the years, stabilisation and settling ponds have been the significant faecal sludge treatment options in Ghana (Kuffour, 2010). Studies by Cofie et al. (2004) highlighted the potentials and acceptance of faecal sludge as a good source of fertiliser by farmers in the Tamale Metropolis.

Nitrogen compounds are essential nutrients for living organisms and undergo biogeochemical transformations in the environment as part of the nitrogen cycle (Lehnert et al., 2015). Plants and micro-organisms convert inorganic nitrogen to organic forms. In the environment, inorganic nitrogen occurs in a range of oxidation states as nitrate (NO_3^-), nitrite (NO_2^-), ammonium ion (NH_4^+) and molecular nitrogen (N_2) while organic nitrogen is found in proteins, amino acids, urea, living or dead organisms and decaying plant material (Wall, 2013). NH_3 is produced by the metabolism of proteins and other nitrogen-containing compounds. Mohiuddin and Khattar (2019) mentioned that glutamine is the primary source of ammonia (NH_3) in urine and also explained that the metabolic mechanism responsible for the regulation of NH_3 in the body causes the removal of nitrogen from peripheral tissues to the liver for its ultimate disposal as urea. Lentner et al. (1981) estimated that about 20% of faecal nitrogen is NH_3, biochemically degraded from proteins, peptides and amino acids. NO_3^- is an important pollutant which in excess serves as nutrient and stimulate the growth of algae responsible for algal blooms (Aniyikaiye et al., 2019) and other plants which decompose to increase biochemical oxygen demand (Okoh, 2010). NO_3^- in faecal sludge is attributed to possibly, the oxidation of nitrogenous waste products in human excreta (WHO, 2008). High NO_3^- concentrations in a treatment system primarily indicate a high level of oxygen available in the system and properly functioning nitrification (Krekeler, 2008).

The study determined the occurrence and concentration dynamics of nitrogen compounds in faecal sludge stabilisation ponds located at the landfill site of the Tamale Metropolis in Ghana.

MATERIALS AND METHODS

Study area

This study was undertaken in the Tamale Metropolis waste stabilisation ponds near Gbalahi community in the Northern region of Ghana. Geographically, the stabilisation ponds are located between latitude 09°26'34.41"N to 09°26'41.90" N and longitude 000°45'24. 13" W to 000° 45'28.30" W. Figure 1 is the map of the study area and location of the faecal sludge stabilisation pond in the Metropolis. The region experiences one rainy season starting from April/May to September/October with a peak season in July/August with an average annual rainfall of 1,000 to 1,300 mm. The dry season is between the months of November and May. The region is one of the hottest in the country with an annual average temperature of 29 to 34°C. Annual average relative humidity is estimated at 47.0% while reference evapotranspiration (ETo) is reported above 600 mm/year (Armah et al., 2010; Abdul-Ganiyu, 2011).

The stabilisation ponds receive faecal sludge from cesspit emptier operators in the Metropolis and the ponds consist of two units, each of three ponds anaerobic, primary facultative, and secondary facultative ponds) in series connected to a single maturation pond.

Field data collection and analysis

Each of the four treatment ponds: Anaerobic (AN), Primary Facultative (PF), Secondary Facultative (SF) and Maturation (MT) were divided into three units: influent point (IP), midpoint (MP) and effluent point (EP) for sampling purposes. Faecal sludge sampling was simultaneously carried out for each of the ponds at marked points and approximate depth of 30 to 50 cm using 500 ml sample collection bottles. A total of 12 samples were collected per each sampling time and at 14 days interval for a period of 5 months (November 2013 to March 2014) in the dry season. Laboratory analyses were thus carried out on a total of 120 samples for the entire study. Using the Nessler Method and Powder Pillows NH_3, NO_3^- and NO_2^- levels were determined through direct reading using a DR 2800 Spectrophotometer. The data was analysed for variation in N compounds among stabilisation ponds by ANOVA performed at 5% level of significance. Minitab 16 was used for the ANOVA and multiple mean comparison while graphs were generated using Microsoft Excel 2016.

RESULTS AND DISCUSSION

Ammonia (NH_3) concentration in stabilisation ponds

The study results indicated that the AN pond recorded the highest NH_3 concentration of 142.53 mg/l at the IP, 114.71 mg/l at the MP, and 116.12 mg/l at the EP with the details presented in Figure 2. Volatilisation of NH_3 was noted to be the only likely nitrogen removal mechanism in AN pond. With a probability value (p-value) of 0.84 for the ANOVA at 5% significance level, the mean concentration of NH_3 was noted to be statistically insignificant. Ramadan and Ponce (2008) explained that in AN pond, organic nitrogen is hydrolysed to NH_3, so concentrations in AN pond effluent are generally higher.

NH_3 exhibited a slight variation in concentration in the PF pond with a maximum concentration of 35.41 mg/l at the IP, which slightly reduced to 34.28 mg/l at the MP and eventually increased to 34.96 mg/l at the EP (Figure 2).

A similar variation in the concentration of NH_3 was recorded in the SF pond and with ANOVA 5% significance level recording p-value of 0.74, and 0.99 for PF pond indicating no statistically significant variation within the various ponds. The evidence of NH_3 removal by volatilising in facultative ponds was noted in the study of

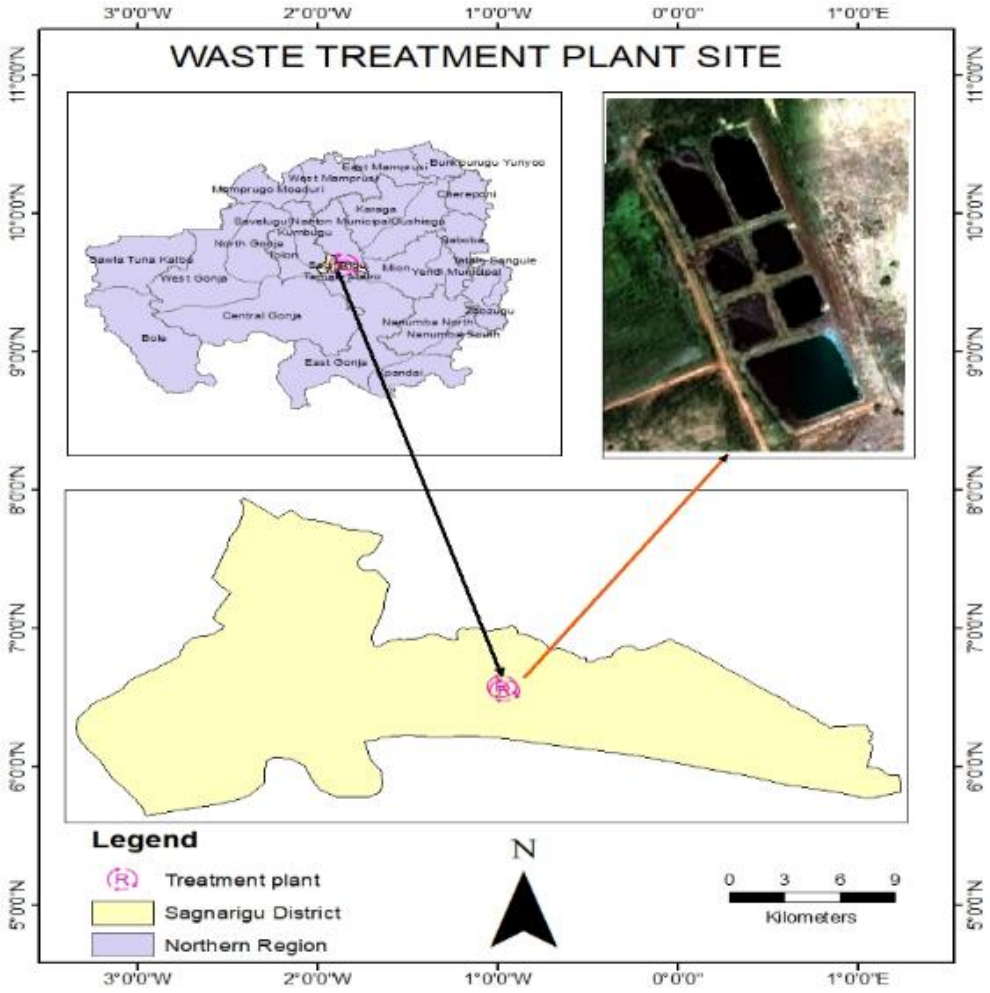


Figure 1. Map of study area.

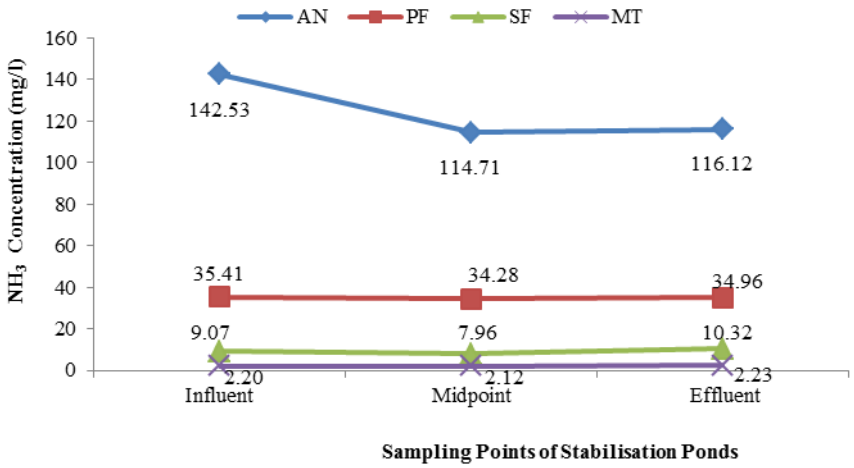


Figure 2. NH_3 concentration across sampling points in stabilisation ponds.

Vendramelli et al. (2016). Similarly, NH_3 in the MT pond recorded mean concentration of 2.18 mg/l with p-value of 0.99, thus indicating statistically insignificant variation. Soares et al. (1996) found that, high degree of NH_3

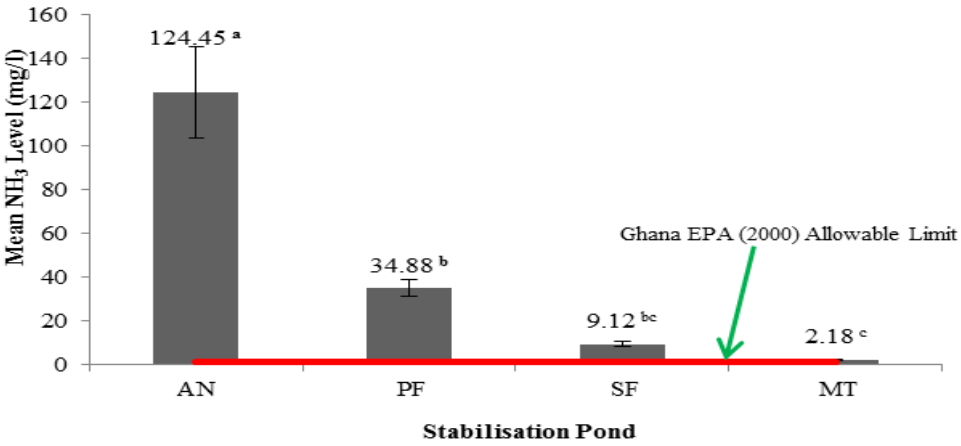


Figure 3. Average NH_3 concentration in stabilisation ponds**.** Data labels that do not share a letter (a, b or c) are significantly different.

removal commenced in the SF pond and subsequent MT pond due to improved aerobic conditions in shallow ponds.

The concentration rate of NH_3 indicated average maximum concentration of 124.45, 34.88, 9.12 and 2.18 mg/l in the AN, PF, SF and MT ponds, respectively as presented in Figure 3. Higher concentrations of NH_3 in the AN pond as well as the PF pond, could be an indication of high organic pollution (Deborah, 1996). Low NH_3 concentrations in the SF and the MT ponds could be attributed to losses via volatilisation which increases with increasing pH (Metcalf and Eddy, 1995; Deborah, 1996). Bastos et al. (2018) proved that algal nitrogen uptake and sedimentation of biologically incorporated organic nitrogen are the principal mechanisms responsible for NH_3 and total nitrogen removal in MT pond. In the study of Mayo (2013), mineralisation and NH_3 uptake by microorganisms accounted for 39.1 to 35.4% of the total nitrogen transformed for which NH_3 served as a source of nitrogen for cellular growth. Nitrification and denitrification also accounted for 31.3 and 26.2%, respectively of total nitrogen transformed in SF pond while in MT pond, NH_3 uptake accounted for 35.9%.

The results of ANOVA at 5% significance level showed that the variation of NH_3 concentrations among stabilisation ponds was statistically highly significant with p-value of <0.001. With least significant difference (LSD) of 29.93, NH_3 concentration in the AN pond was statistically different from the other ponds (Figure 3). All the NH_3 levels in the stabilisation ponds were above the allowable limit of 1 mg/l standard by Ghana EPA (2000) for effluent discharge or reuse for agriculture. High NH_3 levels in sludges may affect the performance of the treatment systems by posing biocidal effects to a range of microorganisms involved in the different biological treatment process and impair or suppress anaerobic degradation and/or algal growth (Montangero and Strauss, 2002; Koné and Peter, 2008; Liu et al., 2019). The effluent should thus further be treated to reduce NH_3 concentration using different treatment options such as the filter beds or constructed wetland prior to reuse for agriculture.

Nitrate (NO_3^-) concentration in stabilisation ponds

NO_3^- exhibited diverse degrees of occurrence within the stabilisation ponds. NO_3^- concentration steadily decreased from IP to EF at respective concentrations of 142.53 to 32.41 mg/l, 10.38 to 7.65 mg/l, and 11.76 to 9.03 mg/l for AN, PF and MT ponds, respectively. SF pond however, decreased from 11.88 mg/l to a minimum of 8.18 mg/l at MP and finally increased to 10.9 mg/l at the EP as presented in Figure 4. Results of ANOVA at 5% significance level for the variation in sampling point location presented no significant difference within the ponds with p-values of 0.24, 0.82, 0.65 and 0.81 for AN, PF, SF and MT ponds, respectively. The subsequent rise of NO_3^- concentration at the EP in SF pond can be attributed to oxidation of NO_2^- to NO_3^- in nitrification processes (Lenntech, 2014). NO_3^- concentrations in stabilisation ponds are largely influenced by nitrification and denitrification processes (Mayo and Hanai, 2014). Accordingly, the higher NO_3^- concentration might indicate a higher nitrification rate than denitrification at the various points within the stabilisation ponds and vice versa.

The dynamics of NO_3^- resulted to an average maximum concentration of 67.06 mg/l in AN pond, which significantly reduced to 9.16 mg/l in the PF pond, 10.32 mg/l in the SF pond and 10.68 mg/l in the MT pond (Figure 5). Bansah and Suglo (2016) similarly recorded an appreciable reduction of NO_3^- from 2.39 to 0.4 mg/l in final effluent of typical waste stabilisation ponds in the Obuasi Municipality of Ghana. NO_3^- reduction from the

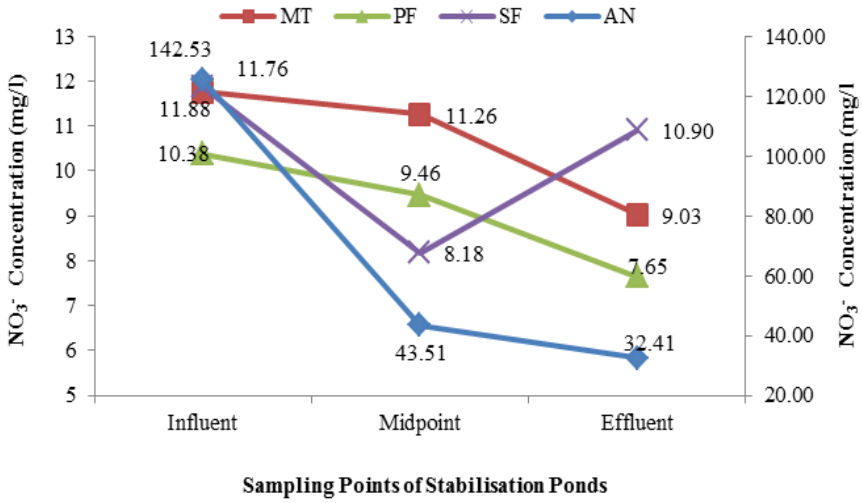
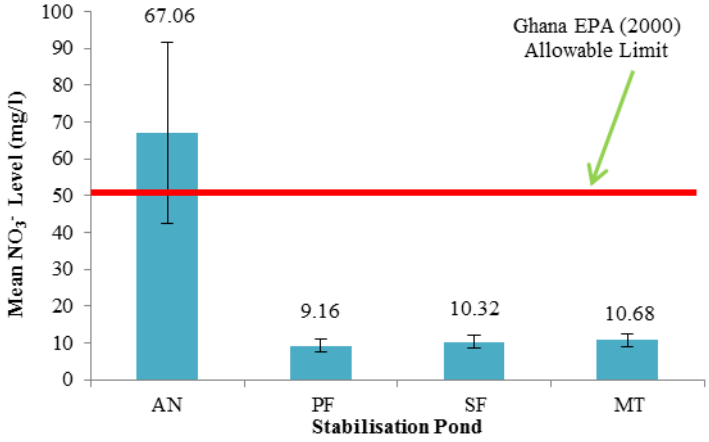


Figure 4. NO_3^- concentration in stabilisation ponds.



Figures 5. Average NO_3^- concentration in faecal sludge treatment ponds.

AN pond to the PF pond can be attributed to the biochemical reduction of NO_3^- to NO_2^-. NO_3^- may biochemically reduce to NO_2^- by denitrification processes, usually under anaerobic conditions (Deborah, 1996).

Statistically, variation of NO_3^- concentrations among stabilisation ponds were realised to be insignificant by ANOVA at 5% significance level with a p-value of 0.119. Aside NO_3^- concentration in the AN pond, all concentrations were below the Ghana EPA (2000) allowable limit of 50 mg/l for effluent discharge or reuse. According to Deborah (1996), NO_3^- concentrations above 5 mg/l usually indicates pollution by human waste, and in cases of extreme pollution, concentrations may reach 200 mg/l. Higher concentrations can, therefore, represent a significant health risk to humans when especially exposure levels are high.

Nitrite (NO_2^-) concentration in stabilisation ponds

Variation of NO_2^- concentration from the IP, MP and the EP for the various ponds is presented in Figure 6.

In the AN pond, a maximum NO_2^- concentration of 0.71 mg/l at the IP reduced to 0.10 mg/l at MP, and 0.12 mg/l at EP. The remaining ponds recorded a marginal increase from the IP to the EP at respective concentrations of 0.06 to 0.17 mg/l, 0.03 to 0.20 mg/l and 0.02 to 0.01 mg/l for PF, SF and MT ponds. Variation of the NO_2^- concentration was determined to be statistically insignificant with p-values of 0.318, 0.740, 0.645 and 0.343 for AN, PF, SF and MT ponds, respectively.

An average NO_2^- concentration of 0.31, 0.13, 0.14, and 0.01 mg/l were recorded for AN, PF, SF and MT ponds, respectively. The general dynamics of NO_2^- in the

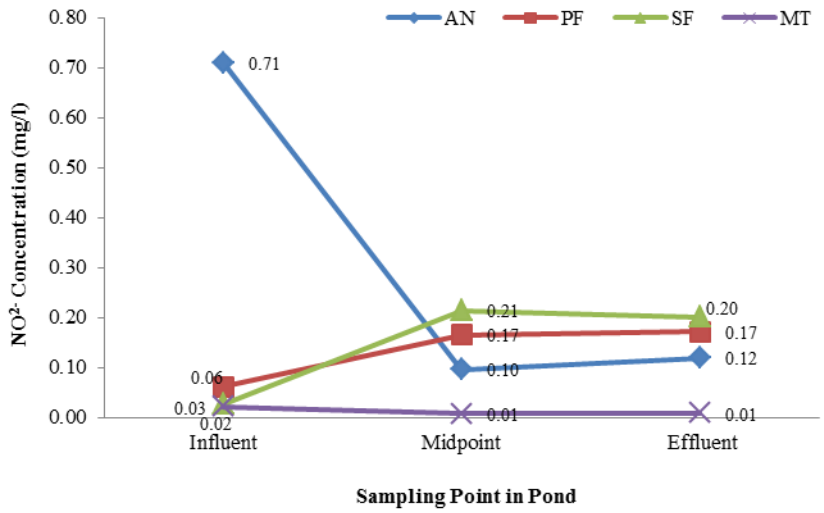


Figure 6. NO_2^- concentration in stabilisation ponds.

stabilisation ponds are mainly influenced by nitrification of ammonium (NH_4^+) to NO_2^- which produces NO_3^- as the final product. However, under favourable conditions, NO_3^- may be denitrified to form NO_2^- and N_2, with the involvement of bacterial species such as *Pseudomonas, Micrococcus, Achromobacter,* and *Bacillus* (USEPA, 2011).

Gad and Abdalla (2017) similarly observed an appreciable increase in NO_2^- and NO_3^- level from anaerobic to facultative ponds due to potential nitrification while further decreased in MT was attributed to denitrification and directly uptake by algal biomass.

The significance of sedimentation as a permanent or primary route for nitrogen removal in stabilisation ponds is highlighted by different authors (Senzia, 1999; Mkama, 2005; Mayo, 2013; Irene et al., 2014). Mayo (2013) found 73.7% of total nitrogen removal by sedimentation while denitrification accounted for over 90% in SF and MT ponds. The role of denitrification as a dominant mechanism for nitrogen removal in MT pond has also been reported by Mtweve (1999).

The acceptable limit of NO_2^- for effluent discharge is not defined by Ghana EPA. NO_2^- concentration are usually found to be very low, of about 0.001 mg/l, and rarely higher than 1 mg/l NO_2^-N thus high concentrations are often associated with unsatisfactory microbiological quality (Deborah, 1996).

Conclusion

Occurrence of nitrogen compounds was observed to vary in the faecal sludge stabilisation ponds. The AN pond on average, recorded the maximum concentration of all the compounds monitored and with the PF pond recording the average minimum concentration of NO_2^-. MT pond however recorded the minimum concentrations for both NH_3 and NO_3^-. Biochemical activities occurring within the ponds were noted to have very little effect on the variation of nitrogen compound concentrations. Average NH_3 concentration in stabilisation ponds was observed to be higher than the allowable limit of EPA Ghana for effluent discharge or reuse for agriculture while NO_3^- was lower, aside concentration in the AN pond. The effluent should thus further be treated to reduce NH_3 concentration using different treatment options such as the filter beds or constructed wetland prior to reuse for agriculture.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Abdul-Ganiyu S (2011). Hydrological analysis of river basins: A case of Nasia, a tributary of the white Volta River Basin of Ghana. VDM Publishing.

Aniyikaiye TE, Oluseyi T, Odiyo JO, Edokpayi JN (2019). Physico-chemical analysis of wastewater discharge from selected paint industries in Lagos, Nigeria. International Journal of Environmental Research and Public Health 16(7):1235.

Armah FA, Yawson DO, Yengoh GT, Odoi JO, Afrifa EK (2010). Impact of floods on livelihoods and vulnerability of natural resource dependent communities in Northern Ghana. Water 2(2):120-139.

Bansah KJ, Suglo RS (2016). Sewage treatment by waste stabilisation pond systems. Journal of Energy and Natural Resource Management 3:1.

Bastos RKX, Rios EN, Sánchez IA (2018). Further contributions to the understanding of nitrogen removal in waste stabilisation ponds. Water Science and Technology 77(11):2635-2641.

Cofie OO, Kranjac-Berisavljevic G, Drechsel P (2004). The use of human waste for peri-urban agriculture in Northern Ghana. Renewable Agriculture and Food Systems, pp. 73-80.

Deborah C (1996). Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - Second

Edition. Published on Behalf of United Nations Educational, Scientific and Cultural Organization and World Health Organization United, Nations Environment Programme (UNESCO/WHO/UNEP).
Environmental Protection Agency (EPA) Ghana (2000). National Environmental Quality Standards Regulations, 2000. Final Draft.
Gad M, Abdalla A (2017). Fate of Heavy Metals and Nutrients in Waste Stabilisation Ponds in Arid Zones. Journal of Engineering Sciences 45:1-16.
Ingallinella AM, Sanguinetti G, Koottatep T, Montangero A, Strauss M (2002). The Challenge of Faecal Sludge Management in Urban Areas - Strategies, Regulations and Treatment Options. Water Science and Technology 46(10):285-294.
Irene TA, Yohana L, Senzia M, Mbogo M, Mbwette TSA (2014). Modeling of Municipal Wastewater Treatment in a System Consisting of Waste Stabilisation Ponds, Constructed Wetlands and Fish Ponds in Tanzania. In: Developments in Environmental Modelling 26:585-600.
Koné D, Peter S (2008). Faecal Sludge Management (FSM). Sandec Training Tool 1.0- Module 5. EAWAG/SANDEC, Department of Water and Sanitation in Developing Countries.
Koné D, Cofie OO, Nelson K (2010). Low-Cost Options for Pathogen Reduction and Nutrient Recovery from Faecal Sludge. In: Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-Income Countries, eds., Drechsel P, Scott CA, Raschid-Sally L, Redwood M, Bahri A. UK: Earthscan; Canada: International Development Research Centre (IDRC); Sri Lanka: International Water Management Institute (IWMI), pp.171-188.
Krekeler T (2008). Decentralised Sanitation and Wastewater Treatment. Revised 2nd Edition, BundesanstaltfürGeowissenschaften und Rohstoffe (BGR) Federal Institute for Geosciences and Natural Resources Stilleweg Hannover, Germany. Available at www.bgr.bund.de/decentralised-sanitation-pdf.
Kuffour AR (2010). Improving Faecal Sludge Dewatering Efficiency of Unplanted Drying Bed. PhD Thesis, Kwame Nkrumah University of Science and Technology (KNUST) Kumasi, Ghana.
Lehnert N, Coruzzi G, Hegg E, Seefeldt L, Stein L (2015). Feeding the World in the 21st Century: Grand Challenges in the Nitrogen Cycle. National Science Foundation: Arlington, VA, USA.
Lenntech (2014). Nitrate and Nitrite. Water Treatment Solution. Available at www.lenntech.com/hazardous-substances/Nitrate and Nitrite.
Lentner C, Lentner C, Wink A (1981). Units of Measurement, Body Fluids, Composition of the Body, Nutrition. Geigy Scientific Tables. CIBA-GEIGY Ltd Basle, Switzerland, ISBN 0-914168-50-9, cited in Nartey EG (2013). Faecal Sludge Reuse in Urban and Peri-Urban Crop Production. MPhil Thesis, University of Ghana, Legon. Available at ugspace.ug.edu.gh.
Liu Y, Ngo HH, Guo W, Peng L, Wang D, Ni B (2019). The roles of free ammonia (FA) in biological wastewater treatment processes: A review. Environment International 123:10-19.
Mayo AW (2013). Nitrogen mass balance in waste stabilisation ponds at the University of Dar es Salaam, Tanzania. African Journal of Environmental Science and Technology 7(8):836-845.
Mayo AW, Hanai EE (2014). Dynamics of Nitrogen Transformation and Removal in a Pilot High Rate Pond. Journal of Water Resource and Protection 6:433-445.
Metcalf & Eddy Inc. (1995). Wastewater Engineering: Treatment, Disposal and Reuse. Third Edition. Revised by Tchobanoglous, G. and Burton F. L. Tata McGraw-Hill Book Co., New Delhi.
Mohiuddin SS, Khattar D (2019). Biochemistry, ammonia. In StatPearls [Internet]. StatPearls Publishing. Available from: https://www.ncbi.nlm.nih.gov/books/NBK541039/
Montangero A, Strauss M (2002). Faecal Sludge Treatment. Eawag/Sandec. IHE, Delft. Available at www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_ewm/downloads_ewm/IHE_lecture_ notes.pdf. Accessed on 4/5/2013.
Mtweve A (1999). Nitrogen Transformation and Removal in Maturation Ponds. MSc Dissertation, MSc (Eng) dissertation, Department of Civil Engineering, University of Dar es Salaam, Tanzania.
Okoh AE (2010). Water Auditing of a Ghanaian Beverage Plant. MSc Thesis, Kwame Nkrumah University of Science and Technology (KNUST) Kumasi, Ghana.
Ramadan H, Ponce VM (2008). Design and Performance of Waste Stabilization Pond. Available at http://stabilizationponds.sdsu.edu. Accessed on 12/11/2014.
Soares J, Silva SA, Oliveira R, Araujo ALC, Mara DD, Pearson HW (1996). Ammonia removal in a pilot-scale WSP complex in northeast Brazil. Water Science and Technology 33(7):165-171.
U.S. Environmental Protection Agency (USEPA) (2011). Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers. PA/600/R-11/088 available at www.epa.gov/nrmrl
Vendramelli R A, Vijay S, Yuan Q (2016). Phosphorus removal mechanisms in a facultative wastewater stabilisation pond. Water, Air, and Soil Pollution 227(11): 417.
Wall D (2013). Nitrogen in Waters: Forms and Concerns. Nitrogen in Minnesota Surface Waters, Minnesota Pollution Control Agency. Accessed May, 25, 2019.
WHO (2008). Guidelines for Drinking-water Quality. Third Edition. Quantifying Environmental Health Impacts. Available at www.who.int/quantifying_ehimpacts/global/globalwater/en/index.htm. Accessed on 4/11/2014.

Vol. 14(10), pp. 336-346, October 2020
DOI: 10.5897/AJEST2020.2880
Article Number: 7CE1F3765071
ISSN: 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Assessment of the phytoremediation capabilities of bracken fern (*Pteridium aquilinum*) for the remediation of heavy metals (Pb, Ni and Cd) contaminated water

Oshiotse Anita Emashogwe, Inengite Azibaola Kesiye*, Godwin Jackson and Ugbome Isaac

Department of Chemical Sciences, Faculty of Science, Niger Delta University, P.M.B 071, Wilberforce Island, Bayelsa State, Nigeria.

Received 30 June, 2020; Accepted 28 September, 2020

This study was carried out to investigate the potential uptake of heavy metals (Pb, Ni, and Cd) by *Pteridium aquilinum* plant from aqueous solutions. The whole plant strands were cultured in 36 experimental pots containing 5, 10 and 15 (mg/L) of Pb^{2+}, Ni^{2+} and Cd^{2+} aqueous solutions. The plants were harvested after 24, 48, 72 and 96 hours of exposure and segmented into leaves, stem and root, respectively. The heavy metals content in the plant parts were analyzed using Atomic Absorption Spectrophotometer version VGP 210. The highest actual accumulations for Pb, Ni and Cd were recorded in the root at 15 mg/L of the aqueous solution after 96 hours of exposure with mean values of 4.29±0.04, 4.06±0.01 and 0.65±0.00 mg/kg, respectively. The highest total actual accumulations recorded in the plant were 9.19±0.14, 10.80±0.03, and 1.23±0.04 mg/kg for Pb, Ni and Cd, respectively. The accumulation of the heavy metals in the plant parts was in this order; root > stem > leaves. The results reveal that, the accumulation of heavy metals in the plant increases with increase in the concentration of the aqueous solutions and the duration of exposure to the aqueous solutions. The uptake of heavy metals by the plant is in this order; Ni > Pb > Cd. The translocation factor (TF) recorded for Pb, Ni and Cd in the plant were all greater than 1 (>1) except for Cd at exposure duration of 96 h in the 15 mg/L Cd^{2+} aqueous solutions, with the highest TF values of 2.500, 1.886 and 1.601, respectively. This indicates that more of the heavy metals were stored in the shoot. *P. aquilinum* is therefore described as a good accumulator plant, which could be used for phytoextraction of Pb, Ni and Cd in aqueous solutions of the metals.

Key words: Phytoremediation, *Pteridium aquilinum,* heavy metals, contamination, translocation factor.

INTRODUCTION

Due to increase in anthropogenic activities, environmental contamination by heavy metals has increased considerably and has become a serious environmental concern (Saha et al*.,* 2017; Yan et al., 2020). It has been known that heavy metals pollution of the biosphere is caused by the increased growth of the chemical

*Corresponding author. E-mail: ainengit@yahoo.com.

industries. Nearly 1000 new chemicals are being synthesized every year and once these chemicals get into the environment, they pose potential health risk to humans and also have great impact on soil, ground water and plants (Shukla et al*.,* 2010). Other factors such as excessive use of pesticides in agriculture, waste from de-acidifying soils and crude oil processing are known to contribute to environmental pollution (Szczygłowska et al*.,* 2011; Uwazie et al., 2020).

Contamination by heavy metals is considered as the most critical threat to soil and water resources as well as humans, because of their non-bio-degradable nature, long biological half-life and their potential to accumulate in different body parts. Also heavy metals are capable of causing serious clinical problems to humans even at relatively lower concentration (Oti and Nwabue, 2013; Ibrahim and El Afandi, 2020). Heavy metals such as Cd can result in muscular weakness and cancers in humans; they can also cause a decrease in the lipid content and plant growth. For instance Ni can reduce proteins and enzymes production while Pb inhibits root and shoot growth (Fernandes and Henriques, 1991; Sarma et al., 2009).

Soil and water contaminated with toxic metals such as Cd, Pb, As, Zn, Ni, and Cu, as a result of worldwide industrialization has increased noticeably within the past few years (Ahmadpour et al*.,* 2012; Li et al*.,* 2019). Environmental pollution is therefore a global problem, and the development of inventive remediation technologies for the de-contamination of impacted sites is therefore of paramount importance.

Physical, chemical and biological methods are available for the remediation of contaminated sites (Kummling et al*.,* 2001). These remediation technologies may be used in conjunction with one another to reduce the contaminants to a safe and acceptable level (Hardiman et al., 2005; Jadia and Fulekar, 2009). Some of these methods (conventional) used for the remediation of contaminated sites include: excavation or dredging, pump and treatment, thermal desorption, solidification and stabilization, precipitation, nitrification, soil washing and air striping (Jadia and Fulekar, 2009). In spite of being efficient, these methods are quite expensive, time consuming and environmentally destructive and some of these methods can also strip the soil of its natural nutrient, even if it has been decontaminated, and also generate large amount of waste to be disposed of (Danh et al*.,* 2009).

Phytoremediation, which is a fast growing technology is considered among the best available technologies and recognized as an effective, appealing method for the remediation of contaminated sites because of its cost effectiveness, aesthetic advantage and long term applicability (Cunningham and Ow, 1996; Cluis, 2004). The term phytoremediation actually refers to diverse collection of plant based technologies that use either naturally occurring or genetically engineered plants for cleaning up contaminated sites (Flathman and Lanzan, 1996; Yoon et al., 2006). It is a green technology.

Studies have been conducted in areas of phytoremediation, using various types of plants in the phytoremediation of contaminated soil and water. Ma et al. (2001) applied *Pteris vittatta* to accumulate 14,500 mg/kg of arsenic in contaminated soil while Schnoor (1997) applied sunflower to remediate soil contaminated with uranium from 350 ppb to 5 ppb, achieving a 95% reduction in 24 h. Saha et al*.* (2017) achieved a 99.5% removal of Cr (IV) using water hyacinth. *Pteridium aquilinun* has also been used in the phytoremediation of zinc (Olaifa and Ajagbe, 2017) and copper (Olaifa and Omekam, 2014), using *Clarias gariepinus* for bioassay. Positive results were recorded. Some other studies investigated the use of phytoremediation in the remediation of soils contaminated with petroleum hydrocarbons and organics (Uwazie et al*.*, 2020). This study therefore aims at assessing the phytoremediation capability of *P. aquilinum* uptake of heavy metals (Pb, Ni and Cd) from contaminated aqueous solution over a given period of time in varying concentrations, following a perceived phytoremediating capability of *P. aquilinum* in its natural habitat.

MATERIALS AND METHODS

Appropriate quality control measures and precautions were put in place in order to obtain reliable data. Samples were carefully handled to avoid contamination, glassware apparatuses were properly cleaned and reagents and salts used throughout the analysis were of analytical grade. Stock solution and working standard solutions were prepared using standard procedures. Distilled water was used throughout the sample preparation and analysis. To prevent heavy metal contamination, all glass and non-glass ware apparatus used in this research work were washed with distilled water and immersed in 2% nitric acid for 24 h. Glass ware used throughout the analysis had no metal linings that could contaminate the samples.

Description of sampling area

This study was carried out in Niger Delta University New Site Campus within Amassoma, Bayelsa State, Nigeria. Here, *P. aquilinum* fern grows wildly around swampy environments with roots spreading all over the ground; it serves as a filtering medium for moving water bodies and also for adorning the environment with aesthetic beauty.

Amassoma is situated around Latitude 5.89° North of the Equator and Longitude 5.68^{o} East of the Greenwich Meridian. The town is characterized by high temperature and heavy rainfall all year round. The town experiences tropical wet and dry climate with a lengthy wet and short dry season. The rainy season runs from March through October with a short spell of dryness in August, while the dry season is between the months of November and February.

Bracken fern (*P. aquilinum*) is a non-flowering vascular plant that possesses true root, stem and complex leaves and it reproduces by spores. It belongs to lower division Pteridophyta, having leaves usually unrolled from a tight fiddlehead (https://en.wikipedia.org/wiki/Fern). *Pteridium aquilinum* is a wild naturally growing plant in Niger Delta that has relatively low

vegetative value. As fern grows in swampy areas with its roots spreading all over the covered ground, and serving as a filtering medium for moving water bodies, it is thought that the plant could also have some phytoremediation capabilities for the uptake of heavy metals from aqueous solutions. Hence, this research work was designed to investigate the potential of *P. aquilinum* fern for the phytoremediation uptake of heavy metals (such as Pb, Ni, and Cd) in aqueous solutions.

Sample collection and treatment

Plant samples collection and preparation was conducted on the 21st of April, 2017. A total of 144 *P. aquilinum* strands were collected. The plant strands were then packed and kept in a well labeled clean polyethylene bags and transported to the laboratory. The plants samples were placed under running tap water to remove any soil particles and finally rinsed twice with distilled water. The plant strands were then conditioned in distilled water for 24 h in order to eliminate contamination from the environment.

Standard solutions (5, 10 and 15) mg/L of Pb, Ni and Cd were prepared from Pb $(NO_3)_2$, $NiCl_2.6H_2O$, and $CdCl_2.H_2O$ salts respectively and put into 36 different experimental pots. After 24 hour(h) of conditioning of the plant strands in distilled water, the plant strands were removed from the distilled water and then cultured into 36 different experimental pots containing the various concentrations (5 , 10 and 15) mg/L of Pb^{2+}, Ni^{2+} and Cd^{2+} and control pots containing only distilled water (0.00 mg/L) respectively. The 0.00 mg/L solution (distilled water) in different pots was treated as the controls. Each set up contained three plant strands for triplicate determinations. The plant strands were harvested after a period of 24, 48, 72 and 96 h of exposure to the various metal solutions from each of the experimental and control pots respectively. The plant samples were then segmented using stainless steel knife into the leaves, stems and roots after each harvest and air dried for 7 days and then further oven dried at 70 ^{o}C until stable weights were obtained. The dried plant samples were then ground with ceramic mortar and pistil and then stored in well labeled plastic containers awaiting further laboratory analysis.

Plant digestion and heavy metals analysis

One gram (1.0 g) of the sieved plants samples (leave, stem and root) was weighed in triplicates and transferred into different 100 ml glass beakers. It was digested with 25 ml of 3:1 mixture of aqua regia (HNO3:HCl) at 100°C using corning PC- 351 model hot plate in a fume cupboard until a clear solution was obtained. The digested samples were left to cool for 5 min and then filtered using Whatman no.42 paper into a 100ml volumetric flask. The solution was made up to the mark with distilled water. The filtrate was transferred into a well labeled dry plastic containers awaiting heavy metal content analysis. The extractions were done in triplicates. The concentrations of the heavy metals in the digested plant parts were determined using Buck Scientific VGP 210 Atomic Absorption Spectrophotometer. The metals analyzed in the plant parts were Pb, Ni and Cd.

Calculation of heavy metals accumulation in plant

The actual accumulations of heavy metals (Pb, Ni and Cd) in plant parts were calculated from the various mean concentrations of these metals in *P. aquilinum* plant parts. They were estimated and determined using Equation 1 below:

$$A_A = C_{\text{plant part from aqueous solution}} - C_{\text{plant parts from control}} \quad (1)$$

Where: A_A = Actual accumulation of heavy metal in the plant part
$C_{\text{plant part from aqueous solution}}$ = Concentration of heavy metals in plant parts obtained from various aqueous solutions of heavy metals.
$C_{\text{plant parts from control}}$ = Concentration of heavy metals in plant parts obtained from the controls.
The actual total accumulation was calculated with Equation 2:

$$\text{Total } A_A = A_{A \text{ in leaves}} + A_{A \text{ in stem}} + A_{A \text{ in root}} \quad (2)$$

Where: Total A_A = Total Actual accumulation of heavy metal in the plant
$A_{A \text{ in leaves}}$ = Actual accumulation in the leaves
$A_{A \text{ in stem}}$ = Actual accumulation in the stem
$A_{A \text{ in root}}$ = Actual accumulation in the root

Translocation factor (TF)

In order to evaluate the potential of plants for phytoremediation, the Translocation Factor (TF) was determined. This is the ability of the plant to translocate metals from the roots to the aerial parts of the plant (Marchiol et al., 2004). Metals that are accumulated by plants and largely stored in the roots of plants are indicated by TF values <1. While the TF values >1 indicates that more of the heavy metals are being stored in the stems and the leaves (shoot) above the ground level than in the root.

In this study, Translocation Factors were calculated to estimate the transfer of heavy metals (Pb, Ni and Cd) from the roots to shoot (leaf + stem) and the Translocation Factor values of these metals were determined using Equation 3:

$$TF\ in\ Shoot\ = \frac{C_{SHOOT\ \ (STEM\ +LEAF\ )}}{C_{ROOT}} \quad (3)$$

Where: C_{SHOOT} = concentration of heavy metal in shoot
C_{ROOT} = concentration of heavy metal in Root

Data analysis

Microsoft Excel was used to determine the mean concentrations and standard deviations. Student t-test was also carried out to compare the mean concentrations of heavy metal in the *P. aquilinum* plant (leaves, stems, and roots) harvested from the various concentrations of the aqueous solution.

RESULTS AND DISCUSSION

The results obtained are as stated and discussed in the subsections that follow.

Lead content in *Pteridium aquilinum* plant parts

The actual accumulations of Pb uptake in plant parts recorded during the experimental period from the different concentrations of the aqueous solutions are presented in Table 1. These values were calculated from the mean concentrations of Pb accumulation in *P. aquilinum* plant parts. Comparison of means was also carried out using the student's t-test to check for statistical differences amongst the mean concentrations of Pb determined in the plant parts. The comparison was

Table 1. Accumulation of lead in plant parts.

Pb solution	24 h			48 h			72 h			96 h		
(mg/L)	5	10	15	5	10	15	5	10	15	5	10	15
Leaf	0.07^{a}±0.00	0.18^{a}±0.02	0.64^{a}±0.01	0.07^{a}±0.01	0.09^{a}±0.02	0.83^{a}±0.01	0.09^{a}±0.01	0.36^{a}±0.02	1.17^{a}±0.00	0.12^{a}±0.01	0.57^{a}±0.02	1.33^{a}±0.03
Stem	0.03^{a}±0.01	0.20^{a}±0.00	0.91^{b}±0.02	0.32^{b}±0.00	0.69^{b}±0.00	2.16^{b}±0.00	0.35^{b}±0.02	1.12^{b}±0.03	3.12^{b}±0.03	0.45^{b}±0.01	1.65^{b}±0.00	3.57^{b}±0.07
Root	0.04^{a}±0.00	0.29^{b}±0.00	1.21^{ab}±0.00	0.26^{b}±0.01	0.68^{b}±0.03	2.40^{ab}±0.02	0.28^{b}±0.02	1.13^{b}±0.02	3.24^{b}±0.04	0.48^{b}±0.00	2.00^{b}±0.01	4.29^{ab}±0.04
Total A_A	0.14±0.01	0.67±0.02	2.75±0.03	0.65±0.01	1.56±0.04	5.39±0.02	0.72±0.05	2.61±0.11	7.53±0.07	1.05±0.02	4.22±0.03	9.19±0.14

Within columns, mean values with different alphabets are statistically different at 95% confidence limits by student t-test (two tailed).

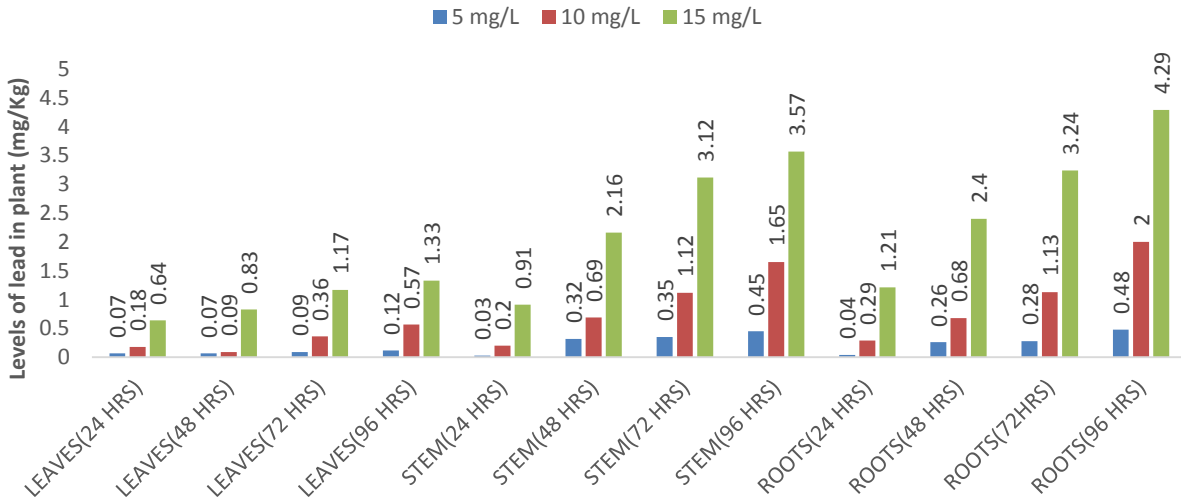


Figure 1. Accumulation of lead (mg/kg) in *P. aquilinum* plant with respect to time.

set at 95% confidence limits.

Pb accumulation in plant parts in the 5mg/L solution after 24 h of exposure showed no significant difference between the leaf and stem; leaf and root; and the stem and root at 95% confidence limits. In the 10 mg/L after 24 h of exposure, leaf and stem had no significant difference, while leaf and root; and the stem and root had significant differences. At 15 mg/L after 24 h of exposure, there was a significant difference between the various plant parts. This shows that as the concentration of the Pb solution increased, more accumulation took place in the plant parts following the trend root>stem>leaves. A similar trend was observed by Mkumbo et al. (2012). The difference in the levels of accumulation can be described as being proportional to the density of the tissues of the various plant parts. The roots were denser followed by the stem and then the leaves.

The findings indicate that *P. aquilinum* has the potential for phytoremediation of Pb, since the concentration of Pb in the shoot is higher than that in the roots, TF > 1 (Cheraghi et al., 2011). The trends of Pb uptake by *P. aquilinum* from Figure 1 show that the uptake kept increasing even at 96 h. It is a strong indication that the uptake would have

still increased beyond 96 h. The trend is similar to the report made by Maha (2012) in its study of two aquatic macrophytes, *Ceratophyllum demersum* and *Lemna gibba*, in removing two toxic metals (Pb and Cr). The plants were grown at four different concentrations in single metal and separately harvested after day 2, 4, 6, 9 and 12 under laboratory experiment, achieving 95% reduction of Pb and 85% reduction of Cr during 12 days' incubation period. However, the removal continued throughout the 12 days and up to the highest value on the twelfth day of the experiment.

Being limited by the period of exposure, which was 96 h in this study, it was difficult to ascertain if *P. aquilinum* is an hyperaccumulator of Pb as stated by Tangahu et al*.* (2011).

The results recorded for Pb in the *P. aquilinum* plant parts after 24, 48, 72, and 96 h of exposure to the various aqueous solutions (5, 10 and 15 mg/L) show that there was a steady increase in the level of Pb concentration in the plant parts, hence as the duration of exposure of the plant to the aqueous solutions increases, so also was the concentration of Pb in the plant parts. The results further revealed that as the concentration of the aqueous solutions increases, the more the uptake of Pb in the plant parts and the concentration of Pb accumulation in the plant from the various aqueous solutions recorded after 24, 48, 72 and 96 h of exposure followed the order of root > stem > leaf. This result agreed with the report by Subhashini and Swamy (2013), in their study of phytoremediation of Pb and Ni contaminated soils using *Catharanthus reseus* (L). They achieved a total accumulation of 0.92, 8.80 and 67.34mg/kg of Pb in the leaf, stem and root respectively throughout the experimental period.

Addition of amendments as nutrients also would have enhanced the plants to live longer due to available nutrients and the period of study would have been longer as studied by Placek et al*.* (2016), that worked on improving the phytoremediation of heavy metals contaminated soil by use of sewage sludge as a source of nutrients; thus the remediation of the *P. aquilinum* would have been better. Shrestha et al*.* (2019) also studied the enhancement of the phytoremediation capability of switchgrass by applying different compost and coir fibre amendments. They recorded significant improvements.

Nickel content in *P. aquilinum* plant

The accumulations of Ni in plant parts recorded during the experimental period from the different concentrations of the aqueous solutions were calculated from the mean concentrations of Ni accumulation in *P. aquilinum* plant parts. The mean concentrations of Ni in the plant parts are as presented in Table 2. The levels of Ni in the plant parts increased with increase in the concentration of Ni solution in which the plant is cultured as in the case of Pb. That is the amount accumulated in the plant followed the trend 15 mg/L > 10 mg/L >5 mg/L for the three solutions of different concentrations that the plant was cultured.

Comparison of the means using the student's t-test at 95% confidence limit showed that there was no significant difference for the lower concentration (5 mg/L) of the Ni solution at 24 and 48 h' exposures but as the period of exposure increased (72 and 96 h) there was a glaring difference in the amounts of Ni in the various plant parts which were significantly different with roots having higher concentrations. At 10 and 15 mg/L after 96 h of exposure, there were significant differences between the various plants parts at 95% confidence limit respectively. Similar trend as shown in Figure 2 was observed in the work reported by Mojiri et al*.* (2013), where they worked on the ability of Southern carttai (*Typha domigenesis)* plant for uptake of Pb, Ni and Cd in contaminated urban leachate within the period of 24, 48 and 92 h and achieved accumulation of 0.9725 mg/kg Pb, 0.468 mg/kg Ni and 0.392 gm/kg Cd, respectively, after the experimental period.

The results recorded for Ni in the *P. aquilinum* plant parts after 24, 48, 72, and 96 h of exposure to the various aqueous solutions (5, 10, and 15 mg/L) revealed that there was a steady increase in the level of Ni concentration in the plant parts, hence as the duration of exposure of the plant to the aqueous solutions increases, so also was the concentration of Ni in the plant parts. The results also show that as the concentration of the aqueous solution increases, the higher the uptake of Ni in the plant parts.

The level of Ni accumulation in the plant followed the order of root > stem > leaf, which shows similar trends with the work reported by Mojiri et al*.* (2013).

Cadmium content in *P. aquilinum* plant

The results recorded in Table 3 show the accumulation of Cd in the leaf, stem and root of the plant during the experimental period. There was significant difference between leaves and stem; leaves and roots; and the roots and the stem except at 5 and 10 mg/L and 24 h exposure where there was no significant difference between the roots and the stem. This indicates that there is good migration of Cd from the roots to the stems and to the leaves at low concentration and short period of time.

At the lower concentration (5 mg/L) and shorter period of exposure (24 h), there does not seem to be difference in the levels of Cd in the various plant parts (Table 3) but as the concentrations of the culture medium increase and the duration of exposure increases, there tends to be a difference between the plant parts with the trend roots>stem>leaves. This indicates that there is poor migration from the roots to the stem and also from the stem to the leaves. The trend is similar to the result reported by Sabeen et al*.* (2013), in their study of the

Table 2. Actual accumulation of nickel in plant parts.

Ni solution	24 h			48 h			72 h			96 h		
(mg/L)	5	10	15	5	10	15	5	10	15	5	10	15
Leaf	01.0^{a}±0.00	0.35^{a}±0.14	0.60^{a}±0.01	0.17^{a}±0.00	0.61^{a}±0.00	1.56^{a}±0.00	0.32^{a}±0.03	0.73^{a}±0.01	1.47^{a}±0.00	0.53^{a}±0.01	1.35^{a}±0.01	2.96^{a}±0.01
Stem	0.07^{a}±0.02	0.39^{a}±0.00	0.71^{ab}±0.02	0.16^{a}±0.01	0.66^{a}±0.02	1.92^{b}±0.01	0.29^{a}±0.00	1.07^{b}±0.01	2.81^{b}±0.02	0.74^{b}±0.01	1.87^{b}±0.01	3.78^{b}±0.01
Root	0.09^{a}±0.00	0.42^{a}±0.00	0.75^{a}±0.00	0.22^{a}±0.00	0.89^{b}±0.01	2.22^{ab}±0.01	0.57^{b}±0.02	1.17^{a}±0.00	3.03^{ab}±0.03	0.76^{b}±0.00	1.97^{ab}±0.01	4.06^{ab}±0.01
Total A_A	0.25±0.02	1.16±0.14	2.06±0.03	0.55±0.01	2.16±0.03	5.77±0.02	1.18±0.05	2.97±0.02	7.31±0.05	2.03±0.02	3.22±0.03	10.80±0.03

Within columns, mean values with different alphabets are statistically different at 0.05 confident limits by student t- test.

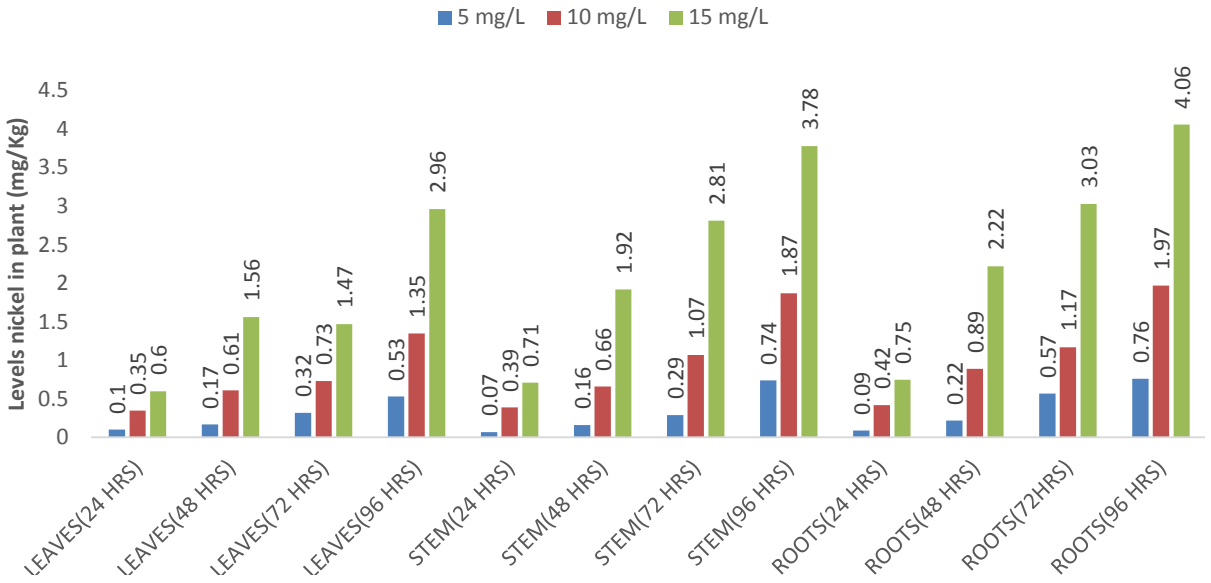


Figure 2. Accumulation of nickel (mg/kg) in *P. aquilinum* plant with respect to time.

potential uptake of *Arundo donax* L for the phytoextraction of Cd from contaminated soil and water after 21 days of exposure. However, the results obtained from Cd accumulation in plant parts also established that the higher the concentration of the aqueous solution, the higher the uptake of Cd in the stem and root of *P. aquilinum* plant. The level of Cd accumulation in plant parts followed the order of root>stem>leaf (Figure 3). The result also agreed with the report made by Sabeen et al. (2013) in their study of Cd phytoremediation by *Arundo donax L.* from contaminated soil and water.

Levels of accumulation of lead, nickel and cadmium by *P. Aquilinum*

The overall results show that *P. aquilinum* plant

Table 3. Actual accumulation of cadmium in plant parts.

Cd solution	24 h			48 h			72 h			96 h		
(mg/L)	5	10	15	5	10	15	5	10	15	5	10	15
Leaf	$0.07^{a}\pm0.02$	$0.10^{a}\pm0.01$	$0.16^{a}\pm0.01$	$0.09^{a}\pm0.01$	$0.13^{a}\pm0.00$	$0.15^{a}\pm0.01$	$0.17^{b}\pm0.0$	$0.22^{b}\pm0.01$	$0.09^{a}\pm0.02$	$0.24^{a}\pm0.01$	$0.26^{a}\pm0.02$	$0.03^{a}\pm0.01$
Stem	$0.10\pm^{a}0.00$	$0.17^{a}\pm0.01$	$0.26^{b}\pm0.01$	$0.16^{b}\pm0.00$	$0.25^{b}\pm0.01$	$0.35^{b}\pm0.01$	$0.24^{a}\pm0.01$	$0.31^{a}\pm0.01$	$0.46^{b}\pm0.01$	$0.32^{b}\pm0.00$	$0.44^{b}\pm0.01$	$0.54^{b}\pm0.01$
Root	$0.12^{a}\pm0.01$	$0.22^{a}\pm0.00$	$0.34^{ab}\pm0.02$	$0.22^{ab}\pm0.01$	$0.33^{ab}\pm0.01$	$0.43^{ab}\pm0.01$	$0.28^{a}\pm0.02$	$0.33^{a}\pm0.01$	$0.59^{ab}\pm0.00$	$0.38^{ab}\pm0.02$	$0.53^{ab}\pm0.01$	$0.65^{ab}\pm0.00$
Total	0.29±0.03	0.49±0.02	0.76±0.04	0.47±0.02	0.71±0.02	0.93±0.03	0.69±0.04	0.86±0.03	1.08±0.03	0.94±0.03	1.23±0.04	1.22±0.02

Within columns, mean values with different alphabets are statistically different at 0.05 confident limits by student t- test (two tailed).

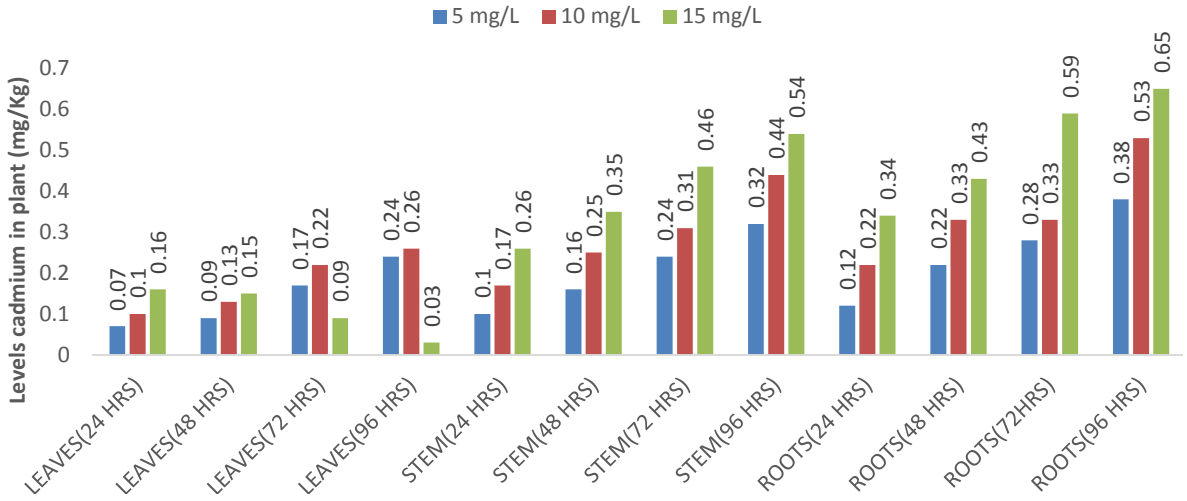


Figure 3. Accumulation of cadmium (mg/kg) in *P. aquilinum* plant with respect to time.

accumulates more of the Ni than Pb and then Cd, that is Ni > Pb > Cd. The highest amounts of Ni, Pb and Cd taken-up by the *P. aquilinum* plant were (10.80 ± 0.03, 9.19 ± 0.14 and 1.23 ± 0.04) mg/kg respectively. Aside other factors, the uptake of heavy metals by plants is influenced by the relevance of the heavy metal in the plant's metabolism; thus plants do not accumulate metals beyond their metabolic needs, which usually is in the range of 10 to 15 ppm (Tangahu et al., 2011), except the plants that are hyperaccumulators. Ni is an essential element in plant's metabolism while Pb and Cd are toxic to plants (Fernandes and Henriques, 1991; Sarma et al., 2009). This could possibly explain the trend, Ni > Pb > Cd in the heavy metal uptake by *P. aquilinum*. Figures 4 to 6 are pictorial presentations of the trends of the levels of uptake of Pb, Ni and Cd by *P. aquilinum*. It is observed that as the duration of exposure increases, Pb competed favourably with Ni and even exceeded Ni especially at higher concentrations of the culture medium (10 and 15 mg/L). This was observed mostly in the roots and stems. It is therefore an indication that there is

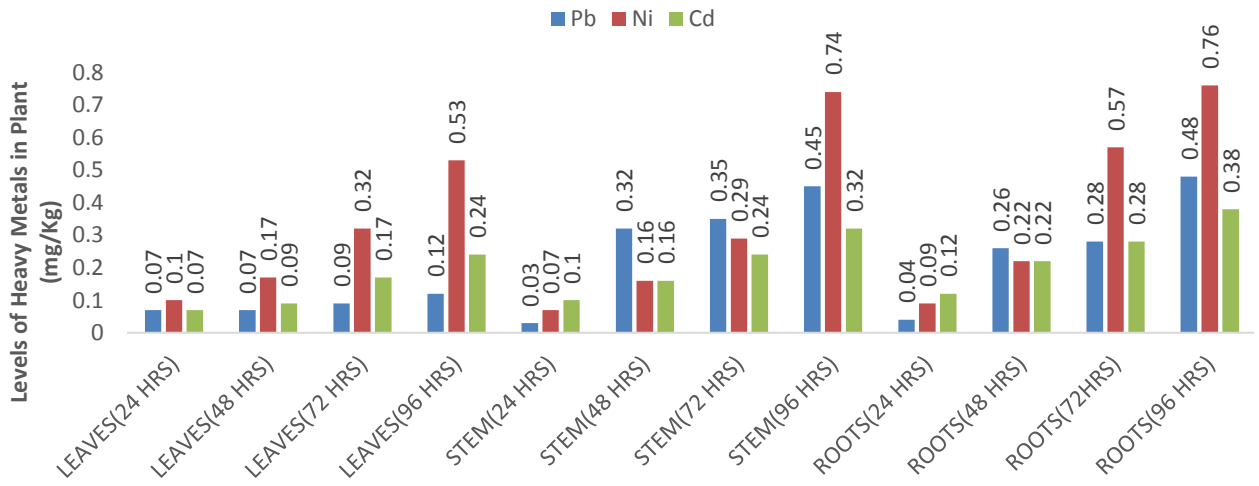


Figure 4. Levels of lead, nickel and cadmium uptaken *P. aquilinum* plant from a 5mg/L metal solution.

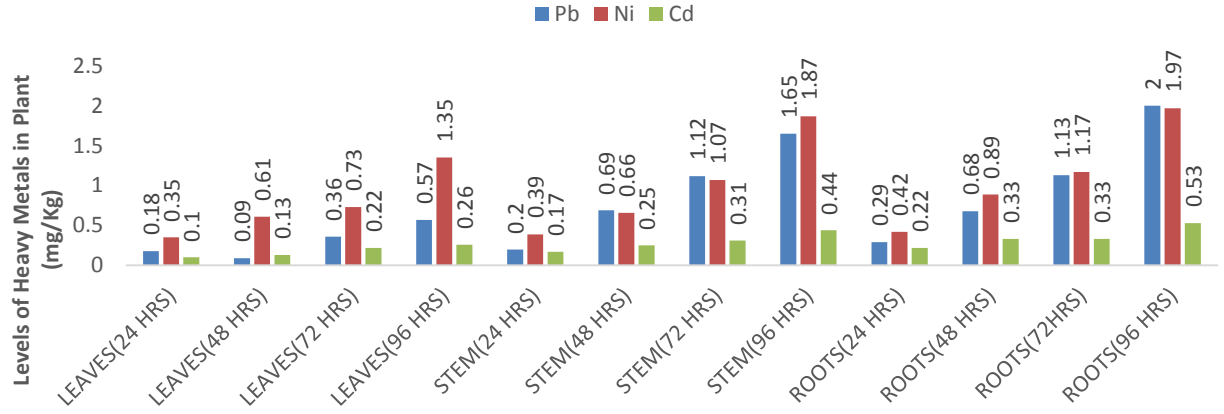


Figure 5. Levels of lead, nickel and cadmium uptaken *P. aquilinum* plant from a 10mg/L metal solution.

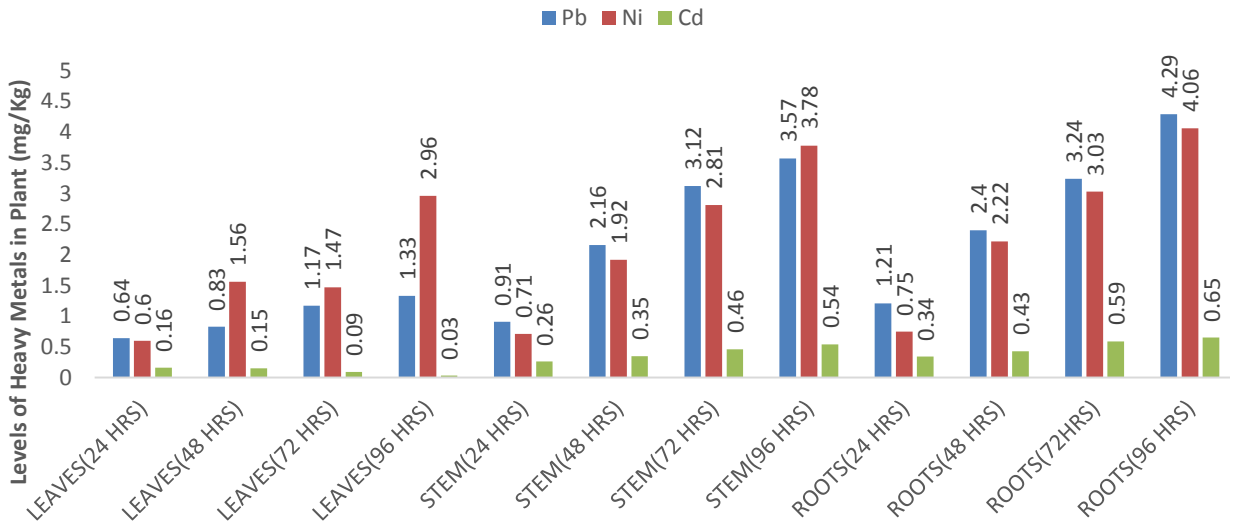


Figure 6. Levels of lead, nickel and cadmium uptaken *P. aquilinum* plant from a 15mg/L metal solution.

Table 4. Translocation factors of Lead, Nickel and Cadmium in *P. aquilinum* plant.

	Concentration of metal solutions (mg/L)	Translocation factors			
		24 h	48 h	72 h	96 h
Lead	5	2.500	1.500	1.571	1.188
	10	1.310	1.294	1.310	1.110
	15	1.240	1.246	1.324	1.142
Nickel	5	1.886	1.500	1.070	1.671
	10	1.762	1.427	1.539	1.635
	15	1.747	1.568	1.413	1.660
Cadmium	5	1.417	1.136	1.464	1.474
	10	1.227	1.152	1.601	1.320
	15	1.235	1.163	1.038	0.877

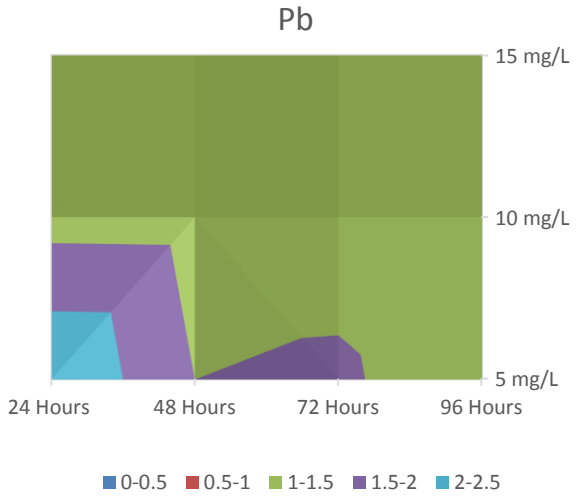


Figure 7. Surface Contour Map of the TFs of Pb.

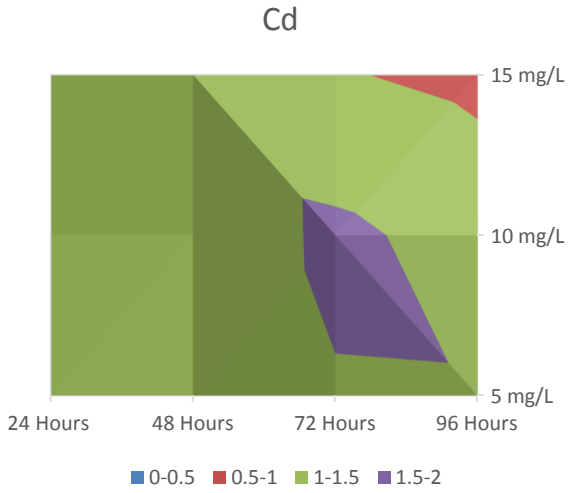


Figure 9. Surface Contour Map of the TFs of Cd.

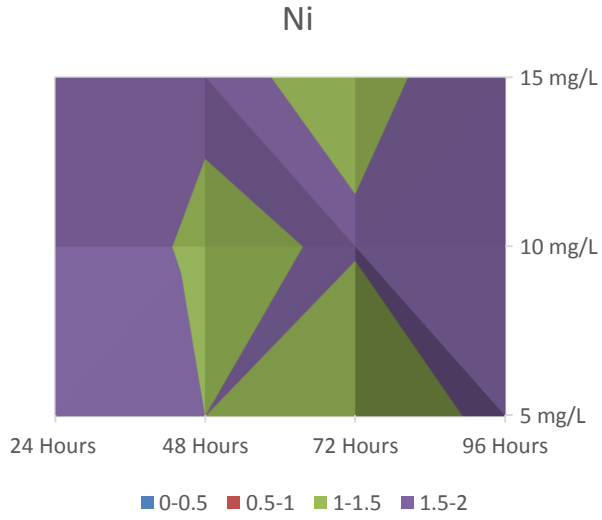


Figure 8. Surface Contour Map of the TFs of Ni

ffective translocation of Pb and Ni as the duration of exposure and concentration of the culture medium increases.

Translocation factors of Lead, Nickel and Cadmium in *P. aquilinum* plant

The translocation factors (TFs) for Pb, Ni and Cd in the plant parts are presented in Table 4. The translocation factors recorded during the experimental period were all greater than unity (>1) except for Cd at exposure duration of 96 h in the 15 mg/L Cd solution. Figures 7 to 9 are Surface Contour Maps illustrating the TFs for Pb, Ni and Cd showing the concentrations and durations that favour the translocation of the heavy metals from the roots to the shoots. The results show that there is relatively higher TFs at a solution concentration of 5 mg/L.

The highest TF value recorded for Pb in the plant was observed after 24 h of exposure at 5 mg/L of the aqueous solution with a TF value of 2.500, while 0.877 recorded for Cd as the least TF value was observed at 15 mg/L of the aqueous solution after 96 h of exposure. The results were similar to those reported by Mojiri et al. (2013) in their study of phytoremediation of heavy metals from urban waste leachate by southern cattail (*Typha domingenesis*) after 24, 48 and 72 h of exposure to the waste leachate. From the contour maps of Pb TFs (Figure 7) it is obvious that at lower concentrations and lower exposure times the migration rate of Pb from the roots to the shoot was high. As the exposure time increases the rates starts dropping thereby resulting to lower TFs. The same applies to concentration of the culture medium.

The trend in the translocation factors of Ni in *P. aquilinum* plant parts are as presented in Figure 8. The results show that the translocation factor recorded for Ni in the plant parts during the experimental period were all greater than 1 (>1) and fell within the range 1.143 to 1.886. Even at 24 h' duration, the migration from the roots to the shoot was almost complete, indicating a higher rate of Ni translocation as compared to Pd. That is why no much difference is observed between the lower and higher duration of exposure. The same applies for the concentrations of the culture media. There is high correlation of observations from this study with finding from studies carried out by Mojiri et al. (2013) and Subhashini and Swamy (2013).

The TF values for Cd recorded in the plant parts during the experimental period from the various concentrations of the culture medium were as presented in Figure 9. The results show that the translocation factors of Cd in the plant parts were all greater than 1 (>1) except after 96 h at 15 mg/L, where the TF value was less than 1 (0.877). The highest TF values were recorded after 72 h at 10 mg/L with a TF value of 1.601, while the lowest TF value was recorded at 15 mg/L after 96 h of exposure with a TF value of 0.877.

The high TF values were recorded within longer periods of duration and lower concentrations of the culture medium. Similar observations were recorded by Mojiri et al. (2013) in their study of phytoremediation of heavy metals from urban waste leachate by southern cattail (*Typha domingenesis*) after 24, 48 and 72 h of exposure to the waste leachate. Furthermore, the TF expresses the capacity of the plant to store the heavy metals in its upper part, hence the translocation factor (TF) results recorded for Pb, Ni and Cd from the various concentration of the aqueous solutions after 24, 48, 72 and 96 h of exposure were all greater than 1 (>1); TF value greater than 1 indicates the translocation of the metals from root to above ground parts (Jamil et al., 2009) showing that more of the heavy metals are stored in the shoot. The translocation factor (TF) patterns were in the order Ni > Pb > Cd.

Conclusion

This study shows that the level of heavy metals uptake by the *P. aquilinum* plant increases with increase in the concentration of the aqueous solutions. It was further established that the longer the duration of exposure by the plant in the aqueous solutions, the higher the level of heavy metals uptake by the plant. The levels of heavy metals accumulation in the plant parts were in the order; root > stem > leaves. The findings reveal that the plant accumulates more of Ni, followed by Pb and lastly Cd. The translocation factors (TF) in the shoot of the plant were > 1 indicating that more of the heavy metals were stored in the shoot. In conclusion, *P. aquilinum* can be described as an effective accumulator plant which could be used for phytoextraction of Pb, Ni and Cd from aqueous solutions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Ahmadpour P, Ahmadpour F, Mahmud TMM, Abdu A, Soleiman M, Tayefeh FH (2012). Phytoremediation of Heavy metals: A Green Technology. African Journal of Biotechnology 11:14036-14043.

Cheraghi M, Lorestani B, Khorasani N, Yousefi N, Karami M (2011). Findings on the Phytoextraction and Phytostabilization of Soils Contaminated with Heavy Metals. Biological Trace Element Research 144:1133–1141.

Cluis C (2004). Junk – Greedy Greens; phytoremediation as a new option for soil decontamination. Biotech Journal 2: 61-62.

Cunningham SO, Ow DW (1996). Promise and prospects of root zone of crops, phytoremediation. Plant Physiology 110:715-719.

Danh LT, Truong P, Mammucari R, Tran T, Foster N (2009). Vetiver Grass, *Vetiveria zizanoides*. A choice plant for phytoremediation of heavy metals and organic wastes. International Journal of Phytoremediation 1:664-691.

Fernandes JC, Henriques FS (1991). Biochemical, physiological and structural effects of excess copper in plants. Botanical Review 57:246-273.

Flathman PE, Lanza GR (1996). Phytoremediation current views on an emerging green technology. Journal of Soil Contamination 7(4):415-432.

Hardiman RF, Jacoby B, Banin A (2005). Factors affecting the distribution of copper**,** cadmium and Pb and their influence upon yield and Zn content in bush beans (*Phaseolus vulgaris*). Plant and Soil 81:17-27.

Ibrahim N, El Afandi G (2020). Phytoremediation uptake model of heavy metals (Pb, Cd and Zn) in soil using Nerium oleander. Heliyon 6(7):e04445.

Jadia CD, Fulekar MH (2009). Phytoremediation of heavy metal: recent techniques. Africa Journal of Biotechnology 8(6):921-928.

Jamil S, Abhilash PC, Singh N, Sharma PN (2009). *Jatrophacurcas*: A potential crop for phytoremediation of local fly ash. Journal of Hazardous Materials 172:269-275.

Kummling KE, Gray DJ, Power JP, Woodland SE (2001). Gas phase chemical reduction of hexachlorocyclohexane and other chlorinated compounds, waste treatment experience and applications. 6th International HCH and Pesticides Forum.

Li C, Ji X, Luo X (2019). Phytoremediation of Heavy Metal Pollution: A Bibliometric and Scientometric Analysis from 1989 to 2018. International Journal of Environmental Research and Public Health

16(23):4755.
Ma LQ, Komar KM, Tu C, Zhang W, Cai X, Kennelley ED (2001). A fern that hyperaccumulate arsenic. Nature 409:579.
Maha AMA (2012). Phytoremediation of heavy metals from aqueous solutions by two aquatic Macrophytes, *Ceratophyllum demersum* and *Lemna gibba L.* Environmental Technology 33(14):1609-1614.
Marchiol L, Assolari S, Sacco P, Zerbi G (2004). Phytoextraction of heavy metals by Canola (Brassica napus) and radish (Raphanus sativus) grown in multi-contaminated soil. Environmental Pollution 132:21-27.
Mkumbo S, Mwegoha W, Renman G (2012). Assessment of the phytoremediation potential for Pb, Zn and Cu of indigenous plants growing in a gold mining area in Tanzania. International Journal of Environmental Sciences 2(4):2425-2434.
Mojiri A, Aziz HA, Zahed MA, Aziz SO, Razip M, Selamat B (2013). Phytoremediation of Heavy Metals from Urban Waste Leachate by Southern Cattail (*Typha domingensis*). International Journal of Scientific Research in Environmental Sciences 1(4):63-70.
Olaifa FE, Ajagbe AO (2017). Accumulation of Zinc by *Pteridium aquilinum* (bracken fern) with different plant stimulants and bioassay with *Clarias gariepinus*. Journal of Environmental Research and Management 8(2): 011-017.
Olaifa FE, Omekam AJ (2014). Studies on Phytoremediation of Copper Using *Pteridium aquilinum* (Bracken Fern) In the Presence of Biostimulants and Bioassay Using *Clarias gariepinus* Juveniles. International Journal of Phytoremediation 16:219-234.
Oti WJO, Nwabue FI (2013). Heavy metals effects due to contamination of vegetable from Enyigba lead mine in Ebonyi state, Nigeria. Environment and Pollution 1(2):19-26.
Placek A, Grobelak A, Kacprzak M (2016). Improving the phytoremediation of heavy metals contaminated soil by use of sewage sludge. International Journal of Phytoremediation 18(6):605-618.
Sabeen M, Mahmood Q, Irshad M, Fareed I, Khan A, Ullah F, Hussain J, Hayat Y, Tabassum S (2013). Cadmuim Phytoremediation by *Arundo donax L.* from contaminated soil and water. Hindawi Biomed Research International 2013:9.
Saha P, Shinde O, Sarkar S (2017). Phytoremediation of industrial mines wastewater using water hyacinth, International Journal of Phytoremediation 19(1):87-96.
Sarma H, Sarma A, Sarma CM (2009). Physiological studies of some weeds grown under heavy metal and industrial effluent discharge zone of fertilizer factory. Journal of Ecology and the Natural Environment 1(7):173-177.
Schnoor JL (1997).“Phytoremediation’’ University of Lowa, Department of Civil and Engineering 1:62.
Shrestha P, Bellitürk K, Görres JH (2019). Phytoremediation of Heavy Metal-Contaminated Soil by Switchgrass: A Comparative Study Utilizing Different Composts and Coir Fiber on Pollution Remediation, Plant Productivity, and Nutrient Leaching. International Journal of Environmental Research and Public Health 16(7):1261.
Shukla KP, Singh NK, Sharma (2010). Bioremediation: Developments, Current Practices and Perspectives. Genetic Engineering and Biotechnology Journal 3:1-20.
Subhashini V, Swamy AVV (2013). Phytoremediation of Pb and Ni contaminated soils using *Catharanthus roseus (L)*. Universal Journal of Environmental Research and Technology 3:465-472.
Szczygłowska M, Pukarsha A, Konieczka P, Namiesnik J (2011). Use of brassica plants in the phytoremediation and biofumigation processes. International Journal of Molecular Sciences 12:7760-7771.
Tangahu BV, Abdullah SRS, Basri H, Idris M, Anuar N, Mukhlisin M (2011). A Review on HeavyMetals (As, Pb, and Hg) Uptake by Plants through Phytoremediation. Hindawi International Journal of Chemical Engineering pp. 1-31. https://doi.org/10.1155/2011/939161
Uwazie MC, Obijiaku JC, Onukwuli OD, Babayemi AK, Umeuzuegbu JC (2020). Remediation ability of melon grass in a crude oil polluted soil in a tropical region. International Journal of Engineering Technologies and Management Research 7(6):89-101.
Yan A, Wang Y, Tan SN, Mohd Yusof ML, Ghosh S, Chen Z (2020). Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land. Frontiers in Plant Science 11:359.
Yoon J, Cao X, Zhou Q, Ma LQ (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Science of the Total Environment 368(2-3):456-464.

Related Journals: