Water Quality of Streams and Springs around a Municipal Landfill Surrounded by Intense Agricultural Activities in a Tropical Environment

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Authors' contributions

This work was carried out in collaboration among all authors. Author BAF designed the study, authors ENN and FZA collected data. All authors read and approved the final manuscript.

| Original Research Article |

ABSTRACT

In Cameroon waste disposal by open dumping and landfilling are the most practised options. The siting, operation and after-care of landfills remain a challenging task. In this study we assessed water quality of stream, spring and leachate samples around/from the Mussaka landfill through physicochemical, heavy metal, microbial, phytoplankton, and benthic algae analyses. HCO_3^-, NH_4^-, NO_3^- concentrations are all above permissible limits EPA and WHO standards for freshwater systems. Concentrations of Ca^{2+} and Mg^{2+} in stream samples were far below standards but far greater (>480 mg/L) in spring and leachate samples. Nickel, lead and cadmium concentrations were above required standards. Contamination factors of all stream samples (CF<3) imply low to moderate contamination but pollution load index for spring sample (PLI>1) imply the spring is polluted. Generally, the obtained concentrations of most of these parameters were far higher for leachate than water samples. Total coliform counts ranged from 3.5 MPN/100mL to 1.1×10^3 MPN/100 mL. Five E. coli species were detected in all samples in counts ranging from 3.0×10^2 to 1.0×10^3 CFU/mL. Thirty phytoplankton species belonging to 5 divisions were identified with

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Bacillariophyta (19 species) having the highest abundance and Euglenophyta (1 species) with least. Ten genera were identified as pollution indicator species. Results of this study justify the assertion that if upgrading options are not sought for the Mussaka landfill, it will become a major source of pollution of aquatic and soil ecosystems within the landfill area and downstream.

1. INTRODUCTION

Over the past few decades, in some developing countries, certain activities of man, though somehow intended for good, are apparently having negative impacts on the environment. These activities include: agriculture, industrialization, other economic generating activities, and consequently the management of waste arising from them. Municipal solid waste (MSW) management mainly involves generation, storage, collection, transportation and disposal in a landfill or open dump (landfilling) or in some advanced cases transformation into other products such as energy. However, as opposed to the former practice of MSW disposal, a number of municipalities in Cameroon are shifting towards waste disposal by landfilling. The considerations for establishing and operating such landfills, as well as nature and quantity of waste bound for landfilling still leaves a lot to worry over especially with respect to pollution.

Rapidly increasing population, urbanization, and expanded waste collection services within municipalities are contributing to increasing pollution [1]. This worry is due to the pressure exerted by human activities on the environment, as land use changes to meet up increasing food demand and waste disposal. Many cities in developing countries face serious environmental degradation and health risks due to lack of adequate management systems [2] to address aspects like negative impacts of waste disposal, water pollution and poor land use practices. This has resulted to changes in the quality of the soil, water and air which are undesirable to humans and other organism [3].

In a broad sense, the management of municipal solid waste is based on three key objectives: i) to guarantee safe disposal of the waste; ii) to protect the environment and; iii) to preserve natural resources. In countries where proper functional elements of the municipal solid waste management system like recycling and reprocessing for energy are not practiced, then the first two objectives are key to ensuring that waste is handled in an environmentally friendly manner.

Amid various pollutions, water pollution is a global challenge that has increased in both developed and developing countries, and a huge or serious threat to environmental and human health. Water, is one of the essential natural resources for human existence and livelihood [4]. Over the years, the quantity of freshwater has dwindled appreciably [5] and the current generation faces the challenge to conserve water resources in the wake of global change. Aggravated by rapid population growth, most developing countries in sub-Sahara Africa do not have access to adequate, clean and reliable water supply [6]. While global awareness is focused primarily on water quantity, water-use efficiency and allocation issues, poor waste management as well as agricultural practices have created serious water-quality problems in many parts of the world, worsening the water crisis.

The discharge of large quantities of agrochemicals, organic matter, and drug residues from farms into water bodies poses risks to aquatic ecosystems, human health and productive activities [7]. The effects of land-uses on soil, surface and ground water quality in many areas has been documented [8,9,10,11,12,13]. Yong and Chen [14] examined the hydrological effects of land use in Ohio (USA) and ascertained that there was a significant relationship between land use types and surface water quality with the resultant effect such as eutrophication and its associated problems like oxygen depletion and loss of aquatic biodiversity [15].

Cameroon has abundant water resources with annual average availability estimated at 21,000 m^3 per capita, that is three times the world's average (7000 m^3) [16] but water still remains a scarce commodity. In addition to the water scarcity is the progressive deterioration of water quality in many parts of the country, reducing the quantity of water that is safe to use. Due to the absence of adequate waste management

facilities in most parts of the country, most of the streams are used as dumping sites and this not only pollutes the water but also exposes the population to waterborne diseases [17,18].

In Cameroon, the management of municipal solid waste is the sole responsibility of local councils. In some cases councils contract waste management services to manage waste generated within the council area. The generally observed approach to municipal solid waste management is the "collect and dispose" in a bid to keep the town municipality clean. Disposal of waste from the Buea municipality is done at the Mussaka landfill, for which there is virtually no engineered controls. A previous study had been conducted to investigate the impacts of the landfill on soils around and within the landfill [13], but the impacts of landfill on water systems around it remains unknown, given that the landfill is located in an area that can be described as constituting a sensitive ecosystem (Fig. 1). The main aim of this research therefore was to assess the impact of the Mussaka landfill on the surrounding aquatic resources. The specific objectives were to: i) determine the chemical contaminants in leachate and water within the landfill environment; ii) isolate the potential pathogenic bacteria in the leachate and water; and iii) assess the abundance, distribution and diversity of bio-indicators of pollution in the landfill environment.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

This study focuses on the landfill operated by the Buea municipal council located at Mussaka, a small village in the outskirts of Buea, on the south eastern flanks of Mount Cameroon along the Limbe – Kumba motorway. The landfill covers an area of about 13,240 m^2 (1.3 ha) and receives about 104 tonnes of waste daily comprising waste from the town of Buea and its surrounding communities. Waste bound for disposal in this landfill is handled (ie collection, transportation and disposal) by a waste disposal agent contracted by the council. The landfill area is characterized by different human activities including: banana plantation agriculture by Cameroon Development Cooperation (CDC); peasant cocoa, tomato and vegetable farming amongst others.

The topographic setting of the landfill comprises a natural semi-circular depression with a base,

partial sidewalls and an open end. The geomorphology of the area is characterized by a gentle to undulating relief with a geologic setting that is volcanic, and whose rock type can be described as mainly basaltic tuff formed from previous eruptions of Mount Cameroon. The open ended side of the landfill is bordered by a wetland. This stream, flowing through the northern and eastern parts of the landfill is being used upstream for car washing and downstream for irrigation of banana plantation by CDC, as well as drinking and irrigation of tomato and other vegetable by local peasant growers (Fig. 1). The presence of the wetland ecosystem and a banana plantation that exports its products to foreign markets renders the area ecologically sensitive.

The landfill which has been operating for eight years receives about 104 tones daily, of non-sorted municipal solid waste comprising: household, institutional, commercial and clinical waste is incinerated. The current method of disposal of waste in the landfill is characterized by: offloading of waste by collection trucks, lateral spreading by heavy duty machinery and subsequent volume reduction by compaction and sparing spread of highly weathered volcanic tuffs on top of compacted waste creating horizontal cells to prevent migration of leachate. Disposal activities at the landfill can be described in two phases namely the active and the passive phases. The active phase is the area where current disposal is taking place. The passive phase is the portion of the land where initial disposal began and ran for close to four years. This area, temporarily abandoned contains buried waste which has been sealed on the surface using volcanic soil material. This area which is more towards the periphery of the landfill is characterized by vegetation growth.

2.2 Sample Collection and Processing

Sample collection points are indicated on Fig. 1. Leachate samples were collected from both the passive (LS1) and active (LS2) sites within the landfill using locally designed lysimeters. The lysimeters were fitted and allowed in positions for two weeks, to collect a good quantity of leachate for analyses. The samples were collected in clean 100ml bottles. Samples were collected in duplicate from both sites.

For chemical and microbiological analyses, two sets of water samples were collected in 0.5 L plastic bottles from five sites around the landfill:
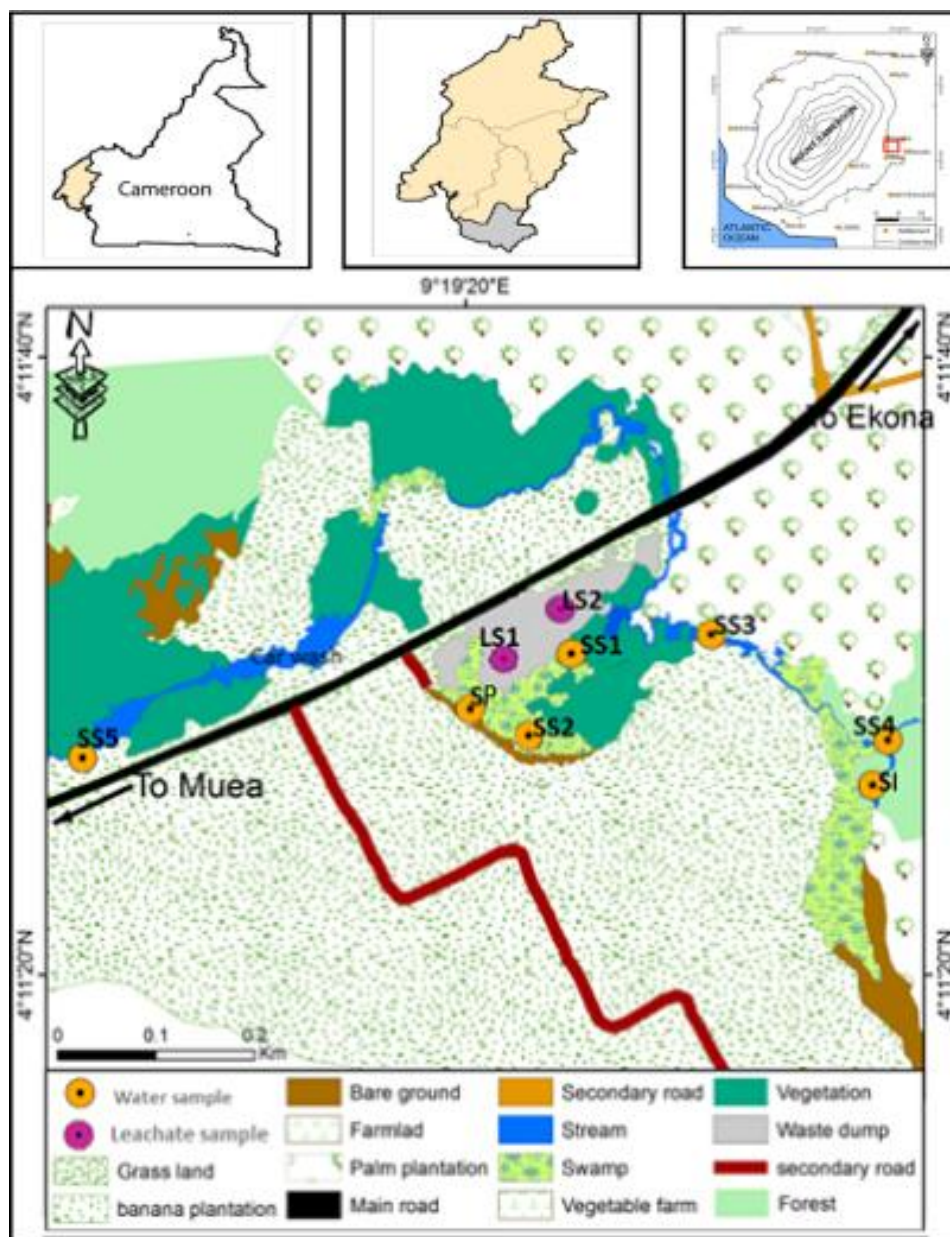
Fig. 1. Study area showing different land uses and sample collection points

along the stream (SS_1 to SS_5), one stream inlet (SI) and one spring source (SP). Before collection, the bottles were rinsed several times with stream water. The plastic bottles were dipped within the top 10 cm, corked and put in coolers containing ice. For phytoplankton analysis, water samples were collected in 50 mL black bottles and 2 - 3 drops of 10% Lugol's Iodine added to fix and preserve the algal cell structure. All samples were collected in duplicates and transported immediately in ice-

containing coolers to the Life Science Laboratory, University of Buea for analyses. Samples for bacterial analyses were stored at 0°C and analysed within six hours.

2.3 Physicochemical Analyses of Water and Leachate

The pH and Electrical conductivity (EC) were measured in situ using a Hanna waterproof field tester meter, model pH/°C/EC. Analyses for

nutrients were done at the Soils and Environmental Chemistry laboratory in the University of Dschang and the following were analysed: Bicarbonate (HCO_3-) (mg/l), Turbidity (NT), Nitrogen-Nitrate (N-NO_3-), Sulphate (SO_4^2), Calcium (Ca), Magnesium (Mg), Iron (Fe), Potassium (K), Sodium (Na), and Soluble Phosphorus (P Soluble) using standard methods [19]. Zinc (Zn), Copper (Cu), Nickel (Ni), Lead (Pb), Cadmium (Cd) and Mercury (Hg) were determined using atomic absorption spectrometer (Perkin Elmer). Salinity and Total Dissolved Solid (TDS) were calculated from conductivity using the conversion factor described by Dohrman [20] as used in Fonge et al. [21].

Salinity = (conductivity) 1.0878 * 0.4665 ....………..equation 1

TDS = conductivity µS/cm * 0.674 ....……………...................……equation 2

2.4 Determination of Microbial Load

A presumptive test was used to assess the total number of coliforms in the samples at the Life Sciences Laboratory of the University of Buea. Three sets of test tubes each containing lactose broth of increasing strength were inoculated with water samples and incubated for 24 hours at 37°C. The presence of cloudiness in the sample was indicative of the presence of coliforms. From the number of positive test-tubes in the presumptive test, the Most Probable Number (MPN) of coliforms was determined by referring to standard tables as described in [19].

Bacteria isolation was done using the Standard Plate count method in the Microbiology and Zootechnique Laboratory, University of Dschang. Five selective media were used: violet Agar for *Enterobacteria,* MacConkey Agar for *E. coli*, Blood Agar for *Streptococcus spp* (Blood Agar plates were incubated at 42°C under anaerobic conditions by placing in candle jar for 24 hours), Triptose phosphate-glucose Agar for *Pseudomonas spp*, *Salmonella Shigella* Agar for *Salmonella spp* and *Shigella spp*. All agar used were produced by Oxoid, USA. Standard media preparation and sterilization procedures as described by [22]. Were observed. 1 mL of each sample was inoculated on 25 mL of the solidified selective medium using the spread plate technique. The plates were incubated for 24 hours at 37° C, and the numbers of colony forming units (CFUs) counted after incubation.

2.5 Phytoplankton Abundance in Water

Phytoplankton analysis was done at the Life Sciences Laboratory, University of Buea. A drop (44µl) of each concentrated sample was extracted and a wet mount prepared on a clean slide and mounted on an Olympus BH-2 light microscope. Three slides were prepared for each sample for quantitative and qualitative analysis to ensure reproducibility. Counting and identification of species was done using an Olympus BH-2 light microscope at magnification of 1000x. For abundance, cells were enumerated under a light microscope. Identification was done using comparative morphology text books, journals and online databases [23]. The trophic status at each site was determined using the Euglenophycean index (EI) as in Equation 3:

Euglenophy cean index = (Euglenophyta / (Cyanophyta + Chorophyta) ....Equation 3

When EI < 1, the site is eutrophic, and if EI > 1 the site is oligotrophic

2.6 Data Analysis

The means of the physicochemical parameters were separated using Kruskal Wallis ANOVA at α = 0.05, following negative tests for normality. These analyses were done at α=0.05 using Minitab version 16 statistical package (Minitab Inc., USA). Spearman Rank correlation was used to check the relationship of water physico-chemical parameters with the bacteria. The extent of heavy metal contamination and pollution of water samples were calculated and interpreted as proposed by Hakanson [24] and Ngole and Ekosse [25]. The contamination factor (CF) and pollution load indice (PLI) were determined using the mathematical formulae as indicated in equations 4 and 5 respectively.

Contamination factor: CF = Cm/Bm
equation 4

Where, *C*m = measured concentration of heavy metal in the soil and *B*m = local background concentration value of the heavy metal. The concentrations of the heavy metals in the control samples (Site SS7, control) were used as the background concentration values to calculate the heavy metal contamination factor (CF) in this study.

Pollution load index:

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times ... \times CFn)}$$
equation *5*

Where, CF is contamination factor and n is the number of elements. PLI values <1 indicate no pollution whereas values >1 indicate pollution.

Shannon Weiner and Simpson's indices were used to compute for diversity of the phytoplankton. Simple correspondence analysis was used to display the spatial distribution and abundance of phytoplankton species across the different sampling sites.

3. RESULTS

3.1 Physicochemical Characteristics of Water and Leachate Samples

The results of the physico-chemical analysis are presented in Table 1. The pH of water in the study area ranged from 6.70 to 8.00 while the leachate was 7.40 – 8.00. The most basic site was SS_5 (8) and the slightly acidic sight was SS_2 (6.70). The pH values were within the WHO permissible limits of 6.5 to 8.5 for portable water. Aside pH and temperature which do not vary much across water samples, the other parameters like turbidity, total dissolved solids and salinity were greater for sample SS1 than all other water sample. Turbidity was highest (67.20 NTU) in site SS_1 and lowest (0.6 NTU) in site SS_3. However, sites SS_1, SS_4 of water and leachate (LS_1 and LS_2) were far above the USEPA [26] /WHO [27] limits while SS_2, SS_3, SS_5, and SI and SP were below limits. Conductivity was highest in LS_2 (16.52 mS/cm) and lowest in SP (0.17 mS/cm). Salinity was highest in LS_2 (6.48 mg/l) and lowest in SI and SP (0.07). SS_1 and leachate (LS_1 and LS_2) had salinity higher than the USEPA [26]/WHO [27] standard.

All the mean concentrations showed no statistical difference in water and leachate across the sampling sites except for carbonate (CO_3^-). Only one site (Site SS_3) showed the presence of Carbonate (0.13 mg/l). Iron (Fe) content ranged from 0.67 to 184.34 mg/l with highest concentration in LS_2 and lowest in SS_2, SS_5, SP and SI. Bicarbonate concentration (HCO_3^-) ranged from 118.95 to 1525.00 mg/l, with highest concentration in LS_2 and lowest in SS_4. Nitrogen-Nitrate ($N\text{-}NO_3^-$) ranged from 1.40 to 7.28 mg/l, with highest value in SP and lowest in SS_4. Sulphate (SO_4^{2-}) ranged from 21.32 to 65.60 mg/l

with the highest SO_4^{2-} concentration in SI and SS_5 and lowest in LS_2. Calcium (Ca) content was highest in LS_2 (2336.00 mg/l) and lowest in SS_2 (7.20 mg/l) while Magnesium (Mg) concentration was highest in LS_2 (1125.10 mg/l) and the lowest in SS_1 (9.23 mg/l). Potassium (K) was highest in LS_2 (1173.60 mg/l) and lowest in SS_5 (4.11 mg/l). Just like Potassium (K), Sodium (Na) concentrations were highest in LS_2 (58.25 mg/l) and lowest in site SS_5 (2.86 mg/l).

Water quality at the different sites and point sources compared with the USEPA [26] /WHO [27] standards revealed that, the concentrations of bicarbonate (HCO_3^-), Nitrogen-Nitrate ($N\text{-}NO_3^-$), Iron (Fe), Nitrogen-Ammonium ($N\text{-}NH_4^+$) and Potassium (K) recorded in the study sites, exceeded the limits for drinking and fresh water ecosystem (Table 2). The concentrations of Iron (Fe), Calcium (Ca), Magnesium (Mg) and Potassium (K) were also higher than the USEPA [26] and WHO [27] standards for fresh water ecosystem.

3.2 Heavy Metal Concentrations and Risk Assessment of the Leachate and Water around the Mussaka Landfill

Six heavy metals were analysed namely zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), cadmium (Cd) and mercury (Hg), the results are presented on Table 2. Zinc ranged from 0.58 to 1.21 mg/l with highest concentration in LS_2 and lowest in SS_4 while Copper had the highest concentration (1.17 mg/l) in LS_2 and lowest (0.55 mg/l) in SS_5. Nickel ranged from 0.43 to 0.56 mg/l with the highest in LS_2 and lowest in SS_1 and SS_3. Lead concentration was highest in SS_2 (0.60 mg/l) and lowest in SS_4 (0.13 mg/l) while Cadmium was highest in LS_2 (0.47 mg/l) and lowest in SS_2 (0.03 mg/l). Mercury was reported in leachate and in site SS_5 (control), while it was absent in all the other sites. The mean concentrations of the heavy metals did not vary significantly ($p > 0.05$) across the sites, point sources (SI and SP) and leachate. The concentrations of nickel, lead, cadmium and mercury exceeded the WHO [27] recommended limits for drinking water while Zn and Cu were below limits.

Contamination factors for waters in the study area indicated that the waters are moderately contaminated with Copper ($1 < CF < 3$), and lowly contaminated ($CF < 1$) with zinc and nickel, except for the spring (SP) which had a moderate

contamination (1 < CF < 3) with Ni. Site SS_2 and SP were moderately contaminated (1 < CF < 3) with Pb while site SS_1, SS_3, SS_4 and SI had a low Pb contamination (CF < 1). It was also observed that CF values with regards to Cu were low (CF < 1) in site SS_1, SS_2, SS_3, SS_4 and SI, and moderate (1 < CF < 3) in the spring (SP) water. The values obtained for pollution index of the sampled sites within the study area indicated that the sites and point sources were unpolluted (PLI < 1) except the spring (SP) (PLI > 1).

3.3 Bacteria as Indicators of Water and Leachate Quality

3.3.1 Total coliform counts, enumeration of bacterial isolates and identification of bacterial isolates in water and leachate samples

Total coliforms were observed in all samples (Table 3). The overall total coliform count was highest in leachate (1.1 ×10^3 MPN/100 ml) and lowest in spring (3.5 MPN/100 ml). There were significant differences (P < 0.05) in counts between SP and site SS_1, between SP and leachate (LS_1 and LS_2), and between site SS_5 and leachate. Bacterial counts in the water and leachate samples were in the range of 3.0×10^2 to 1.0×10^3CFU/ml (Table 3). Very high counts were recorded in the leachate samples. There was no significant difference (P > 0.05) in counts between the different sampling sites.

From the cultural and morphological characteristics, it has been shown that the samples contain species of *Escherichia coli*, *Salmonella spp*, *Shigella spp*, *Streptococcus spp* and *Pseudomonas spp*. All five species were detected in all samples. There was no statistical difference in species counts between the sites. *Salmonella spp.* and *Shigella spp.* were low (CFU/ml < 10) in SP and SS_3 while *E. coli* had the lowest count in site SS_3 (CFU/ml). However, the counts in all the isolated species were highest in the leachate samples. The values obtained were far above the World Health Organisation (WHO) and United State Environmental Protection Agency (USEPA) standards for bacteria in freshwater ecosystems.

3.3.2 Relationship between bacterial quality and physicochemical property of water around the landfill

There was a strong positive correlation between odour, colour and pH with bacteria count.

Bacteria count strongly decreases with an increase in conductivity and dissolved oxygen (Table 4). A strongly negative correlation was observed between *Salmonella spp.* (ρ = -0.944) and dissolved oxygen, *E. coli* (ρ = -0.937) and oxygen, *Shigella spp.* and dissolved oxygen (ρ = -0.922), *Pseudomonas spp.* and dissolved oxygen (ρ = -0.933). Hydrogen sulphide *Salmonella spp.* is positively correlated (ρ = 0.877) with colour while the Non-hydrogen sulphide *Salmonella spp.* is negatively correlated with colour. *E.coli* had a strong positive correlation with *Salmonella spp* and *Shigella spp*.

3.4 Phytoplankton Abundance and as Bio-indicator for Water Quality of the Surface Water around the Mussaka Landfill

A total of 30 species belonging to 5 divisions were identified in six stream sites including the stream inlet (SI) within the landfill environment. The division with the highest species abundance across the sampling sites was the Bacillariophyta (19 species) followed by Chlorophyta (5 species) and Cyanophyta (3 species). The divisions with the least abundance were Chromophyta (2 species) and the Euglenophyta (1species).

The relationship between phytoplankton abundance and water sampling sites assessed using simple correspondence analysis, shows that Components 1 and 2 contributed 37.48% and 23.61% respectively of the total inertia (Fig. 2). The two components effectively explain 61.09% of the total abundance of species across all sites. The symmetric plot showed that site SS_1 had high abundance with species like *Gyrosigma sp.* and *Navicula sp* while site SS_2 had high abundance of *Microcystis sp.* The point source SI had high abundance of *Pyrosigma sp.* Majority of the Phytoplankton species are abundant in site SS_3 while the remaining species are cosmopolitan.

Ten genera, having indicator species of pollution were identified (Fragillaria, Navicula, Nitzchia, Cyclotella, Surirella, Frustulia, Microcystis, Oscillatoria, Chlorella and Euglena) (Table 1 of Supplementary material).

3.4.1 Phytoplankton diversity across the different sampling sites

In terms of diversity, site SS_3 had the highest diversity of phytoplankton (H = 3.0), with the

second even distribution of species. It had more species (28), which on average occurred in higher numbers than the other sites. Site SS_4 was the least diverse (H = 2.35), with the most even distribution of species; it was species-poor (12). All the sampling sites were eutrophic (Euglenophycean index< 1). (Table 5).

4. DISCUSSION

The physicochemical parameters determined revealed values generally higher compared to values recommended by USEPA [26] and WHO [27] for fresh water ecosystems and drinking water. There were no significant differences in the physico-chemical parameters of water across the sampled sites. This could be as a result of the following anthropogenic activities: agriculture (subsistent and industrial), car wash along the water sources, and landfilling activity.

From our findings, the values of the pysico-chemical parameters were highest in the leachate, followed by SS1 (slope of the landfill) than the other sites. The pH values of leachates from a landfill can give an indication of the maturity of the landfill [28]. The weakly alkaline pH values of leachate from the Mussaka landfill, which are mostly between 7.00 – 8.00 are indications that the landfill is moving towards a mature stage [29]. Conductivity, turbidity and salinity were very high in leachate from the active site (LS_2) and site SS_2. Conductivity and total dissolved solids are influenced dissolved organic and inorganic components present in a solution, and are thus a reflection of the degree of salinity and mineral contents of leachate. Thus in the case of Mussaka, high values for conductivity are attributable to high levels of cations and anions in solution. This could be as result of high rate of waste decomposition at the active site of the landfill causing the formation and migration of leachate plume into site SS_1. High values of nitrates, like other anions, are reported in this study. The major cations commonly present in leachate include sodium, potassium, calcium, and magnesium. In this study, these cations all record values higher that those recommended for drinking water. In municipal solid waste leachate, these constituents are derived through mass transfer processes, the concentration of which is specific to the composition of the waste mass and the prevailing phase of stabilization in the landfill, and their increased concentration often considered as an indicator of leachate pollution [30].

Nitrates basically represent the most oxidized form of nitrogen found in the natural system and are often regarded as an unambiguous indicator of domestic and agricultural pollution. Since Mussaka is a landfill receives mainly domestic waste, nitrates in it can be linked to domestic pollution. Leachate in this study (LS_2) shows higher concentrations of most macronutrients and heavy metals, which is similar to results by [31] in a Gaborone landfill, Botswana. Leachate usually is composed of numerous materials and the concentrations of most of these components depend on the age, hydrology and stabilization process in the landfill [32,33]. This could account for the slight variability in concentrations of the macronutrients and heavy metal in the leachate. Migration of leachate of this nature into nearby surface waters might lead to alteration of these ecosystems.

Generally, the physico-chemical parameters of water and phytoplankton community are interrelated. In this study, the concentrations of bicarbonate (HCO_3^-), Nitrogen-Nitrate ($N-NO_3^-$), Iron (Fe), Nitrogen-Ammonium ($N-NH_4^+$) and Potassium (K) exceeded the USEPA [26] and WHO [27] water quality standards. The levels of $N-NO_3^-$ and $N-NH_4^+$ recorded during this study ranged from 68.60 to 233.30 mg/l and 0.56 to 5.04 mg/l respectively, far beyond the WHO [27] thresholds at all sites. Such increased levels in water influence the growth, abundance and diversity of phytoplankton species. The Euglenophycean index indicated that all the sites were eutrophic. The presence of large numbers of phytoplankton species that are indicators of eutrophication suggest some level of nutrient input at these sites, which render the water eutrophic. This gives support to the result obtained by [13], who recorded high values of these nutrients in soils from the same municipal landfill, surrounded by banana plantation in the eastern flank of Mount Cameroon. The division with the highest species abundance across the sampling sites was the Bacillariophyta, followed by chlorophyta. This trend is consistent with the findings of [34] who reported Bacillariophyta abundance as indication of eutrophication. of the ten genera identified as indicator species of eutrophication in this current study, six belong to the bacillariophyta family. Celekli and Kulkoyluoglu [35] explained that, the dominance of the Bacillariophyta could be a result of their high tolerance to chemicals and nutrients such as nitrates, phosphates, and other metals.

Table 1. Physical parameters and macronutrients load of leachate and water around the Mussaka landfill

Site/Point Source	Physical parameters						Mean macronutrients (mg/l)									
	pH	Conductivity (mS/cm)	Turbidity (NTU)	Temp (^{0}C)	TDS (mg/l)	Salinity (mg/1)	Fe	HCO_3^-	$N-NH_4^+$	$N-NO_3^-$	SO_4^{2-}	CO_3^-	Ca^{2+}	Mg^{2+}	K^+	Na^+
SS_1	7.75ab	6.40ab	67.20a	23.5a	4.40ab	.51ab	41.24a	233.00a	0.56a	5.32a	43.46a	0.00a	20.80a	9.23a	761.60a	30.56a
SS_2	6.70a	0.19ab	0.95a	23.2a	0.13a	.08ab	0.67a	148.00a	1.68a	2.80a	47.60a	0.00a	7.20a	22.35a	8.54a	4.42a
SS_3	7.20ab	0.23ab	0.60a	23.3a	0.16ab	.09ab	0.90a	163.20a	3.78a	3.64a	49.2a	0.13b	9.20a	12.15a	8.54a	2.88a
SS_4	6.85ab	0.21ab	20.00a	23.4a	0.14ab	.25ab	0.69a	118.95a	1.54a	1.40a	49.2a	0.00a	13.60a	20.90a	12.97a	4.42a
SS_5	8.00ab	0.25ab	0.55a	23.4a	0.17ab	.10ab	0.67a	196.70a	5.04a	3.78a	65.60a	0.00a	8.80a	13.61a	4.11a	2.86a
SI	6.90ab	0.18ab	0.95a	23.2a	0.12ab	.07a	0.67a	233.30a	4.20a	1.82a	65.60a	0.00a	8.800a	18.47a	4.14a	2.88a
SP	7.40ab	0.17a	1.10a	23.3a	0.12a	.07a	0.67a	165.62a	1.82a	7.28a	40.18a	0.00a	480.00a	96.70a	4.11a	2.95a
LS_1	7.80ab	5.37ab	55.4a	23.5a	3.65ab	.90ab	89.70a	292.80a	BDL	1.68a	45.92a	0.00a	1504.00a	709.56a	757.21a	30.56a
LS_2	8.00ab	16.52b	63.7a	23.5a	11.23b	.48b	184.34a	1525.00a	2.24a	1.96a	21.32a	0.00a	2336.00a	1125.10a	1173.60	58.25a
EPA/WHO	6.5-8.5	-	5	-		1.5	0.3/5	8.50	0.30	0.045	250		75	700	150	0.1

SS_1=Swamp below the dump, SS_2=Old dumpsite, SS_3= down bridge, SS_4=Downstream, SS_5=Control site, SP= Spring, SI= Stream inlet, LS= Leachate. Kruskal Wallis test was used to test for significance and the means were separated using Turkey method at α = 0.05; Means that do not share a letter within the column are statistically different

Table 2. Heavy metal concentrations and risk assessment of the leachate and water around the mussaka landfill

Site/Point Source	Heavy metals concentrations (mg/l)						Contamination factor and pollution load index of water						
	Zn	Cu	Ni	Pb	Cd	Hg	CF-Zn	CF-Cu	CF-Ni	CF-Pb	CF-Cd	CF-Hg	PLI
SS_1	0.86a	0.76a	0.43a	0.20a	0.15a	BDL	0.83	1.38	0.86	0.71	0.52	NA	0.82
SS_2	0.63a	0.86a	0.47a	0.60a	0.03a	BDL	0.61	1.56	0.94	2.14	0.1	NA	0.72
SS_3	0.58a	0.83a	0.43a	0.21a	0.17a	BDL	0.56	1.51	0.86	0.75	0.59	NA	0.80
SS_4	0.84a	0.97a	0.49a	0.13a	0.13a	BDL	0.82	1.76	0.98	0.46	0.45	NA	0.78
SS_5	1.03a	0.55a	0.50a	0.28a	0.29a	0.09a	NA	NA	NA	NA	NA	NA	NA
SI	0.78a	0.83a	0.47a	0.15a	0.13a	BDL	0.76	1.51	0.94	0.54	0.45	NA	0.77
SP	0.77a	1.02a	0.52a	0.31a	0.38a	BDL	0.75	1.85	1.04	1.02	1.31	NA	1.14
LS_1	0.93a	0.92a	0.50a	0.21a	0.18a	0.04a	NA	NA	NA	NA	NA	NA	NA
LS_2	1.21a	1.17a	0.56a	0.27a	0.47a	0.20a	NA	NA	NA	NA	NA	NA	NA
EPA/WHO	20/400	2.00	0.02	0.05	0.005	0.001	NA	NA	NA	NA	NA	NA	NA

*=irrigation limits, SS_1=Swamp below the dump, SS_2=Old dumpsite, SS_3=down bridge, SS_4=Downstream, SS_5=Control site, SP=Spring, SI= Stream inlet, LS= Leachate BDL=Below detectable limit. Kruskal Wallis test was used to test for significance and the means were separated using Turkey method at α = 0.05; Means that do not share a letter within the column are statistically different. CF < 1 =low contamination, 1 < CF < 3 =moderate contaminated, 3 < CF < 6 =considerable contaminated, CF >6 =very high contaminated. PLI < 1 = Not polluted, PLI > 1 = Polluted, NA=Not applicable

Table 3. Bacterial quality and counts in leachate and water around the Mussaka landfill

Isolates	Sampling sites								
	SI	SP	SS$_1$	SS$_2$	SS$_3$	SS$_4$	SS$_5$	LS$_1$	LS$_2$
Total coliform (MPN index/100ml)	2.25×10^2abcd	3.5d	1.1×10^3a	5.7×10^1bcd	1.1×10^3ab	4.6×10^2abcd	1.1×10^1cd	1.1×10^3a	1.1×10^3a
Standard plate count (CFU/ml)	3.0×10^2a	4.4×10^2a	9.4×10^2a	4.9×10^2a	3.9×10^2a	4.4×10^2a	4.45×10^2a	9.3×10^2a	1.0×10^3a
Enteriobacteria (CFU/ml)	2.4×10^2a	2.45×10^2a	1.55×10^3a	5.15×10^2a	2.9×10^2a	1.9×10^2a	3.9×10^2a	1.55×10^3a	1.4×10^3a
E. coli (CFU/ml)	7.5×10^1a	9.75×10^1a	8.05×10^2a	2.1×10^2a	0.5×10^1a	7.8×10^1a	4.5×10^1	8.2×10^2a	8.5×10^2a
Salmonella spp. (CFU/ml)	6.8×10^1a	0.5×10^1a	9.25×10^2a	2.05×10^2a	0.2×10^1a	2.5×10^1a	2.8×10^1a	9.5×10^2a	1.0×10^3a
Shigella spp. (CFU/ml)	1.0×10^1a	0.5×10^1a	4.0×10^2a	2.4×10^1a	0.2×10^1a	1.2×10^1a	3.2×10^1a	4.8×10^2a	4.6×10^2a
Streptococcus spp. (CFU/ml)	4.55×10^2a	4.3×10^2a	2.55×10^2a	3.35×10^2a	2.1×10^2a	3.45×10^2a	4.9×10^2a	3.4×10^2a	3.0×10^2a
Pseudomonas spp. (CFU/ml)	6.3×10^1a	1.0×10^2a	9.25×10^2a	2.3×10^2a	2.8×10^1a	3.8×10^1a	2.45×10^2a	8.0×10^3a	9.0×10^3a

SS$_1$=Swamp below the dump, SS$_2$=Old dumpsite, SS$_3$= down bridge, SS$_4$=Downstream, SS$_5$=Control site, SP=Spring, SI= Stream inlet, LS= Leachate Kruskal Wallis test was used to test for significance and the means were separated using Turkey method at α = 0.05; Means that do not share a letter within the column are statistically different

Table 4. Relationship between bacterial quality and physico-chemical characteristic of water and leachate samples

	Color	Odor	Temp	pH	Conductivity	DO	Plate count	Enterobacteria	Esch. Coli	All Salmonella	Salmonella HS+non	Salmonella non HS	Salmonella HS	Shigella spp.	Streptococcus spp.
Odor	0.853														
	0.000														
Temp	0.261	0.479													
	0.266	0.032													
pH	0.868	0.928	0.472												
	0.000	0.000	0.035												
Conductivity	-0.879	-0.902	-0.440	-0.974											
	0.000	0.000	0.053	0.000											
DO	-0.836	-0.862	-0.359	-0.938	0.920										
	0.000	0.000	0.120	0.000	0.000										
PlateCount	0.811	0.926	0.483	0.975	-0.942	-0.938									
	0.000	0.000	0.031	0.000	0.000	0.000									
Enterobacteria	0.879	0.936	0.492	0.953	-0.939	-0.907	0.963								
	0.000	0.000	0.028	0.000	0.000	0.000	0.000								
Esch. Coli	0.890	0.933	0.458	0.987	-0.987	-0.937	0.976	0.969							
	0.000	0.000	0.043	0.000	0.000	0.000	0.000	0.000							
All Salmonella spp	0.904	0.928	0.424	0.988	-0.982	-0.944	0.971	0.963	0.996						
	0.000	0.000	0.062	0.000	0.000	0.000	0.000	0.000	0.000						
Salmonella HS+non	-0.051	-0.323	-0.384	-0.339	0.228	0.183	-0.306	-0.220	-0.221	-0.220					
	0.831	0.165	0.095	0.143	0.334	0.441	0.190	0.350	0.350	0.351					
Salmonella non HS	-0.503	-0.317	-0.144	-0.345	0.368	0.282	-0.264	-0.374	-0.375	-0.389	-0.277				
	0.024	0.174	0.544	0.136	0.111	0.229	0.260	0.104	0.103	0.090	0.238				
Salmonella HS	0.877	0.936	0.460	0.996	-0.975	-0.932	0.975	0.956	0.988	0.991	-0.347	-0.341			
	0.000	0.000	0.041	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.134	0.142			
Shigella spp.	0.886	0.946	0.476	0.991	-0.969	-0.922	0.975	0.962	0.989	0.991	-0.322	-0.364	0.996		
	0.000	0.000	0.034	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.167	0.114	0.000		
Streptococcus spp	-0.183	-0.257	0.196	-0.321	0.236	0.419	-0.356	-0.277	-0.279	-0.303	0.207	-0.153	-0.318	-0.275	
	0.441	0.275	0.408	0.167	0.317	0.066	0.124	0.238	0.234	0.194	0.380	0.518	0.172	0.240	
Pseudomonas spp	0.848	0.892	0.470	0.973	-0.962	-0.933	0.964	0.960	0.976	0.977	-0.227	-0.396	0.970	0.967	-0.248
	0.000	0.000	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.335	0.084	0.000	0.000	0.292

Top value for each pair of correlation = ρ, the Spearman Rank Correlation Coefficient; bottom value for each pair of correlations = p, the level of significance. Correlations exist where p value is less than 0.05
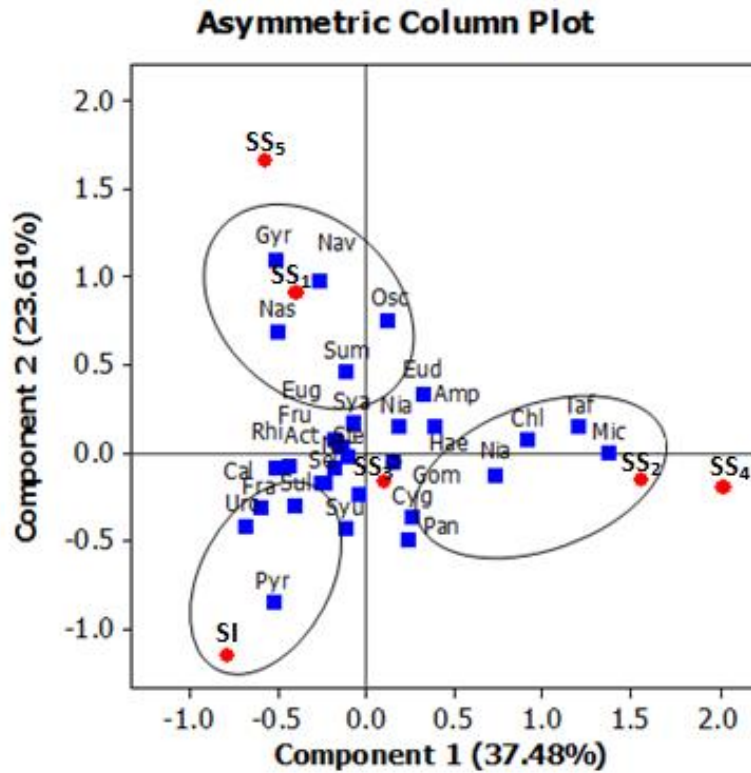
Fig. 2. Ordination of species abundance across the sampling sites
Red dots = sites, Blue squares =Phytoplankton species, Circles shows species incidence with sites.
Fra:Fragillaria sp. Pyr: Pyrosigma sp. Eug: Euglena sp. Sya: Synedra acus, Nil: Nitzchia linearis, Cyg:Cyclotella
glomerata, Syu: Synedra Ulna, Nia: Nitzchia acicularis, Gyr: Gyrosigma sp. Act: Actinoptychus senarius, Gom:
Gomphonema augur, Rhi: Rhizosolenia sp. Uro: Uroselenia sp. Sul:Surirella linearis, Ste: Stenopterobia sp.
Sum:Surirella minuta, Hae: Haematococcus sp. Nia: Nitzchia amphibian, Chl: Chlorella sp. Mic: Microcystis sp.
Cal: Caloneis sp. Fru: Frustulia sp. Amp: Amphipleura sp. Nas: Navicula subtilissima, Eud: Eudorina sp. Pan:
Pandorina sp. Taf: Tabelaria fenestrate, Sel: Selanastrum sp. Osc: Oscillatoria sp. Nav: Navicula sp

Table 5. Phytoplankton diversity Indices of the different sampling sites

Site	S	D	1-D	1/D	H	H max	E	EI
SS$_1$	26	17.09	-16.09	0.06	3.03	3.26	0.93	0.50
SS$_2$	20	12.58	-11.58	0.08	2.74	3.00	0.92	0.00
SS$_3$	28	16.79	-15.79	0.06	3.07	3.33	0.92	0.85
SS$_4$	12	9.52	-8.52	0.12	2.35	2.49	0.95	0.24
SS$_5$	26	13.62	-12.62	0.07	2.90	3.26	0.89	0.90
SI	26	13.58	-12.58	0.07	2.91	3.26	0.89	0.88

SI=Stream inlet, H= Shannon index, E=Evenness, S=Species richness, D= Simpson Index, EI = Euglenophycean
Index. When EI < 1, the site is eutrophic; when >1, the site is oligotrophic

In terms of phytoplankton diversity, site SS$_1$ was the most diverse, with species most evenly distributed and high species richness. This could be attributed to nutrient input from the landfill as leachate migrates into the swamp. This is evident in the high concentrations of nitrates and ammonium in leachate. However, site SS$_3$ was highly diverse, most species rich, and second

highly distributed. Hence, other anthropogenic factors different from the presence of the landfill could be responsible for the observed trends in species richness. Site SS$_3$ is located beside a small cocoa and vegetable farm, with possible inputs of fertilizers and pesticide use. Correspondence analysis reveals that most of the phytoplankton species are cosmopolitan,

though a few indicator species (*Gyrosigma sp.*, *Navicula subtilissima* and *Navicula sp.*) incident at site SS1. This probably could be as a result of additional nutrient inputs from the landfill. This corroborates the findings of [36], who reported high values of NO_3^- from surrounding influx into wetland ecosystems.

The presence of total coliform in all the water samples, including the control in the sampled sites is an indication of the presence of disease causing organisms. Several sources could account for enteric bacteria counts, but all are of faecal origin e.g. human, birds, animals etc. [37]. The counts obtained indicated that the water samples were all heavily contaminated and did not meet the WHO standards that stated that coliforms or faecal coliform must not be detectable in any 100 mL of drinking water. These counts were higher in leachate and water from site SS_1 and SS_3 which are proxy to the landfill, suggesting the presence of faecal waste in the landfill. However, the fact that counts were recorded upstream implied that human activities such as open defecation, bathing and car washing contributed to the presence of coliforms. This is consistent with the findings of Badmus et al. [38], who reported that coliform contamination of wells near landfill is not primarily due to leachate but human defecation and bathing.

Contamination of water has been frequently found associated with transmission of diseases causing bacteria. According to WHO [39], the isolation of pathogenic organisms such as *Salmonella* spp. and *Shigella* spp. is of public health significance, having been associated with gastrointestinal infections like dysentery, diarrhoea and typhoid fever. *Escherichia coli*, *Salmonella spp.*, *Shigella spp., Streptococcus spp.* and *Pseudomonas spp.* were isolated from the collected water samples and leachate in higher counts (CFU/ml). This suggests risk of gastrointestinal infections in the study area as a result of human activities including the landfill operation. This is in line with the findings of Akoachere et al*.* [17], who isolated pathogenic bacteria such as *Escherichia coli* in well water in Douala, Cameroon, where waste are dumped indiscriminately. More of a concern is *Salmonella typhi*, which has the potential to cause epidemics, as farmers and palm wine tapers rely on the stream for drinking and processing of palm wine respectively. It is likely that the usage of these water resources as potable water may result to typhoid fever being endemic in the Buea municipality, a major health challenge.

5. CONCLUSION

The Mussaka landfill is a relatively young landfill and located in an ecologically sensitive area (streams, spring and swamps). The landfill operates with little or no environmental and engineering considerations being put in place. The levels and mean concentration of physicochemical, exchangeable bases, heavy metals are far higher in leachate samples than in water samples from the streams studied. Based on the contamination factors, the streams surrounding these landfills are low to moderately contaminated. The pollution index revealed that the spring is polluted. The findings depicted that the streams studied are eutrophic and loaded with nutrients. The most dominant algal species were Bacillariophyta. The presence of *Escherichia coli*, *Salmonella spp*, *Shigella spp, Streptococcus spp* and *Pseudomonas spp* in the streams studied presents a risk to human health. As the landfill evolves through maturation (through age) it is likely several chemical and biochemical reactions will be taking place which will lead to the release of numerous entities, which in most cases are undesirable for introduction into water bodies. Considering the age of the landfill, the spring water used for drinking, spring and stream water used for irrigation of vegetables and that the landfill continues to receive unsorted waste, it is crucial that corrective measures be put in place to avoid future risk that may arise from after-closure of the landfill.

DISCLAIMER

The landfill site studied was openly accessible to the public and we were freely granted access. There is absolutely no conflict of interest between the authors and the company running the landfill because we do not intend to use this information as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

ACKNOWLEDGEMENTS

and Environmental Chemistry) for assisting in chemical analysis.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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