OPEN ACCESS

African Journal of Environmental Science and Technology

April 2018
ISSN 1996-0786
DOI: 10.5897/AJEST
www.academicjournals.org

AcademicJournals
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African Journal of Environmental Science and Technology

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academicJournals

Vol. 12(4), pp. 123-131, April 2018
DOI: 10.5897/AJEST2017.2433
Article Number: F36923956352
ISSN 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Distribution and level of arsenic in selected environmental indicators

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Received 7 October, 2017; Accepted 29 November, 2017

In this study, total arsenic was determined in soil, common grass (*Cenchrus ciliaris*), plant leaf (Dogwood; *Cornus florida*) and an invertebrate (Stag beetle; *Rhinotia hemistictus*). This was with a view of investigating its distribution and level in the environment. Samples were randomly collected from stratified sections of the study area, processed and analysed using validated acid extraction technique. Detection of arsenic was by use of ICP-OES. Percentage recovery range of 78-92% was obtained and can be adjudged acceptable for application. Overall mean concentration of arsenic ranged from 0.35 ± 0.12 to 2.52 ± 1.85 mg kg^{-1}; 0.01 ± 0.03 to 0.34 mg kg^{-1}; 0.02 ± 0.03 to 0.46 mg kg^{-1} and 0.04 ± 0.02 to 0.72 ± 0.54 mg kg^{-1} across sampling sections 1 to 4 for soil, grass, leaf and insect samples respectively. Arsenic was detected in all samples, however levels obtained were below prescribed toxicity limits. Samples were highly contaminated based on contamination factors of > 6. The strong correlation coefficients (> 0.9) showed association between arsenic and analysed samples while analysis of variance revealed no statistical significant difference between arsenic and samples. The study revealed widespread distribution of arsenic in analysed samples which portend serious health implications across the food chain.

Key words: Pollution, trace metal, grass, arsenic, environment, health, invertebrate, Namibia.

INTRODUCTION

Arsenic (As) is a toxic trace metal that is non-essential and do not play any physiological role in human system even in low doses (Tchounwou et al., 2012; Chung et al., 2014). It has also been reported to be of no benefit to plants and animals (Roggeman et al., 2013). Arsenic has been implicated in the inhibition of proper functioning of important enzymes in human body (Le et al., 2013; Le et al., 2015). Arsenic also exists naturally in the earth's crust (Jang et al., 2016) just as other metals such as Cd, Pb and Mn. The level has however increased tremendously in the past decade because of anthropogenic activities (Chung et al., 2014; Chen et al., 2016). Industrial processes such as the production of herbicides, pesticides, electronic components, pharmaceuticals,

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metal alloys and others have been found to contribute to elevated level of arsenic in the environment (Jang et al., 2016; Vimercati et al., 2017). Prevalence and elevated level of arsenic in groundwater have also been reported in groundwater in India where significant correlation between arsenic contamination in groundwater with depth and distance from river Ganga was found (Kumar et al., 2016). Similar detection of high level of arsenic in groundwater and the health effects in Bangladesh was also reported (Islam et al., 2017).

The ecosystem that is most susceptible as the recipient of the toxic pollutants is the soil. The soil has generally been described as the reservoir for pollutants including toxic trace metals (Han et al., 2017). This unenvious attribute however has serious implications on the aquatic and atmospheric ecosystems. This is due to the fact that soil can act as a conduit for toxic trace metals into other ecosystems. Erosional process of surface soil can significantly increase the metallic load of the aquatic body (Issaka and Ashraf, 2017). In addition, wind dispersal can massively mobilise and introduce metal-bound particulate matters into the atmospheric sphere (Craw and Pacheco, 2002; Martin et al., 2014). These particles can be dispersed far beyond the point of source or generation and deposited on water, on plant leaves, soil and other media.

In soil, arsenic commonly associates with minerals such as arsenopyrite (FeAsS) and inorganic arsenopyrite. In contaminated soil however, it exists mostly as inorganic arsenic (V) and (III) but can also bind to some organic compounds (Lim and Goh, 2005). Chemical conversions between the inorganic and organic forms of arsenic are usually dictated by the oxidation-reduction, biomethylation and precipitation-adsorption and volatilisation processes (Jang et al., 2016). Generally, the availability of arsenic in soil is usually influenced by some factors such as the source that is whether natural or anthropogenic, soil clay content and redox potential (Manning et al., 2002; Cai et al., 2005). However, anthropogenic activities, low clay content and high pH play significant role in the availability of arsenic in soil (Wuana et al., 2011). Arsenate, being the predominant form of As present in most soils, means that plants take up As mostly as arsenate. As such, studies on the kinetics of plant As uptake have focused almost entirely on arsenate (Meharg et al., 2002).

Some of the activities through which arsenic find its way into the ecosystems include the use of arsenical liquid in the removal of parasitic ticks from animals such as cattle through a process commonly referred to as arsenic deep. The metal is also utilised in the preservation of wood, in the medical and electronic fields as well as in several industrial processes (Sharma et al., 2011). Hence, arsenic can find its way into the soil through atmospheric deposition of metal-bound particulate matters (PMs), indiscriminate dumping of electronic components on soil and dump sites. Transfer of trace metals from contaminated soil to plant and uptake by lower animals (van der Fels-Klerx et al., 2016) and ruminants has been reported (Roggeman et al., 2013; Mandal, 2017) with possible bioconcentration and bioaccumulation across the food chain.

Prevalence of toxic level of arsenic in the ecosystems has serious health implications across the food chain. Hence, environmental monitoring of its' trend, distribution and level are usually carried out. Of interest in this study is the prevalence and distribution of arsenic in living organisms that depend on the terrestrial ecosystem in view of close and direct interaction with the ecosystem (soil) and the high toxicity of arsenic.

Hence, the study aimed at investigating the level and distribution of arsenic in selected environmental samples in a local municipal area of Namibia. This was with a view of investigating the prevalence of the metal as a result of anthropogenic activities in environmental samples of soil, grass, plant leaf and insect through their interactions and dependence on soil. Possible implications on the outcome on human and environmental health will also be reflected.

MATERIALS AND METHODS

Description of the study area

The study was conducted within the municipal township of Tsumeb, located in the Oshikoto region in the Northern part of Namibia. It has a population of about 22, 500 (NSA, 2011) and covers an area of about 271 km^2. The study area is notable for its dynamic agricultural practices including food crops farming and animal husbandry as well as industrial activities. The area lies within an altitude of 1, 266 m, latitude 19° 13’ 59.88” S and longitude 17° 43’ 0.12” E. In view of the size of the study area, stratification was adopted, and the area was stratified into four sections for sample collection purposes. Replicate samples were randomly collected within each section here in referred to as sampling section (SS). Hence each section, designated as SS1, SS2, SS3 and SS4 and their coordinates are presented in Table 1.

Samples and sample collection

Selected samples utilised in this study were the soil, common grass (*Cenchrus ciliaris*) that grow widely, plant leaf (Dogwood; *Cornus florida*) and an invertebrate (Stag beetle; *Rhinotia hemistictus)* as shown in Figure 1. All samples were randomly collected from each sampling section. Soil samples were collected to a depth of about 100 mm using clean stainless-steel soil trowel. The trowel was adequately washed and rinsed with distilled water after each sampling to prevent cross contamination of soil samples which may lead to concentration augmentation across sampling areas and influence the final results obtained. Plant samples (grass and leaf) as well as the invertebrate were also collected randomly from each section.

Samples were collected from each of the four stratified sampling sections represented as SS1, SS2, SS3 and SS4 between the periods of July to November 2015. Six (6) set of samples were

Table 1. Sample collection sections of the study area and their coordinates.

Sample Point	Coordinates
SS1	S19˚13’58,8″; E 017˚42’35.7″
SS2	S19˚14’41.7″; E017˚43’12.0″
SS3	S19˚15’21.6″; E017˚42’08.5″
SS4	S19˚15’38.5″; E017˚42’43.2″
CS	S22˚34’00.1″; E017˚04’42.5″

*SS=Sampling Section; CS= Control Site.

collected within this period which falls within late winter and beginning of summer period in Namibia. This was with a view of evaluating possible differences in arsenic level across sampling periods (months) and within sampling sections but not necessarily due to weather variation. Control samples were also collected within the Namibia University of Science and Technology environment. The institution is located 400 km away from the study area and is devoid of anthropogenic activities that may introduce the metal under investigation to soil. Samples were placed in transparent plastic zipper bags, labelled and taken to the laboratory for further treatment and analysis.

Sample treatment

All soil samples were gently dried in oven overnight for about 12 at 30°C and then ground using acid washed mortar and pestle. These were passed through a 0.63 µm pore size sieve to obtain very fine particles following similar soil pre-treatment protocol (Aziza et al., 2015; Chowdhury et al., 2016). Determination of arsenic in samples was based on the final fine powdery samples. The plant samples were rinsed with water and then distilled water to remove any attached soil particles that may cause metallic concentration augmentation. They were cut into smaller pieces with the aid of stainless steel scissors, placed in clean crucible and dried in the oven at 120°C for 24 h. Dried plant samples were also ground in clean acid-washed mortar and pestle and passed through 0.63 µm sieve to obtain fine particles on which all metallic analysis was based. This process was also applied to the invertebrate samples.

Quality assurance and analysis

All reagents used were of analytical grades and metal standard solutions prepared from 1000 ppm stock solution was of high purity (>99.98%) and purchased from Merck Germany. All glass ware used was properly washed, rinsed and soaked in dilute acid for 12 h and then rinsed with distilled water. Working standards were prepared from the stock solution with good linearity of calibration curve. Arsenic in samples was extracted through acid digestion process following a previously described method of Awofolu (2005). Total arsenic concentration in all samples was determined using Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES)- Optima 7000 DV from Perkin Elmer.

Quality assurance of the analytical process was by addition of arsenic standard. To 5 g of pre-digested soil sample in 100-ml beaker, 0.5 ppm of arsenic (As) was added. This was followed by 3 ml of 30 % H_2O_2 and the contents were allowed to stand for 1 h until the vigorous reaction ceased. Thereafter, about 75 ml of 0.5 M solution of HCl was added and the content heated gently at low heat for about 2 h on hot plate. The content was allowed to cool, filtered into 50 ml standard flask and made up with deionised water. Triplicate digestion together with blank was carried out to verify the precision and bias of the process respectively. The process was also applied to invertebrate sample. For grass and leaf samples, 0.5 ppm of standard As was added to 0.5 g of pre-digested sample of each in a 100-ml beaker and digested with 5 ml of conc. HNO_3 and 2 ml of $HClO_4$ on low heat until the volume was about 2 ml. The content was allowed to cool, filtered into 50 ml standard flask using 0.45 µm Millipore Filter paper and then made to volume with deionised water. Triplicate digestion was also carried out as previously described (Awofolu, 2005)

Statistical analysis

Pearson Correlation Coefficient (r) using Microsoft Excel version 2010 was used to evaluate possible relationship between arsenic load and the analysed samples across SS1-SS4, using the overall mean concentration as presented in Table 7. The extent of contamination of these samples by arsenic was also assessed through the contamination factor (CF) as applied in a previous study (Likuku et al., 2013). The CF was calculated as the ratio of the overall mean concentration of arsenic in samples across SS1-SS4 to that obtained from the control site (CS).

That is: CF = X/CS

Where X = overall mean concentration and CS = metal concentration at control site. Classification of the degree of contamination is as shown in Table 8. Two-factor analysis of variance (ANOVA) at $p = 0.05$ using Microsoft Excel version 10 was applied for possible statistical significance between the metal and analysed samples.

RESULTS

Method quality assurance

Results of the quality assurance process of experimental protocol utilised in the analysis of environmental samples are presented in Table 2. Percentage recoveries of arsenic through the standard metal addition protocol for soil, grass, leaf and invertebrate samples ranged from 82 ±0.15; 92 ± 0.12; 84 ± 0.17 and 78 ± 0.25 respectively. This range can be adjudged acceptable for application in the analysis of environmental samples.

Level of arsenic in environmental samples

Results of the analyses of arsenic in a total of 96 samples of soil, grass, plant leaf and invertebrate across sampling sections (SS) and sampling periods (SPs) are presented in Tables 3 to 6. The concentration of arsenic in analysed samples at SS1 and across the sampling period during the first period of sampling that is month of July is as presented in Table 3. Arsenic concentration varied from 0.67 ± 0.05 (SP5) to 5.50 ± 0.27 mg kg^{-1} (SP1); 0.11 ± 0.03 mg kg^{-1} (SP2) to 0.48 ± 0.13 mg kg^{-1} (SP1); 0.20 ± 0.04 mg kg^{-1} (SP5) to 1.36 ± 0.24 mg kg^{-1} (SP1) and 0.28

Figure 1. Pictures of environmental samples: Stag Beetle (L), Common grass (M) and Dogwood Plant Leaf (R).

Table 2. Percentage recoveries (±SD) of arsenic (n = 3) from spiked samples.

Sample	Spiked concentration (µg/ml)	% Recoveries
Soil	0.5	82.0 ± 0.15
Grass	0.5	90.0 ± 0.12
Leaf	0.5	84.0 ± 0.17
Invertebrate	0.5	78.0 ± 0.25

Table 3. Total arsenic concentration (mg/kg, dry wt.), (± SD) in environmental samples collected in July 2015; n = 24.

Parameter	SP	Soil	Grass	Leaf	Insect
SS1	SP1	5.50 (0.27)	0.48 (0.13)	1.36 (0.24)	0.47 (0.02)
	SP2	3.35 (0.18)	0.11 (0.03)	0.37 (0.06)	1.56 (0.12)
	SP3	1.19 (0.07)	0.32 (0.16)	0.25 (0.05)	0.28 (0.05)
	SP4	3.21 (0.14)	0.12 (0.05)	0.27 (0.04)	0.10 (0.03)
	SP5	0.67 (0.05)	0.62 (0.12)	0.20 (0.04)	0.79 (0.01)
	SP6	1.18 (0.04)	0.39 (0.18)	0.22 (0.03)	1.10 (0.03)

SS = Sampling section; SP = sampling period.

± 0.05 (SP3) to 1.56 ± 0.12 mg kg^{-1} (SP2) respectively for soil, grass, leaf and invertebrate samples.

The outcome of arsenic analysis at SS2 during the second period (August) of sampling is as shown in Table 4. Concentration of arsenic varied from 0.33 ± 0.05 (SP5) to 1.06 ± 0.15 mg kg^{-1} (SP1) in soil samples; 0.11 ± 0.05 (SP1) to 0.57 ± 0.08 mg kg^{-1} (SP4) in grass samples; 0.10 ± 0.04 (SP6) to 0.42 ± 0.13 mg kg^{-1} (SP1) in plant leaf sample and 0.12 ± 0.02 (SP2) to 1.47 ± 0.04 mg kg^{-1} (SP5) in invertebrate samples.

The level of arsenic across the sampling periods at SS3 is as shown in Table 5. The concentration ranged from 0.15 ± 0.04 (SP5) to 0.60 ± 0.03 mg kg^{-1} (SP1); 0.04 ± 0.03 (SP2) to 0.21 ± 0.05 mg kg^{-1} (SP4); 0.04 ± 0.02 (SP6) to 0.12 ± 0.04 mg kg^{-1} (SP1) and 0.13 0.06 ± 0.03 (SP5) – 0.91 ± 0.02 mg kg^{-1} (SP2) for soil, grass, leaf and invertebrate samples respectively. The concentration of arsenic in analysed samples at SS4 during the fourth sampling period is as presented in Table 6. The concentrations of arsenic obtained varied from 0.20 ± 0.06 (SP5) to 0.56 mg kg^{-1} (0.05) for soil; 0.02 ± 0.01 (SP2) to 0.10 ± 0.03 mg kg^{-1} (SP5) for grass; 0.02 ± 0.04 (SP5) to 0.21 ± 0.05 mg kg^{-1} (SP1) for leaf samples and 0.18 ± 0.05 mg kg^{-1} (SP1) to 1.14 ± 0.06 mg kg^{-1} (SP6) in the invertebrate.

The overall mean concentration of arsenic across the sampling sections (SS) within the study area as well as the mean concentration of arsenic in samples from the

Table 4. Total arsenic concentration (mg/kg, dry wt.), (± SD) in environmental samples collected in August 2015; n = 24.

Parameter	SP	Soil	Grass	Leaf	Insect
SS2	SP1	1.06 (0.15)	0.11 (0.05)	0.42 (0.13)	0.17 (0.04)
	SP2	0.63 (0.04)	0.04 (0.01)	0.25 (0.05)	0.12 (0.02)
	SP3	0.64 (0.07)	0.13 (0.02)	0.13 (0.07)	0.68 (0.07)
	SP4	0.34 (0.05)	0.57 (0.08)	0.23 (0.03)	0.47 (0.02)
	SP5	0.33 (0.05)	0.13 (0.03)	0.12 (0.02)	1.47 (0.04)
	SP6	0.76 (0.11)	0.09 (0.03)	0.10 (0.04)	0.93 (0.06)

SS = Sampling section; SP = sampling period.

Table 5. Total arsenic concentration (mg/kg, dry wt.), (± SD) in environmental samples collected in September 2015; n = 24.

Parameter	SP	Soil	Grass	Leaf	Insect
SS3	SP1	0.60 (0.03)	0.08 (0.02)	0.12 (0.04)	0.24 (0.03)
	SP2	0.35 (0.05)	0.04 (0.03)	0.07 (0.02)	0.91 (0.02)
	SP3	0.55 (0.03)	0.09 (0.01)	0.08 (0.03)	0.22 (0.05)
	SP4	0.26 (0.13)	0.21 (0.05)	0.06 (0.02)	0.27 (0.04)
	SP5	0.15 (0.04)	0.09 (0.02)	0.05 (0.03)	0.13 (0.06)
	SP6	0.35 (0.06)	0.10 (0.03)	0.04 (0.02)	0.45 (0.03)

SS = Sampling section; SP = sampling period.

Table 6. Total arsenic concentration (mg/kg, dry wt.), (± SD) in environmental samples collected in October 2015; n = 24.

Parameter	SP	Soil	Grass	Leaf	Insect
SS4	SP1	0.26 (0.08)	0.04 (0.02)	0.21 (0.05)	0.18 (0.05)
	SP2	0.56 (0.05)	0.02 (0.01)	0.05 (0.02)	0.53 (0.03)
	SP3	0.36 (0.04)	0.05 (0.03)	0.04 (0.01)	0.38 (0.10)
	SP4	0.32 (0.03)	0.09 (0.02)	0.03 (0.02)	0.24 (0.04)
	SP5	0.20 (0.06)	0.10 (0.03)	0.02 (0.04)	0.80 (0.05)
	SP6	0.37 (0.05)	0.05 (0.01)	0.04 (0.03)	1.14 (0.06)

SS = Sampling section; SP = sampling period.

control site (CS) are presented in Table 7. The overall mean level of arsenic across SS1-SS4 ranged from 0.35 ± 0.12 to 2.52 ± 1.85 mg kg^{-1}; 0.01 ± 0.03 to 0.34 ± 0.20 mg kg^{-1}; 0.07 ± 0.03 to 0.46 ± 0.45 mg kg^{-1} and 0.37 ± 0.29 mg kg^{-1} to 0.72 ± 0.54 mg kg^{-1} for soil, grass, plant leaf and invertebrate samples respectively.

Statistical applications

The extent of contamination of the study area by arsenic was evaluated and presented in Table 8. The CF at SS1-SS4 ranged from 6.5 to 34, 1.6 to 16, 1 to 10 and 0.9 to 13.8 respectively across soil, grass plant leaf and invertebrate samples. In terms of correlation coefficient, r values of 0.96 (soil/grass), 0.97 (soil/leaf) and 0.99 (leaf/grass) were obtained. However, result of the analysis of variance at $p < 0.05$ generated a *p* value of 0.11.

DISCUSSION

Method quality assurance

The outcome of the quality assurance process revealed

Table 7. Overall mean concentration (mg/kg, dry wt.), (± SD) of arsenic across SS and threshold values in environmental samples.

Parameter	Samples				
	SS	**Soil**	**Grass**	**Leaf**	**Insect**
Sampling sections	SS1	2.52 (1.85)	0.34 (0.20)	0.46 (0.45)	0.72 (0.54)
	SS2	0.63 (0.27)	0.18 (0.09)	0.21 (0.12)	0.64 (0.51)
	SS3	0.38 (0.17)	0.10 (0.06)	0.07 (0.03)	0.37 (0.29)
	SS4	0.35 (0.12)	0.06 (0.03)	0.07 (0.07)	0.55 (0.37)
Control site (CS)		0.39 (0.07)	0.01 (0.03)	0.02 (0.03)	0.04 (0.02)
Threshold values		7.4	0.1-0.9	2.1-9.5	100 - 1,000

SS = Sampling section.

Table 8. Metal contamination factor (CF) in samples and contamination criteria.

Samples					Classification degree of contamination	
SS	**Soil**	**Grass**	**Leaf**	**Insect**		
SS1	6.5	34	23	18	CF < 1	Low
SS2	1.6	18	11	16	1 ≤CF < 3	Moderate
SS3	1	10	3.5	9.3	3≤CF < 6	Considerate
SS4	0.9	6	3.5	13.8	CF > 6	High

SS = Sampling section.

applicability of the analytical process based on the relatively high percentage recoveries obtained. Generally, in quality assurance evaluation processes, the amount of recovered analyte(s) either through standard addition or use of Standard Reference Material (SRM) is utilised as an indication of the efficiency and applicable of the analytical method for the intended experimental process. In a related study, metal recovery range of 75 -125 percentage was obtained and considered acceptable (Leshe and Tessema, 2014). This recovery is similar to the range of 78-92 percentage obtained in this study. In addition, recovery range of 80 to 120 was also considered acceptable for metals and metalloids (Simpson and Batley, 2016).

Level of arsenic in environmental samples

Arsenic is a ubiquitous metalloid of significant environment importance in view of its' toxicity and health implications. One of the exposure pathways of arsenic into the food chain has been through ingestion of food that emanates from arsenic contaminated soil or soil irrigated with arsenic-contaminated water (Hong et al., 2014). In this study, arsenic was detected in all the analysed environmental samples across the sampling sections which perhaps support the assertion of ubiquity of the metalloid. Highest concentration of 5.50 mg kg^{-1} of arsenic in soil samples was obtained at SS1 when compared to 0.62 mg kg^{-1}, 1.36 mg kg^{-1}and 1.56 mg kg^{-1} obtained in grass, leaf and insect samples respectively.

This result possibly supports the general assertion of soil as a sink for heavy metals (Han et al., 2017). In terms of the sampling period, highest level of arsenic was also obtained during SP1, SP5 and SP2 in soil and leave, grass and insect respectively. This might be due to higher level of anthropogenic activities in this section of the study area. Many petrochemical operators are located within this section of the study area. There was a decreasing trend in the distribution of arsenic across the sampling periods in soil and leaf samples from SP1-SP3 followed thereafter by irregular pattern. The decreasing trend could be due to lesser contribution of arsenic into the environment by impactors. There was no specific trend in the level of the metal in grass and invertebrate samples.

At SS2 however, the highest level of 1.47 mg kg^{-1} arsenic was obtained in insect during SP5 while the lowest value of 0.04 mg kg^{-1} in grass was obtained during SP2. This lower level in grass might be due to lower amount of arsenic in the sampled grass. The high level of arsenic obtained in insect might have occurred through bio-augmentation and bio-accumulation processes over a long period of time. Invertebrates especially the beetle insect are known to feed on particles of leaves and organic matter that may also contain trace metals (Chiarelli and Roccheri, 2014). Hence, ingestion of these materials over a long period of time might account for the high level obtained in this study. Generally, there was no observable pattern of metallic trend across the sampling periods as well as analysed samples within this sampling section of the study area.

At sampling section 3 (SS3), highest level of 0.91 mg kg^{-1} arsenic was obtained in the invertebrate sample during SP2 while the lowest (0.04 mg kg^{-1}) was obtain in grass and leaf samples during SP2 and SP6 respectively. Concentration of arsenic at this section also did not show any peculiar pattern or trend either across the SP or in the analysed environmental samples. In the leaf samples however, the value decreased across the sampling period (SP1-SP6) except during SP3 where it rose slightly before continuing the decreasing trend. The non-peculiarity of concentration pattern could be due to relative difference in the level of uptake of arsenic by analysed samples.

At sampling section 4 (SS4), highest metallic value of 1.14 mg kg^{-1} of arsenic was obtained in insect during SP6 while the lowest concentration of 0.02 mg $kg^{-1}$was obtained in grass and leaf samples during SP2 and SP5 respectively. Also, at this section, there was no defined distribution pattern of arsenic in the analysed samples except in leaf where decreasing trend was observed from SP1-SP5 with a slight increase during SP6. Similar study with irregular metallic distribution and trends in analysed samples has been reported (Raulinaitis et al., 2012).

In environmental pollution studies, control sites are expected to be devoid of or are very low in anthropogenic influence relative to the area under investigation. The overall mean range of 0.35 to 2.52–mg kg^{-1} of arsenic obtained in soil samples from this study was lower than the prescribed limit of 7.4 mg kg^{-1} of arsenic in uncontaminated soil (Dudas, 1984). In addition, the highest value of 5.50 mg kg^{-1} (SS1, SP1) arsenic obtained in this study was also lower than the prescribed limit. However, continual anthropogenic contributions on soil over a long period of time may exacerbate the pollution situation. Some of these contributions include atmospheric deposition of metal-carrying particulate matters (Qian and Wan, 2013), deposition of metal containing wastes (Wuana et al., 2011) and use of metal containing sludges as soil enrichment during agricultural activities (Karczewska et al., 2013).

With respect to the overall mean of arsenic in grass samples, the range obtained in this study (0.01 to 0.34 mg kg^{-1}) was also found to be lower than the prescribed range of 0.1 to 0.9 mg kg^{-1} (dry wt.) in grass in non-treated area (NAS, 1977). At this range, the plant may not experience serious toxicity issues. Although, these values did not represent the bioavailable fraction of the metal for toxicological inferences on plant, tolerance level of 2 mg kg^{-1} of arsenic has been reported to disrupt enzyme function and impair phosphate flow in the plant system (Kabata-Pendias and Mukherjee, 2007). In plant leaf, the overall mean concentration range of 0.07 to 0.46 mg kg^{-1} arsenic obtained in the study was also lower than the prescribed range of 2.1 to 9.5 mg kg^{-1} of total arsenic level in plant leaf of White spruce, *Picea alba* (Jenkins, 1980). At this lower concentration range, serious impact on proper leaf functioning was not expected. Hood (1985), prescribed a range of 100 to 1,000 mg kg^{-1} as fatal arsenic concentration in pestiferous species including beetles. Overall concentration range of 0.37 to 0.72 mg kg^{-1} arsenic in invertebrate samples obtained in this study was much lower than the prescribed range. Hence, no serious impact of the metal on the insects would be expected.

Contamination factor (CF), metal inter-sample correlation and analysis of variance

Based on the contamination assessment criteria, CF range of 6.5 to 34 obtained at SS1 reflects a section that can be regarded as highly contaminated. At SS2 with CF range of 1.6 to 16, high contamination was also recorded in samples except for soil having moderate contamination. At SS3, the CF values ranged from 1 to 10. At this section, the grass and insect samples were highly contaminated while the leave and soil recorded considerable and moderate contamination respectively. At SS4, low and considerable contamination was observed in soil and leave samples respectively while the grass and insect samples were highly contaminated. The contamination trend in the analysed samples followed the pattern grass > leave > insect > soil. From this pattern, higher CF in grass relative to others may be related to wider contact with soil and exposure to possible atmospheric deposition of arsenic laden particulate matter when compared to other samples. The pattern could also have been influenced by the level of arsenic obtained in analysed samples from the CS. Metal accumulation by the grass from soil is highly possible.

Generally, all sampling sections (SS1 to SS4) of the study area can be adjudged to be contaminated by arsenic in view of the high CF values obtained across the samples. Similar high CF in environmental samples and sites have been reported (Rahman et al., 2012). Although, all the sampling sections might be regarded as contaminated by arsenic based on the CF values, there are differences in contamination level across the sections. SS1 reflected the most contaminated site which could be as a result of higher level of anthropogenic activities such as petrochemical occupations as earlier mentioned. Differences in contamination level across sampling sections might also be due to chemical phenomenon such as volatilisation. The chemical

Table 9. Correlation of arsenic between environmental samples.

	Soil	Grass	Leaf	Insect
Soil	1	0.956*	0.970*	0.722
		0.044	0.030	0.278
	4	4	4	4
Grass	0.956*	1	0.991**	0.759
	0.044		0.009	0.241
	4	4	4	4
Leave	0.970*	0.991**	1	0.823
	0.030	0.009		0.177
	4	4	4	4
Insect	0.722	0.759	0.823	1
	0.278	0.241	0.177	
N	4	4	4	4

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

properties of soil as well as soil bacterial activities in methylation and volatilisation of arsenic in soil may play a role in the level of arsenic obtained at respective sampling sections (Chirenje et al., 2002).

Detection of arsenic in analysed environmental samples has serious implications on human and environmental health as well as across the food chain. Arsenic has been classified as environmental carcinogen (Duker et al., 2005) and enter the food chain through edible plants that might have accumulated high level of arsenic which eventually poses health problems to human. Ruminants are known to feed on road side grass and plant leaves (Roggeman et al., 2013). Consumption of arsenic laden grasses by livestock such as cows and goats may have health implications indirectly on human through the consumption of milk and meat of these animals (Chung et al., 2014). In the same manner, consumption of insects with high level of arsenic by birds and other terrestrial lower animals such as chickens will seriously affect the trophic balance of the ecosystem. Hence, possible transfer of arsenic across the food chain may occur through the sequence of soil to grass, to ruminant and to human. Long-term exposure to arsenic may result in skin lesions, lung and kidney cancer (Mondal et al., 2006).

High correlation ($r > 0.9$) was obtained between soil and grass and soil and leaf with moderate correlation between soil and insect at $p < 0.05$. Strong positive correlation ($r > 0.99$) was recorded between the leaf and grass at $p < 0.01$ while moderate correlation was obtained between the insect, grass and leaf (Table 9). These significant correlations indicate common association between arsenic and analysed samples. Result of the analysis of variance of possible association between the metal and the analysed samples revealed a *p* value of 0.11, hence there was no statistical significant difference between the focus (arsenic) and the analysed samples.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interest

ACKNOWLEDGEMENT

The author acknowledged the funding provided by the National Commission on Research, Science and Technology (NCRST) Namibia for the research project.

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academicJournals

Vol. 12(4), pp. 132-140, April 2018
DOI: 10.5897/AJEST2017.2463
Article Number: F04E9F356354
ISSN 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Microbiological and physico-chemical analyses of hand dug well-water near pit latrine in a rural Area of Western Nigeria

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Received 12 December, 2017; Accepted 17 January, 2018

Contamination of water from feacal sources can lead to major outbreaks of water-borne diseases when such water is consumed without proper treatment. The microbiological and physicochemical analyses of well-water sample collected near pit latrines in Oko, Oyo State, Nigeria were carried out during rainy and dry seasons. Microbiological analysis was carried out by using Most Probable Number (MPN) technique while physico-chemical parameters of the well-water samples were determined by standard procedures. Thermotolerant coliforms were present in all the well-water analysed during both seasons, while total coliform ranged from 350 to 160,000 and 110 to 160,000 MPN/100 ml in rainy and dry season respectively. Results obtained showed that seasonal changes had a significant impact on water quality and that some of the chemical, physical, biological and trace metal parameters analyzed in the samples from study locations were above the acceptable standards for portable water. Water samples from these wells were unsafe for human consumption without proper treatments.

Key words: Hand dug well, thermotolerant coliform, physico-chemical parameters, Most Probable Number.

INTRODUCTION

The development of water resources has often been used as a yardstick for the socio-economic and health status of many nations. However, pollution of water often negates the benefits obtained from the development of these water resources. Water is extremely abundant on the earth's surface, but access to portable water can be restricted. When safe portable water is not available at the right time or at the right place for human or ecosystem use, the well-being of the local population is at risk (Karikari and Ansa-Asare, 2009).

Water pollution and reduction in quality is a major contributor to global freshwater scarcity, stressing the need for more integrated water management and monitoring (Dahunsi et al., 2014). Li and Jennings (2017a) also conducted a study on worldwide regulation of drinking water quality and pointed out that many

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global nations are in lack of drinking water that meet quality standards, which is also an important factor affecting the global drinking water crisis. The provision of portable water to both rural and urban population is necessary to prevent communicable diseases that might accompany the consumption of faecally contaminated water. Moreover, before water can be described as 'portable', it has to comply with certain physical, chemical and microbiological standards, which are designed to ensure that the water is portable and safe for drinking. Therefore, portable water is defined as water that is free from disease producing microorganisms and chemical substances that are deleterious to health (Okonko et al., 2007).

Pit latrines are used for defecation in the rural areas including some parts of urban areas, and it has been estimated that over 1.77 billion people around the world used pit latrines (Graham and Polizzotto, 2013). Structures like pit latrines remain a potential source of pollution to hand dug wells when sited indiscriminately. Pit latrines and seasonal variations (that is, changes from rainy to dry seasons) are widely recognized as a threat to the safety and reliability of drinking water and sanitation supplies, particularly in low-income countries (WHO/UNICEF, 2006). Accordingly, the status of water quality is examined by two approaches: the water is subjected to tests by bacteriologists to ensure safety for human consumption, while physio-chemical parameters should conform to standard regulations (Adebayo and Bashire, 2002; Ahmed, 2002; Awalla, 2002; Egbulem, 2003; Akpabio and Ebong, 2004).

As a result of the increasing usage of both pit latrine structures and indiscriminate location of hand-dug wells near pit latrines in Oko town, there is concern that the well-being of the hand-dug well users might be compromised leading to a serious public health problem. Despite the fact that groundwater is one of the major sources of water supply for majority of the Nigerians, there is no integrated ground water quality monitoring scheme in Nigeria (Adebola et al., 2013). The present study is therefore carried out to examine the microbiological status and qualitative analysis of some physical, chemical parameters and trace metals of hand dug well water samples in the study area.

Study area

Oko in Oyo State, Nigeria lies between latitudes 7° 57' 7'' North to 7° 57' 18'' North and longitudes 4° 20' 24'' East to 4° 20' 37'' East, and is situated at an average elevation of 392 m above mean sea level (MSL). The justification for selecting the study area was based on the high usage of pit latrine in the community. The main method of excreta disposal is through the use of traditional pit latrine. Some of which are reasonably separated from a domesticated hand dug well, while some are few meters away from the well. The topography of the area is of gentle low land in the south, rising to the plateau of about 40 m. The town has an equatorial climate of dry and raining seasons, and relatively high humidity. The dry season is mostly at its peak in February while the raining season peak is always observed around August / September. Average daily temperature ranges from 25 and 35°C almost throughout the year. Geographical location of study area is shown in Figure 1.

MATERIALS AND METHODS

Sample collection

The sampling locations consist of hand dug wells having a distance of 8 to 30 m to the pit latrines. Ground water samples were collected from eleven (11) wells at various locations within the study area during dry and rainy season respectively. The collected water samples were labeled as K1, K2, K3 to K11. The sampling covered both dry (December to March) and rainy (April to October) season. Samples for physico-chemical parameters analysis were collected in duplicate in plastic container to avoid unpredictable changes in characteristics as per standard procedure (APHA, 1998). Samples for bacterio-logical analyses were collected into sterilized plain glass vials according to world health organisations (WHO) sampling procedure (WHO, 2006). All samples were stored in an icebox at 4°C, and transported to Research Laboratory for analyses within 6 h of sampling.

Microbiological analyses

Most probable number (MPN) techniques for isolation of total coliform and total thermotolerant coliform

Multiple-tube method according to WHO (1997) was used for total coliform count, three rows of five test tubes each containing a sterilized inverted Durham tube and MacConkey broth culture medium was arranged on test tube racks, the tubes in the first row (F1) holds 10 ml of double strength of MacConkey broth culture medium while tubes in second and third rows (F2 and F3) contains 10 ml of single strength of MacConkey broth culture medium. A sterile pipette was used to dispense 10 ml test portion of the water samples to each of the five tubes in row F1 while 1mL of the water samples was also dispensed to each of the five tubes in row F2, and finally 1 mL of 1:10 diluted water sample was dispensed to each of the five tubes in row F3. The tubes were shaken gently to mix the content, all sample test tubes were incubated at 35±1.0°C for 24 h. The same procedure was observed for total thermotolerant coliform but was incubated at 47±1.0°C for 24 h, each tube showing gas formation is regarded as "positive result" since the gas indicates the possible presence of coliforms (WHO, 2006). The most probable number (MPN) of bacteria present was estimated from the number of tubes inoculated and the number of positive tubes obtained using specially devised statistical tables (WHO, 2006).

Physicochemical and heavy metal analyses of the hand dug well water samples

The collected samples were analyzed for different physicochemical

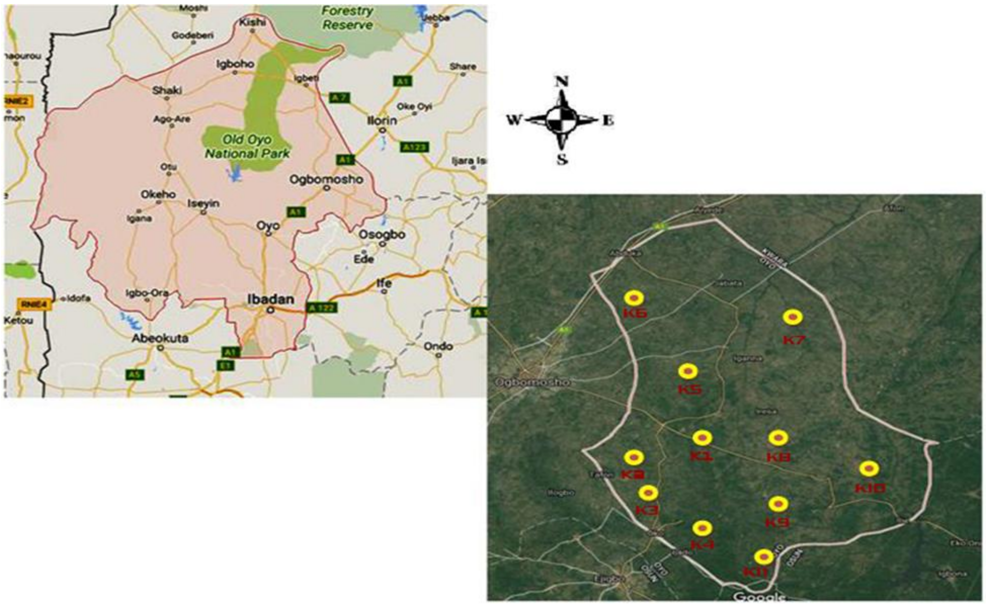

Figure 1. Map showing the geographical location of the study area and collection points.

parameters such as pH, electrical conductivity, total dissolve solids, total hardness, temperature, dissolve oxygen, biochemical oxygen demand, total alkalinity, phosphate, magnesium, chloride, nitrate, lead and iron with standard methods (APHA, 1998). pH was measured immediately the water samples were drawn from the sampled wells. Temperature and pH were measured in situ, using a temperature probe and portable pH meter (Eijkelkampod pH meter, model No. 3.36) respectively. Dissolved oxygen (DO) was determined by DO meter (Eijkelkampod DO meter, model No. 18.36). Other parameters were analyzed in the laboratory according to standard method of American Public Health Association (APHA) (1998).

Statistical analysis

The Statistical Package for Social Scientist (SPSS) 16.0 model was used for the statistical analysis. The t-test analysis of mean was used to establish the significant differences between the dry and the rainy seasons for the microbial and physicochemical quality of the studied well water at $p < 0.05$.

RESULTS

Determination of bacteriological qualities

The mean values of both thermotolerant coliform counts and total coliform counts were shown in Table 1. The most probable number (MPN) for total thermotolerant coliform count of the water samples in rainy season ranged from 13000 to 160000 MPN/100 ml (Table 1), Sampling point K1 and K10 had the highest loads (160000 MPN/100 ml) followed by K4 and K7 (35000 MPN/100 ml) while that of dry season ranges from 33000 to 28 MPN/100 ml. It was observed that a statistically significant difference exists between the two seasons for both thermotolerant and total coliforms counts. High counts of thermotolerant bacteria were observed during the rainy season as compared to dry season with the exception of K6 and K11 that had the counts of 28,000 and 16,000 respectively. The total coliforms count of water samples ranged from 350 MPN/100 ml in K2 to 160000 MPN/100 ml in K5, K8, K9 and K11 as indicated in Table 1.

Determination of physico-chemical and heavy metal analyses of the studied well water samples

The results of physical parameters observed in the studied well during dry and rainy seasons were presented in Tables 2 and 3, while chemical parameters observed in the studied wells during dry and rainy seasons are presented in Table 4. Lead and iron ranged from 0.005 to 0.043; 0.011 to 0.059 mg/L and 0.057 to 0.086; 0.030 to 0.108mg/L in rainy and dry season respectively (Figure 2).

DISCUSSION

The mean values of total coliform counts showed no satstitical significant difference ($p<0.05$) during rainy and dry seasons, while there was a significant difference between the Total Thermotolerant counts for both seasons (Table 1). The WHO and Nigeria Standard of

Table 1. Most probable number for both total thermotolerant and total coliforms.

Sampling point	T-Rain	T-Dry	C-Rain	C-Dry
K1	160000^{f}	34^{a}	54000^{d}	920^{ab}
K2	13000^{a}	350^{c}	350^{a}	160000^{g}
K3	28000^{cd}	1600^{e}	920^{b}	54000^{e}
K4	35000^{e}	350^{c}	92000^{e}	54000^{e}
K5	17000^{ab}	33^{a}	160000^{f}	92000^{f}
K6	13000^{a}	28000^{f}	54000^{d}	17000^{c}
K7	35000^{e}	920^{d}	35000^{c}	350^{a}
K8	22000^{bc}	350^{c}	160000^{f}	54000^{e}
K9	17000^{ab}	350^{c}	160000^{f}	160000^{g}
K10	160000^{f}	170^{b}	92000^{e}	110^{a}
K11	24000^{bc}	16000^{g}	160000^{f}	35000^{d}

*Values were calculated with MPN per 100 ml.
T = Thermotolerant coliform; C= Total coliform.
Values with the same alphabet are not significantly different.

Drinking Water Quality (NSDWQ) standard for coliforms count in portable water is 0 in 100 ml but none of the sample analyzed complied with this standard. This showed that a change in season (from rainy to dry) had a significant impact on the bacteriological qualities of all the examined hand dug well water samples. Although a number of factors might be responsible for the gross contamination of the well: such factors include:

(1) Distance of the well to pit latrine which may result in cross contamination by the well users.
(2) Topography of the land (well located along sloppy water table are more prone to contamination than those cited in a hilly environment), and
(3) Hygienic condition of the hand dug well environment.

The results obtained showed that all the studied well water was heavily contaminated during the rainy season when compared with the dry season. This was also observed by Jeje and Kamar (2013) and Nwachukwu and Otokunefor (2006) in their work.

Salim et al. (2014) also recorded highest total counts during the winter season as compared with other seasons used in their work at both 35 and 22°C. While Onuigbo et al. (2017) also reported increase in bacterial population during rainy season than dry season. However, contrary to what was obtained in this study, Salim et al. (2014) in their own study observed high coliform counts in autumn compared to other seasons used in their work. The high total coliform counts observed might be an indication of poor sanitary handling and/or environmental conditions affecting the wells. Groundwater is usually contaminated due to improper construction, shallowness, animal wastes, proximity to toilet facilities, sewage, natural soil-plant-bacteria contact, refuse dump sites and various human activities around the wells (Bitton, 1994; EPA, 2003; Shittu et al., 2008).

According to Fakayode (2005), the pH of a water body is very important in the determination of water quality since it affects other chemical reactions such as solubility and metal toxicity. Most of the pH observed during the rainy season fall within the WHO standard but the pH of the water samples during the dry season was below the standard, it is highly acidic; this can result in low quality of water available during this season. Water with low alkalinity has little capacity to buffer acidic inputs and is susceptible to acidification (low pH) (Gopala et al., 2015). However, the results obtained in this study is contrary to what was observed by Shaikh and Mandre (2009) and Shittu et al. (2008) where they reported low pH during the wet season.

Temperatures observed in this study fell within the acceptable standard of 28 to 30°C (Tables 2 and 3) (NSDWQ, 2007; WHO, 2011). Although temperature generally influences the overall quality of water (physico-chemical and biological characteristics) but, there are no general guidelines values for drinking water in many parts of the world (Palamuleni and Akoth, 2015). Total dissolved solids (TDS) is another important parameter for drinking water, water with high solid content will have low palatability and may produce unfavourable reactions from consumers (Basavaraddi et al., 2012).

TDS also include most of the inorganic salts that are dissolved in water, the concentration of TDS in drinking water vary based on local geology and geography (Jimmy et al., 2012). TDS values observed in this study ranged from 42 – 465 mg/l. All water samples studied fell within the acceptable range of 1000mg/l (WHO, 2011). But Rao (2006) and Srinivasamoorthy et al. (2009) reported high values of TDS in their work, which is contrary to what was obtained in this study.

Total suspended solids (TSS) is a parameter used in water quality and is also known as non –filtrable residue (NFR). TSS gives a measure of turbidity of water and it causes the water to be milky or muddy looking. A significant difference ($p<0.05$) exist between the TSS in K3 which is having the highest value of 1252.25 and the TSS values recorded for the other water samples in the dry season (Table 2). While in rainy season, result shows no significant difference in the TSS of the samples with K6 having 12.89, 18.35 for K7 and 22.46 for K8 which were of low values but are different significantly from 381.98 of K1, 98.53 of K2, 120.76 of K3, 81.17 of K4, 38.71 of K5, 674.68 of K9, 214.09 of K10 and 442.49 of K11 (Table 3). Water high in suspended solid may be aesthetically unsatisfactory for bathing (WHO, 2007).

The higher amount of total solids in the present study with comparison to WHO standard might be due to the fact that the concerned wells are not ringed and also drawer could be responsible for aggittation during

Table 2. Physicochemical characteristics of the studied well during dry season.

Sample	pH	TSS	TDS (mgl^{-1})	Temp^{0}C	E.C (µs cm^{-1})	D.O (mgl^{-1})	BOD (mg O_2l^{-1})	Total hard. (mgCaCO_3l^{-1})	Total ALK ($CaCO_3$ mgl^{-1})	PO_4^{3-} (mgl^{-1})	Mg^{+2} (mgl^{-1})	NO_3 (mgl^{-1})	Pb (mgl^{-1})	Fe (mgl^{-1})	Cl (mgl^{-1})
K1	5.42^{b}	7.53^{b}	55^{a}	29.1^{a}	77^{a}	9.90^{a}	3.80^{d}	27.37^{a}	17^{ab}	0.79^{a}	0.100^{e}	19.41^{a}	0.050^{g}	0.087^{c}	298.77^{g}
K2	4.08^{a}	480.05^{h}	415^{fg}	29.0^{a}	640^{e}	9.62^{a}	1.66^{a}	153.68^{f}	18^{bc}	4.38^{e}	0.103^{f}	107.46^{g}	0.046^{e}	0.081^{b}	317.18^{j}
K3	5.55^{bc}	1252.25^{k}	378^{f}	29.1^{a}	659^{ef}	9.85^{a}	1.60^{a}	184.21^{g}	20^{cd}	3.79^{e}	0.085^{c}	92.90^{f}	0.059^{h}	0.094^{e}	143.08^{b}
K4	6.00^{bcd}	642.56^{i}	442^{g}	29.8^{a}	741^{f}	10.41^{a}	1.40^{a}	101.05^{cd}	30^{f}	5.43^{g}	0.117^{i}	133.12^{k}	0.048^{f}	0.100^{f}	299.01^{h}
K5	6.30^{cd}	18.12^{c}	218^{de}	29.3^{a}	396^{cd}	9.93^{a}	3.45^{bc}	181.05^{g}	61^{h}	2.42^{b}	0.128^{j}	83.89^{d}	0.044^{d}	0.104^{g}	310.22^{i}
K6	6.47^{d}	78.15^{e}	132^{c}	29.0^{a}	242^{b}	10.28^{a}	3.77^{d}	98.94^{c}	31^{f}	3.70^{e}	0.100^{e}	90.82^{e}	0.045^{de}	0.093^{e}	270.54^{e}
K7	6.34^{cd}	387.47^{g}	120^{bc}	29.2^{a}	228^{b}	10.03^{a}	2.90^{bc}	111.58^{d}	46^{g}	5.32^{g}	0.092^{d}	130.34^{j}	0.039^{b}	0.091^{d}	252.54^{c}
K8	5.76^{bcd}	909.13^{j}	66^{ab}	29.0^{a}	135^{a}	10.22^{a}	3.41^{bc}	35.79^{a}	26^{e}	4.81^{f}	0.082^{b}	115.34^{h}	0.049^{fg}	0.108^{h}	371.10^{k}
K9	6.15^{bcd}	2.16^{a}	42^{a}	28.5^{a}	70^{a}	10.37^{a}	4.65^{e}	33.68^{a}	15^{a}	3.31^{d}	0.113^{h}	81.12^{c}	0.041^{c}	0.101^{f}	283.32^{f}
K10	6.26^{bcd}	51.99^{d}	261^{e}	28.9^{a}	445^{d}	10.34^{a}	2.72^{b}	137.89^{e}	31^{f}	5.17^{g}	0.105^{g}	126.88^{i}	0.050^{g}	0.100^{f}	136.85^{a}
K11	5.88^{bcd}	95.18^{f}	181^{cd}	28.4^{a}	347^{c}	10.10^{a}	3.58^{cd}	74.73^{b}	22^{d}	3.08^{c}	0.033^{a}	75.57^{b}	0.011^{a}	0.030^{a}	260.24^{d}
WHO	6.5-8.5	500	1000	28-30	400	5.0-7.0	-	300	120	-	-	50	0.01	0.1-1.0	250
NSDWQ	6.5-8.5	-	500	Ambient	1000	-	-	150	-	-	0.20	50	0.01	0.3	250

Values = Mean, values followed by the same alphabets in the columns are not significantly different according to Duncan's multiple range test ($p \leq 0.05$).

Table 3. Physicochemical characteristics of the studied well during rainy season.

Sample	pH	Temp^{O}C	TDS (mgl^{-1})	TSS	EC (µs cm^{-1})	D.O (mgl^{-1})	BOD (mg O_2l^{-1})	Total.ALK ($CaCO_3$mgl^{-1})	Total Hardness (mgCaCO_3l^{-1})	Mg^{2+} (mgl^{-1})	PO_4^{3-} (mgl^{-1})	Cl (mgl^{-1})	NO_3^- (mgl^{-1})	Pb (mgl^{-1})	Fe^{3+} (mgl^{-1})
K1	6.42^{b}	28.5^{a}	381.0^{d}	381.98^{e}	647^{i}	10.7^{j}	2.84^{d}	57^{c}	139.08^{k}	0.089^{f}	2.140^{c}	231.54^{k}	14.33^{a}	0.043^{g}	0.086^{g}
K2	6.27^{a}	29.0^{a}	367.0^{d}	98.53^{bc}	620^{h}	4.8^{b}	0.12^{a}	76^{e}	59.32^{f}	0.101^{g}	3.470^{d}	143.27^{f}	84.19^{h}	0.030^{cd}	0.058^{a}
K3	7.40^{e}	28.5^{a}	216.0^{bc}	120.76^{c}	367^{de}	7.6^{i}	0.45^{b}	78^{f}	46.49^{b}	0.056^{c}	0.038^{b}	122.05^{b}	72.63^{e}	0.038^{f}	0.069^{d}
K4	8.18^{g}	29.0^{a}	215.3^{bc}	81.17^{abc}	359^{d}	7.4^{h}	2.63^{c}	142^{h}	48.10^{c}	0.087^{f}	0.023^{ab}	127.63^{c}	107.35^{k}	0.023^{b}	0.073^{e}
K5	8.10^{g}	28.5^{a}	205.0^{b}	38.71^{ab}	339^{c}	5.9^{e}	5.05^{h}	63^{d}	104.21^{j}	0.098^{g}	0.029^{b}	210.30^{j}	65.88^{d}	0.029^{cd}	0.078^{f}
K6	7.82^{f}	29.0^{a}	138.0^{a}	12.89^{a}	233^{b}	5.5^{d}	3.80^{f}	50^{b}	44.09^{a}	0.065^{d}	0.033^{b}	112.04^{a}	77.37^{f}	0.033^{de}	0.060^{ab}
K7	7.38^{e}	30.0^{a}	254.0^{bc}	18.35^{a}	435^{f}	5.9^{e}	5.25^{i}	84^{g}	52.50^{d}	0.062^{d}	0.027^{b}	130.51^{d}	101.60^{j}	0.027^{c}	0.057^{a}
K8	7.38^{e}	28.5^{a}	212.0^{b}	22.46^{a}	369^{e}	4.7^{a}	5.96^{j}	64^{d}	76.49^{i}	0.047^{b}	0.030^{b}	165.78^{h}	80.61^{g}	0.030^{cd}	0.071^{de}
K9	7.34^{e}	29.0^{a}	117.0^{a}	674.68^{f}	206^{a}	5.0^{c}	2.93^{e}	186^{i}	72.95^{h}	0.088^{f}	0.035^{b}	158.99^{g}	62.46^{c}	0.035^{ef}	0.065^{c}
K10	7.18^{d}	28.5^{a}	277.0^{c}	214.09^{d}	479^{g}	6.6^{g}	10.4^{k}	62^{d}	57.72^{e}	0.081^{e}	0.032^{b}	138.69^{e}	90.95^{i}	0.032^{de}	0.059^{a}
K11	6.82^{c}	28.5^{a}	465.0^{e}	442.49^{e}	767^{j}	6.0^{f}	4.14^{g}	18^{a}	68.94^{g}	0.035^{a}	0.005^{a}	169.45^{i}	50.23^{b}	0.005^{a}	0.063^{bc}
WHO	6.5-8.5	28-30	1000	500	400	5.0-7.0	-	120	300	-	-	250	50	0.01	0.1-1.0
NSDWQ	6.5-8.5	Ambient	500	-	1000	-	-	-	150	0.02	-	250	50	0.01	0.3

Values = Mean, values followed by the same alphabets in the columns are not significantly different according to Duncan's Multiple range Test ($p \leq 0.05$).

Table 4. Mean Concentration of the Chemical parameters observed in the studied wells during both dry and rainy season.

Variable		K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11
Phosphate	D	0.79±0.01	4.38±0.01	3.79±0.02	5.43±0.01	2.42±0.01	3.7±0.01	5.32±0.02	4.81±0.01	3.31±0.01	5.17±0.01	3.08±0.01
	R	2.14±0.01	3.47±0.03	0.038±0.01	0.023±0.01	0.029±0.01	0.033±0.01	0.027±0.02	0.03±0.01	0.035±0.01	0.032±0.03	0.005±0.03
Magnesium	D	0.100±0.01	0.103±0.01	0.085±0.02	0.117±0.01	0.128±0.01	0.100±0.01	0.092±0.01	0.082±0.01	0.113±0.01	0.105±0.01	0.033±0.02
	R	0.089±0.01	0.101±0.01	0.056±0.01	0.087±0.01	0.098±0.01	0.065±0.01	0.062±0.01	0.047±0.02	0.088±0.01	0.081±0.01	0.035±0.01
Chloride	D	298.77±1.11	317.18±1.10	143.08±1.08	299.01±1.12	310.22±1.22	270.54±1.11	252.54±1.11	371.1±1.09	283.32±1.16	136.85±1.23	260.24±1.22
	R	231.54±1.09	143.27±1.09	122.05±1.11	127.63±1.11	210.3±1.14	112.04±1.11	130.51±1.09	165.78±1.08	158.99±1.12	138.69±1.14	169.45±1.32
Nitrate	D	19.41±0.01	107.46±0.03	92.9±0.03	133.12±0.01	83.89±0.03	90.82±0.02	132.34±0.01	115.34±0.01	81.12±0.02	126.88±0.03	75.57±0.03
	R	14.33±0.03	84.19±0.02	72.63±0.03	107.35±0.02	65.88±0.02	77.37±0.02	101.6±0.01	80.61±0.01	62.46 0.03	90.95±0.02	50.23±0.03

Values = Mean, values followed by the same alphabets in the columns are not significantly different according to Duncan's multiple range test ($p \leq 0.05$).

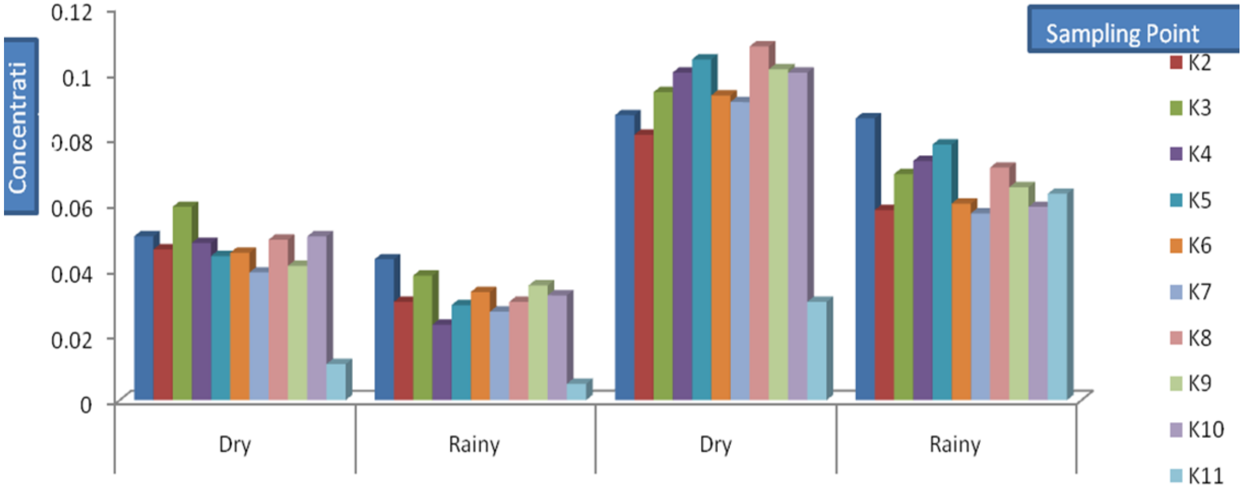

Figure 1. Mean comparative studies of trace metals observed in both dry and rainy season.

abstraction. Mahananda et al. (2010) confirms these similarities in their report by concluding that higher concentration of this parameter is an index that the wells are grossly polluted. In natural waters, there is a close relationship between alkalinity and hardness. Total hardness is the sum of calcium and magnesium hardness, in mg/L as $CaCO_3$. High levels of hard water ions such as Ca^{2+} and Mg^{2+} can cause scaly deposits in plumbing, appliances, and boilers (Shinde and Nagre, 2015). The results obtained showed that 44.09 mg/L which was the lowest value was found in K6 while 139.08 mg/L the highest value, was obtained in K1. The WHO (2011) indicates that hardness above 200 mg/L result in scale deposition, particularly on heating while soft waters with a hardness of less than about 100 mg/L have a low buffering capacity and may be more corrosive to water pipes.

No health-based guideline value has been proposed for hardness but however, the degree of hardness in water may affect its acceptability to the consumer in terms of taste and scale deposition. Contrary to what was obtained in this study, Sanusi and Akinbile, (2013) observed higher values of total hardness during the wet season in their own work. Water samples with high alkalinity values are considered undesirable because of excessive hardness and high concentrations of sodium salts. Electrical conductivity is a measure of water's ability to conduct an electric current, and it is related to the amount of dissolved minerals in the water, but it does not give an indication of the element present. Higher value of conductivity is a good indicator of the presence of contaminants such as sodium, potassium, chloride or sulphate (Orebiyi et al*.,* 2010).

Results of the analysis showed that the range of conductivity values obtained in samples ranged from 206 to 767 µS/cm in rainy season, while the highest value was observed in K3 (659 µS/cm) and the least was found to be 70 µS/cm in K9 during the dry season. The results obtained corresponds to that of Jayalakshmi et al. (2011) and Singh et al*.* (2010) who reported different ranges of electrical conductivity as a good and rapid method to measure the total dissolved ions which is directly related to the total solids in the water sample. While Sanusi and Akinbile (2013) observed no difference in electrical conductivity values obtained during the two seasons used in their study. Heavy deposition of the dissolved oxygen (DO) by the pollutants was noticed and this showed that the wells were unsafe for consumption. 9.1 and 63.6% of the water samples during the rainy and wet seasons respectively fall below the NSDWQ (2007) standard for DO. Efe et al. (2005) also observed high values in DO during the dry season as compared to rainy season.

The value recorded for the two seasons for biological oxygen demand (BOD) analysis was significantly different from each other. The result obtained from the BOD test revealed the measure of the amount of oxygen consumed by microorganisms in breaking down the organic matter. Igbinosa and Okoh (2009) reported high turbidity and BOD in their work, while Jihyun et al. (2013) also reported that water BOD often increases during periods of heavy rain and high river flows - as organic matter are washed in from surrounding lands and drainage channels.

Though, phosphates are not toxic to people or animals unless they are present in very high levels. Digestive problem could occur from extremely high level of phosphate (Kumar and Puri, 2012). Comparative study of the two seasons shows a statistical significant difference between the recorded values of the samples because rainfall can cause varying amounts of phosphates in well water. Chloride concentrations in excess of about 250 mg/L can give rise to detectable taste in water. When it is above 250 mg/L the water is unsuitable for human consumption (WHO, 2011).

Graham and Polizzotto (2013) have reported positive correlation between chlorides and water temperature. In addition, numerous studies have confirmed that ground water inputs also tend to increase the concentration of chlorides (Cengiz Koc, 2010). Previous report in similar research confirmed nitrate as the largest chemical concerns from excreta deposited in on-site sanitation systems (BGS, 2002; Fourie and Vanryneveld, 1995; Pedley et al., 2006).

High concentrations of nitrogen in water sample makes it an excellent indicator of faecal contamination, nitrate has been the most widely investigated chemical contaminant derived from pit latrines. Consumption of high concentrations of nitrate in drinking water is known to cause methemoglobinemia associated with cancer in humans (Fewtrell, 2004; WHO, 2011). Fatombi et al*.* (2012) also associated the presence of nitrates in groundwater to waste water from domestic source and from leaking septic tanks built near wells.

Although, all the studied well water samples conformed with the recommended standard for iron, yet their presence in such small concentration is a clear indication of the presence of toxic wastes in those hand dug wells, the maximum permissible level of iron content in drinking water is 0.3 mg/L, a level above this concentration makes the water unsafe for domestic consumption. High level of iron makes the water turbid, discoloured and imparts unpalatable taste to water (Trivedi et al., 2010). However, Lead must not be more than 0.01 mg/L as the water becomes poisonous if present in higher concentration. Some of the values obtained were higher than the desired concentrations for domestic water consumption, hence making it unfit for use as portable water. High concentration of iron in domestic water samples from well water have also been reported (Dissanayake et al., 2010; Ogedengbe and Akinbile, 2007; WHO, 2006). Values above the standard pose danger to consumers when such water is consumed. Generally, groundwater quality varies from place to place, sometimes dependent on seasonal changes (Vaishali and Punita, 2013), the types of soils, rocks and surface through which it moves (Seth et al., 2014; Thivya et al., 2014).

Currently, worldwide nations including Nigeria are in lack of drinking water quality regulations (Li and Jennings, 2017a) and ingestion of contaminated drinking water is one of the major exposure pathways to hazardous chemicals and diseases (Li and Jennings, 2017b). Thus, it is necessary for nations to provide strict maximum concentrations level of hazardous substances to protect public health. And considering the level of pollution observed in this study, groundwater quality monitoring and testing is of paramount importance both in the developed and developing countries.

Local authorities and public health practitioners should be mandated to carry out house to house inspection for the concerned communities and major treatment of water from these wells should be encouraged before its domestic consumption either by disinfection of wells water or other forms of treatment such as chlorination, sedimentation and filtration.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENT

The authors sincere thanks go to the members of Pure and Applied Biology Department, Ladoke Akintola university of Technology, Nigeria.

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academicJournals

Vol. 12(4), pp. 141-149, April 2018
DOI: 10.5897/AJEST2017.2408
Article Number: C16C48756356
ISSN 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Land-use/cover change analysis using Remote Sensing techniques in the landscape of Majang Zone of Gambella Region, Ethiopia

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Received 17 August, 2017; Accepted 30 October, 2017

Recently, forest land grant for investment which is often misquoted as bare land is posing a challenge to biodiversity conservation efforts in the Majang Zone of Gambella Region, Ethiopia. On the other hand, Majang zone has always been known for dense forest cover and rich biodiversity; but recently threatened due to plantation investment. In order to tackle such prevailing problems, timely information about past and existing land- use/cover scenarios is needed. This study therefore aim to drive reliable information about land-use/cover trends for the last 30 years using Remote Sensing techniques. Landsat Thematic Mapper (TM) for year 1987 and Landsat 8 Operational Land Imager (OLI) for year 2016 were used for image classification. By applying all the approaches and algorithms recommended for image classification, six major land-use/cover classes were identified. The landscape ever covered with dense forest was dramatically updated to new land-use/cover. The 1987 land-use/cover map put forest as the major land cover accounted for 86.73%. However, findings from recent satellite image uncovered new land-use/cover class-plantation accounted for16.16 % that comes out of almost none existent land use pattern in 1987. The result also showed that agricultural land and settlement expanded at alarming rate (3.4 and 0.13 hectare) per year respectively but, the forest cover is the most altered part decreasing by 0.32 hectare per year. Thus, it is important to take urgent action against further conversion of forest to other land cover class, which might have negative impacts in advance on the remaining natural forest.

Key words: Remote Sensing technique, Landsat image, Land-use/cover change.

INTRODUCTION

Concepts related to land use and land cover activities are closely related and in many cases have been used interchangeably. However, land cover is the material or the observed cover at the ground, such as vegetation,

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grass,crops, water, asphalt, etc. (Gómez et al., 2016), whereas, land use-refers to man’s activities on land which is directly related to the land (Kaul and Sopan, 2012; Martínez and Mollicone, 2012; Rujoiu-Mare and Mihai, 2016). Remote sensing imaging cannot detail the land use being used directly like natural or artificial land cover. It is thus, up to interpreters to identify simply using patterns, tones, texture, shapes, site association to acquire information and as well as field and ground information such as surveys and census.

Knowledge about land-use/cover dynamics is becoming important as the nation plans to overcome the problems of uncontrolled development and deteriorating of biodiversity or environmental quality as a whole (Alqurashi and Kumar, 2014; Madugundu et al., 2014; Tilahun and Teferi, 2015). Majang zone was known for its dense forest cover and rich biodiversity conservation but recently threatened by land pressure due to plantation investment. This challenge is currently being fueled and aggravated by forest land granting or grabbing which often misquoted as bare land or lacks signs of agriculture. Initially, forest land awarding for investment is approached to positively impact the communities and to bring ecologically sustainable economic development to the area but they failed to keep the promises (Saturnino and Franco, 2011). Such trends are very common in the study area and currently experienced serious challenges that holding back many biodiversity conservation efforts. Inviting investment particularly to areas where jungle forest exist needs prior information to overcome the problem of uncontrolled development that discount biodiversity quality (Selçuk, 2008; Mishra et al., 2014). In order to tackle such prevailing problems, it needs dynamic information about past and present land-use/cover scenarios.

For better environmental analysis and making sound decisions, reliable information about the land-use/cover is vital (Basanna and Wodeyar, 2013;Tilahun and Teferi, 2015; Rawat and Kumar, 2015; El-Hattab, 2016).The Remote Sensing technique is a very advanced method and has great role for obtaining timely and valid information about land cover status (Fu, 2003; Manandhar et al., 2009; Blaschke, 2010; Subhash, 2012; Fichera et al., 2012; Forkuo and Frimpong, 2012; Baynard, 2013;Esmail et al., 2016; Haque and Basak, 2017; Wang et al., 2017).

This study was, therefore, aimed to derive reliable information about land-use/cover trends for the last 30 years using Remote Sensing techniques.

MATERIALS AND METHODS

Study area description

Majang zone is one of the three administrative zones found in Gambella region with capital town Meti. The region has three zones namely: Anyuak, Majang and Nuer and with one special woreda (Itang). The relative location of the study area is bordered on the east by Southern Nations and Nationalities and Peoples Region (SNNPR), on the west by Anyuak zone and on the north by Oromia region. Absolutely, the Majang zone is located on latitude 7° 4’ 2.41’’N to 7° 46’ 47.79’’N and longitude 34° 36’ 30.54 E’’ to 35° 38’ 48.00’’ E. It has two woreda: Godere and Mengesh, which constitute the study area (Figure 1). This study area was selected for change detection due to recent plantation investment pressure.

Data sources

Both primary and secondary data were used: Ground control points (GCP) for ground truthing was collected as primary data using GPS handheld technology for creating signature or training site. Whereas, secondary data like Landsat Thematic Mapper (TM) for year 1987 and a very recent Landsat data that is Landsat 8 Operational land imager (OLI) images for the year 2016 were accessed directly from recommended and freely available websites from United States Geological Survey (http:// *glovis.*usgs.gov) online imagery portals. All Landsat images utilized for this research were geometrically-corrected level 1T (L1T) data. Other Geo-spatial data like Shapefiles, and topographic maps were collected from Central Statistical Agency (CSA) and Ethiopian Mapping Agency (EMA) for extraction and delineation of area of interest.

Data setting method

Prior to full-fledged image classification process, image preprocessing operation were carried out. These include image geo-referencing (Geometric corrections and Rectification), image enhancement (Spectral and Spatial), and false color composite for simple visualization or discrimination of scene in image.

By using ERDAS IMAGINE 9.2 software, image-to-image registration or image-to-map rectification using ground control points were easily checked for exact alignment of image to area of interest (Alemu et al., 2015).

Image enhancement was done for making an image more interpretable to the human eye. The technique used in image enhancement depends on objectives, data, expectations, and backgrounds. In addition to image enhancement, making False Color Composite (FCC) also better results in various shades and tones of red color observed for healthy chlorophyll-rich vegetation image. The schematic diagram (Figure 2) shed light on the entire procedures and processing of raw satellite image data from image acquisition to change analysis.

Image processing and analysis

Many image processing and analysis techniques have been developed to aid the interpretation of remote sensing images and to extract as much information as possible from the images.

Image preprocessing

Prior to any data analysis, initial processing on the raw satellite image data was usually carried out to correct any distortion. Some standard correction procedures done; like radiometric correction to correct uneven sensor response over the whole image and geometric correction to correct geometric distortion due to Earth's rotation. Hence, distortions related with raw image data can be handled using ERDASIMAGINE 9.2 software and the HANTS

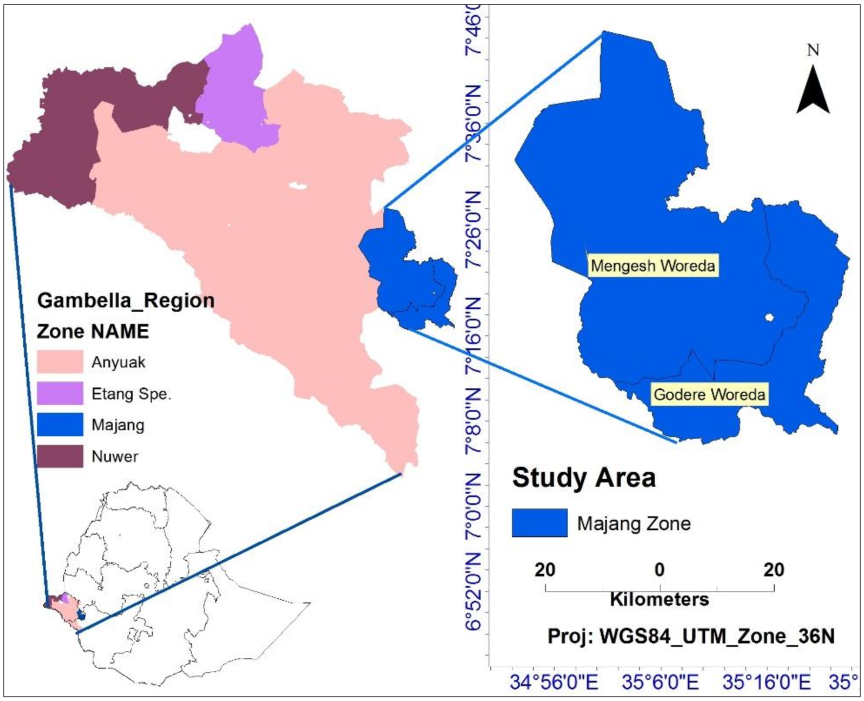

Figure 1. Location Map of study area.

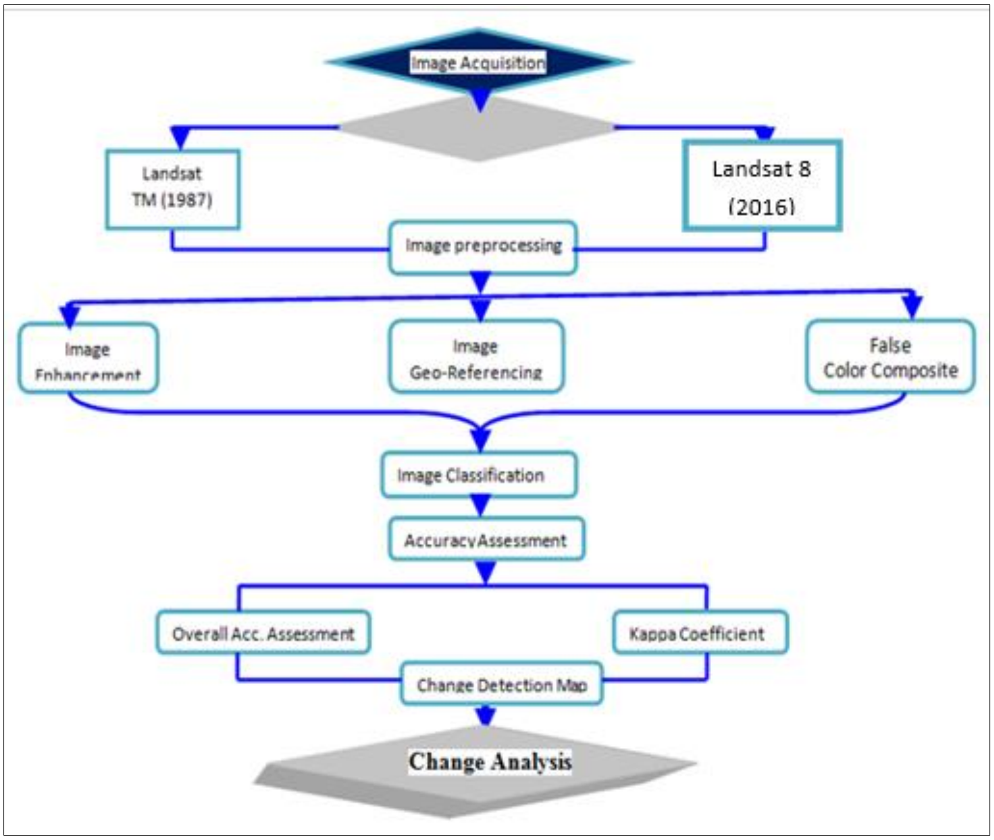

Figure 2. Framework of data analysis.

(Harmonic Analysis of Time Series) algorithm. Harmonic Analysis of Time Series algorithm with special consideration was used particularly for screening cloud contaminated images and there for temporal interpolation to compensate the missing observation for particular time. Most of the Landsat images were geometrically corrected so there was no need for geo-referencing except geometrically correcting to align into particular map projection system.

Image enhancement

In order to aid visual interpretation, hazy visual appearance of the unenhanced objects in the image were improved by image enhancement techniques such as grey level stretching to improve the contrast and spatial filtering for enhancing the edges. For making image enhancement, different methods of image enhancement were used to prepare the "raw data" so that the actual analysis of images became easier, faster and more reliable.

Determining number of classes mapped

The type and number of land-use/cover categorization must be determined based on land capability, vulnerability of present land use to certain management practices and potential for any particular activity. To this end, the preliminary field survey observation was conducted for the area under consideration and inaccessible areas were sensed with the help of topographic maps and Google Earth. Finally, six land cover classes were identified for the Majang Zone. The following were categories of land classes and their descriptions:

1) Forest Land: area with high density of forest with little or no disturbance.
2) Woodland: areas with open canopy that permits under growth of grass or shrubs.
3) Agricultural land: areas covered with predominantly small household mosaic agricultural farms, cultivated land and cultivable land.
4) Water body: area which holds water (lakes), rivers and marshy land most of the time.
5) Settlement land: areas covered with both towns and rural settlement areas.
6) Plantation land: areas covered with coffee and tea plantation (for recent images).

To classify and verify these major land-use/cover types, training sites were prepared. On the number of ground truth data sampling, there is no single ideal method of ground truth data sample taking that the scientists are subjective on the number of points collected. However, Congalton (1991) suggested 50 ground control points for single class as minimum requirements for GPS based reading. But, what is recommended most of the time was taking more GPS readings for a single class of feature for training computer and creating signature. The more points collected, the lower the standard error. For these land classes, a total of 480 ground control points were collected during field survey using GPS. Additional information collected by using google earth and interviewing elderly people who saw the changes happened in the area. From 480 ground control points, 60% of the ground truth was used for training purpose keeping out the other 40% for validation.

Image classification method

Classification is the process of sorting pixels into a finite number of individual classes, or categories of data based on their data file values. In this study, both supervised and unsupervised classification methods were adopted. Unsupervised classification method was used first to have an idea representing overall land use and land cover cluster of pixels. Thereafter, supervised classification method was used with Maximum Likelihood Classification algorithm. This algorithm unlike others considers the spectral variation within each category and the overlap covering the different classes (Rientjes et al., 2011; Rawat et al., 2013).

Knowledge of the data, the classes desired, and the algorithm used was required before selecting training samples. Every pixel in the whole image was then classified as belonging to one of the themes depending on how close its spectral features are to the spectral features of the training areas. Finally, the classified image was verified for its accuracy or acceptance having gone through different mechanisms assuming that resulting class corresponds against ground truth field samples often obtained with a GPS.

RESULTS AND DISCUSSION

Land-use/cover dynamics between 1987 and 2016

Comparison of change dynamics was made by classifying images from 1987 and 2016 years, respectively. By doing so, the classification result revealed the increment or decrease of some classes at the expense of other classes. Figure 3 shows the dynamics of land cover classes after 30 years.

Having these two different time period images, it is therefore possible to produce change detection image just by subtracting the before image (1987) from the after image (2016). Since change detection calculates change in brightness values over last 30 years' time, the image difference file reflects that change using the grayscale image.

The highlighted change image is basically a five-class thematic image, typically divided into the five categories of background, decreased, some decreased, unchanged, some increase, and increased. But depending on user defined value or percent input, class thematic image finally produced can vary in number. Based on user defined value (Figure 4b), the thematic image was classed as: decreases, increased and some increased. Quantification of land-use/cover change through 30 years' time series is very important due to domination or recession of some features class by others. Unless one zooms out and zooms in to particular themes, one might never sense the change due to the compactness of the produced map. Hence, Table 1 clearly indicates each class change in hectare as well as in percent for better understanding of change dynamics.

The major land-use/covers of Majang were forest, wood land, agricultural land, plantation, settlement and water body. The rate of change was also calculated for better understanding of change either increasing or decreasing hectare per year. The change detection was carried out using individual image classification area to identify the changes in the period 1987-2016 by using

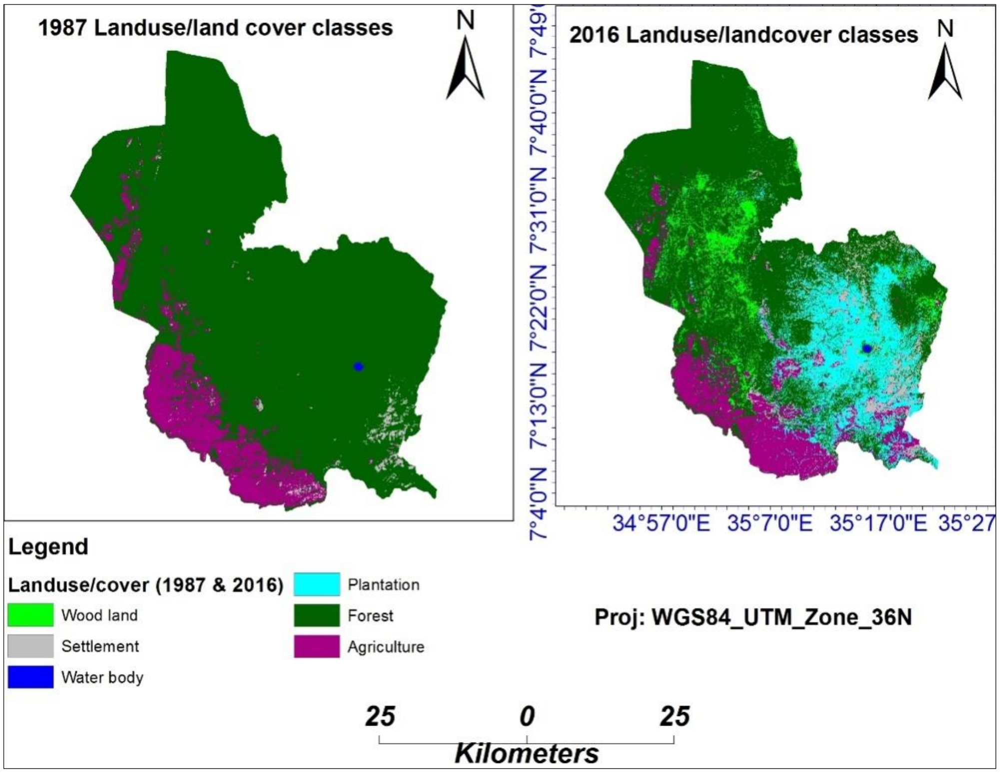

Figure 3. Land-use/cover map (1987-2016).

the formula:

$$\frac{\boldsymbol{area\ of\ final\ year - area\ of\ initial\ year}}{\boldsymbol{area\ of\ initial\ year}} * \mathbf{100}$$

During 1987, Majang Zone was one of the forest dominant sites. The 1987 land-use/cover map produced from Landsat Thematic Mapper reveals forest as the major land cover which covers almost all parts of the Zone. It covers 195,390.63 ha (86.73%) of zone followed by agriculture, settlement and water body which covers 26,946.36 ha (11.96%), 2,797.74 ha (1.24%) and144.45 ha (0.06%), respectively. The spatial distribution of the different land-use/covers and rate of change through passage of 30 years is detailed in Table 1. For year 2016, a recent satellite image data [Landsat 8 Operational Land Imager (OLI)] were used to discriminate the recent scenes of the zone so as to compare and describe change that has gone through 30 years. Accordingly, the most striking changes happened to the area after 30 years. Despite this change, the result still indicates that forest covers large part of the area (Table 1).

Finding from classified recent satellite image uncovered new land-use/cover class (plantation) accounted for 16.16 hectare that came out of none existent land use pattern in the year 1987. The result also showed that agricultural land expansion had been increasing at an alarming rate among others that is 3.4 hectare per year, followed by settlement that accounted for 0.1 hectare per year. Regarding water body, the change was insignificant when compared to others. But, the forest cover was the most altered part of land cover decreasing at 0.32 hectare per year. The above change generally was an indication of the change which happened to the area updating the rural landscape to new scenario. Studies made on some African countries (Tsegaye et al, 2010; Jayne et al., 2014) also justified updating of rural landscape due to investment induced reasons.

Confusion matrix

The classified image was verified for its accuracy or acceptance having gone through different mechanisms assuming that resulting class corresponds against ground truth field samples often obtained with a GPS (Hegazy and Kaloop, 2015; Haque and Basak, 2017). Therefore, it is common practice to create a confusion matrix to assess the accuracy of an image classification (Butt et al., 2015). Table 2 indicates the strength of a confusion matrix, the nature of classification errors and their

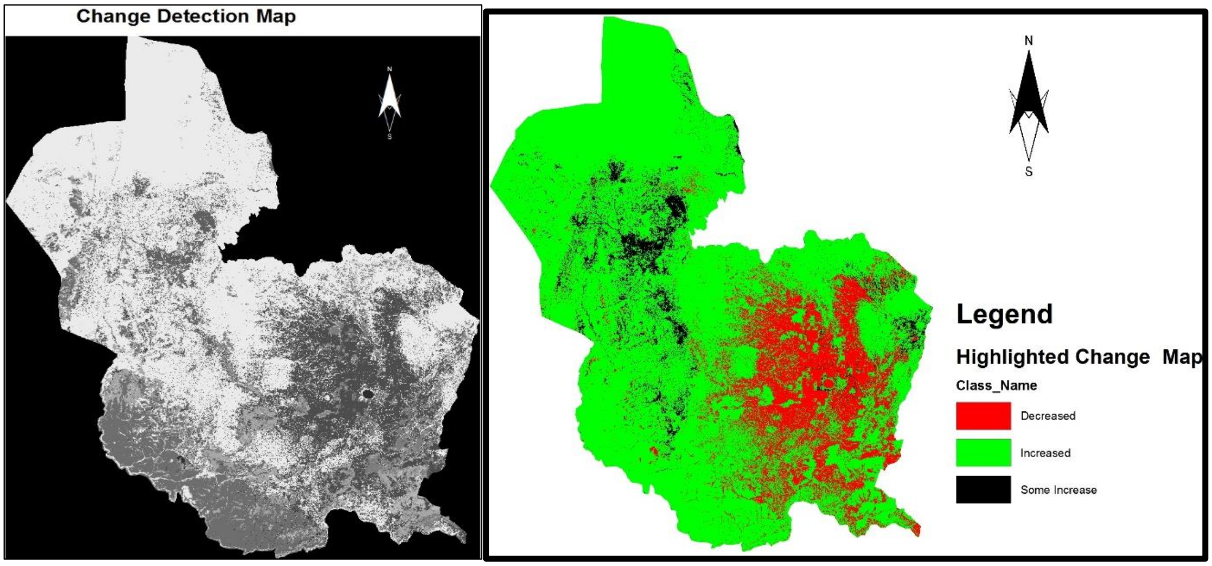

Figure 4. (a) Change detection Map. (b) Highlighted change image.

Table 1. Change dynamics analysis.

1987			2016			Rate of change (30 years)
Land cover	**Area in Hectare**	**Area in %**	**Land cover**	**Area in hectare**	**Area in %**	
Settlement	2797.74	1.24	Water body	147.6	0.07	0.007073775
Forest	195390.63	86.73	Plantation	36414.63	16.16	
Water body	144.45	0.06	Wood land	13269.15	5.89	
Agriculture	26946.36	11.96	Settlement	12333.6	5.47	0.130616157
			Agriculture	30465.99	13.52	3.408415364
			Forest	132648.2	58.88	-0.321112737
Total	225,279.2		Total	225,279.2	100%	

quantities. In general, the overall accuracy assessment was about 88.2% and its kappa coefficient more than 0.80 indicate good classification (Adam et al., 2013) and thus, it was about 0.89 meaning that there is 89% better agreement than by chance alone. Diagonal values represent sites classified correctly according to reference data whereas off-diagonals indicate mis-classified classes.

The transition matrix

This section highlights on classes that indicate areas of overlap and transition of particular class type to other types of classes. The finding also visualized the most abused classes among others that need urgent intervention. When we say forest area shows a significant reduction over time (Table 1), this may appear vague to policy makers to take any intervention actions toward forest conservation. Hence, it is usually important to analyze the transition matrix (Figure 5) that avoids confusion in detailing to what class's type some class was converted. Moreover, the transition matrix aid to know undisturbed and altered areas due to conversion to other classes and generally gives mental picture for decision.

The diagonal values indicate the classes that had never changed or altered throughout 30 years. Whereas the off-side values in hectare indicates transition of year 1987 particular class cover to year 2016 class type. Generally, the overall persist percent of the different land-use/cover is 65.5%. Between two time periods (1987 to 2016), 35,977 area of hectare of forest was converted to plantation (Coffee). Forest cover also damaged because

Table 2. Confusion matrix.

Classification	Reference data								
	Settlement	Forest	Water body	Agriculture	Wood land	Plantati on	Total	User accuracy	Error of commission
Settlement	25	0	1	1	1	1	29	86.2	17.2
Forest	1	36	1	1	2	1	42	85.7	16.7
Water body	0	0	26	0	0	0	26	100.0	15.4
Agriculture	1	1	2	30	2	0	36	83.3	16.7
Wood land	0	2	0	0	29	1	32	90.6	9.4
Plantation	0	2	0	0	2	26	30	86.7	13.3
Total	27	41	30	32	36.0	29	172		
Producer's accuracy	92.6	87.8	86.7	93.8	80.6	89.7		88.2	
Error of Omission	14.3	16.7	15.4	6.3	19	17.24			
		195							

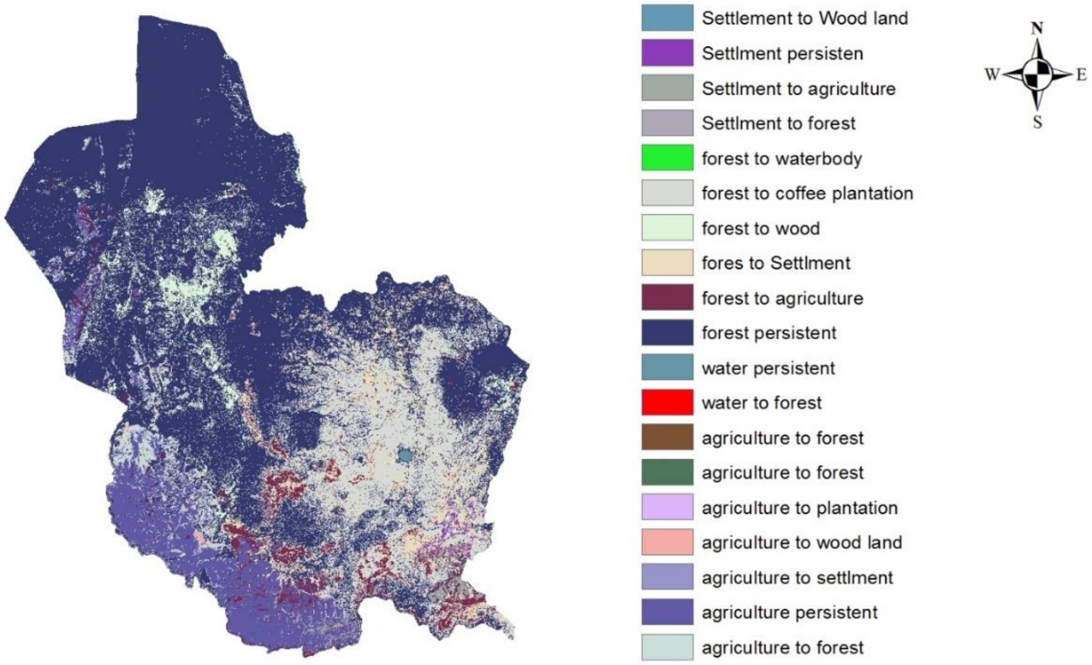

Figure 5. Transition matrix map (1987 to 2016).

Table 3. Matrix of transition and its area in hectare.

1987	**2016**							
	Agriculture	**Forest**	**Settlement**	**Water body**	**Plantation**	**Wood land**		
Agriculture	19997.6	138.13	281.43	0	5858.6	669.44		
Forest	11299.6	12,6577	8,829.7	10.89	35,977	12,908.8		
Settlement	2.16	195.03	752.31	0	0	1637.19		
Water body	0	7.74	0	136.7	0	0		
Plantation	0	0	0	0	0	0.0		
Wood land	0	0	0	0	0	0		
Total area persistent							147,463.9	
Percent (%)								65.5%
Total area of the woreda (Ha)								**225,279.2**

of its conversion to woodland and agriculture to the tune of 12,908.8 and 11,299.6 hectare respectively. The other significant change was also observed in the case of forest to settlement transition (8,829.7 ha). The conversion of agriculture to plantation and woodland also cannot be taken as lightly when compared to others.

As indicated in Table 3, 10.89 hectare of forest cover was converted to water body. This happened due to overshadowing of riparian forest along rivers and was classified as forest since 1987. However, the forest domination ended due to its conversion to wood land and uncovered some portions of river when observed with the recent satellite image. It is because of this reason that the result seems unrealistic.

Conclusion

In the landscape of Majang zone of southwest Ethiopian, land-use/cover changes had occurred in the last three decades. Applying all the approaches for change detection, six major land-use/covers were identified and increment or decrease in some classes due to their conversion through passage of time at the expense of other classes was observed in study area. The overall persistence percent of the different land-use/cover is 65.5%. The most dynamic change and damage was done to the forest as it was scrambled for different land-use/cover classes. The 1987 land-use/cover map put forest as the major land cover which covers almost all parts of Majang Zone (195,390.63 hectare). However, findings from recent classified satellite image uncovered new land-use/cover class (plantation) accounted for 16.16 % that came out of almost none existent land use pattern in 1987. The result also revealed that agricultural land expansion increases at an alarming rate (3.4 hectare) per year, succeeded by settlement (0.13 hectare) per year. But, the forest cover is the most endangered part of land cover decreasing at 0.32 hectare per year. For long period of time, the area was known for its shift cultivation and this was the reason for the alteration of forest, agriculture and settlement classes to woodlands. Plantation takes the highest portion of land in hectare (16.16%) among others due to its recent rapid expansion in the area as seen in the recent satellite images. Generally, the landscape ever covered with dense forest was dramatically updated to new land-use/cover classes. Thus, it is important to prevent or take urgent action against further conversion of forest to other land cover class types, which might have negative impacts in advance on the remaining natural forest.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGMENT

This study was financially supported by Swedish International Development agency (Sida), as parts of project entitled “Improving the life of communities and conserving the environment in Majang Zone, Gambella region” managed by Movement for Ecological Learning and Community Action (MELCA-Ethiopia).

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academicJournals

Vol. 12(4), pp. 150-157, April 2018
DOI: 10.5897/AJEST2017.2439
Article Number: 212938F56358
ISSN 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Comparative risk of pit latrine sludge from unplanned settlements and wastewater in Mzuzu City, Malawi

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Received 18 October, 2017; Accepted 8 February, 2018

Most developing countries use existing knowledge and infrastructure for wastewater in the treatment, reuse and disposal of faecal sludge. There is need to have a clear picture of the risk faecal sludge poses in relation to wastewater if effective treatment, disposal and reuse systems are to be implemented. Little work has been done to quantify the risk faecal sludge poses in relation to wastewater in a localized setting. This study quantifies the comparative risk of faecal sludge from pit latrines in unplanned settlements in Mzuzu City and wastewater. A total 80 sludge samples were obtained from 20 pit latrines in five unplanned settlement Laboratory characterisation was performed for Organics (chemical oxygen demand and biochemical oxygen demand), nutrients (total ammonia nitrogen and total phosphorus) and pathogens (*Escherichia coli* and helminth eggs) were determined through laboratory analyses. Documentation review was used to get wastewater characteristics. The study found a higher risk (comparative risk >1; p < 0.0001) for organics and nutrients in pit latrine sludge as compared to wastewater. Pit latrine sludge was found not to pose significantly higher public health risk from both *E. coli* (comparative risk <1; *p* < 0.0001) and helminth eggs (comparative risk < 1; *p* < 0.165) than relation to wastewater.

Key words: Faecal sludge, environmental risk, public health risk, faecal sludge treatment.

INTRODUCTION

Many developing countries are adopting faecal sludge management as a long-term and sustainable strategy for

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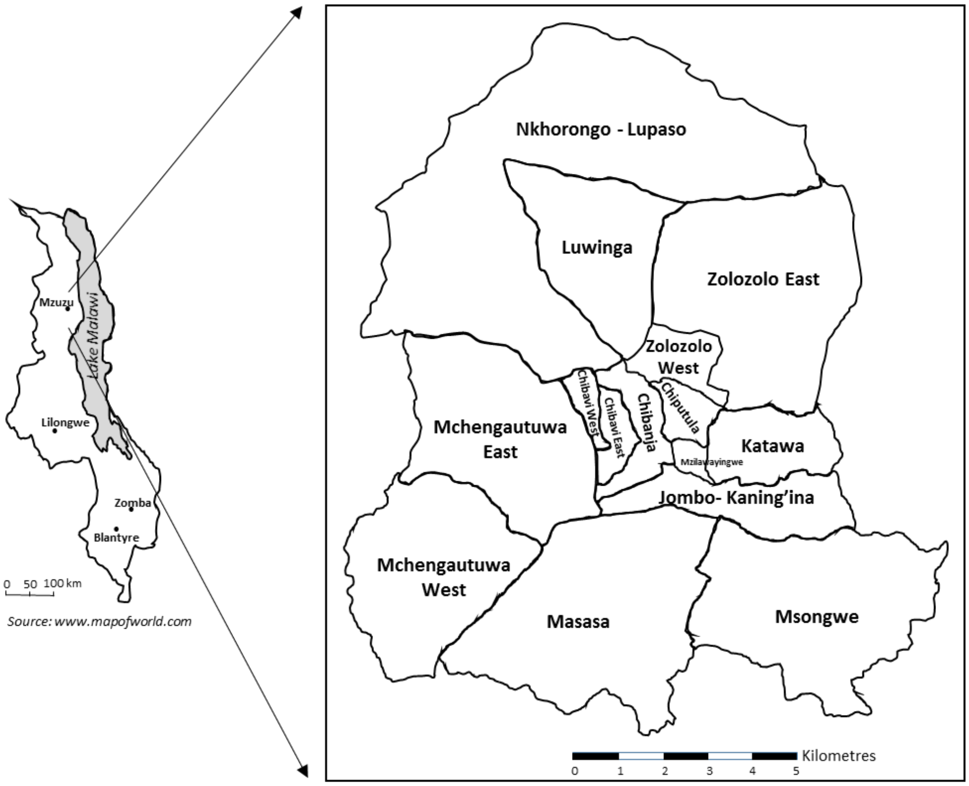

Source: www.mapofworld.com

Source: Mzuzu City Council

Figure 1. Map of the study area.

improving access to sanitation in unplanned settlements in urban areas (Mara and Alabaster, 2004; WHO/UNICEF, 2017). Faecal sludge treatment, reuse and disposal in these countries are mostly carried out using existing knowledge and infrastructure for wastewater management (Blackett et al., 2014). Since faecal sludge and wastewater differ in their characteristics, there is need for a clear picture of the risks faecal sludge poses in relation to wastewater if effective faecal sludge treatment, reuse and disposal systems are to be implemented. Little information is available in the existing body of knowledge for comparison (both directly and implicitly) of risks in faecal sludge and wastewater (Doku, 2002; Koné and Strauss, 2004; Bassan et al., 2013; Strande et al., 2014). While these studies can give a crude indication of the global comparative risk between faecal sludge and wastewater, limited work has been done for localized settings. This study assessed the comparative risk of faecal sludge from pit latrines and wastewater in unplanned settlements in Mzuzu City in Malawi. This was done by characterizing pit latrine sludge and comparing its characteristics with those of wastewater. In this study, comparative risk was defined as the ratio of parameter levels in pit latrine sludge to levels in wastewater. The study focused on both environmental and public health comparative risks. Environmental risk was considered in terms of organics (biochemical oxygen demand and chemical oxygen demand) and nutrients (total ammonia nitrogen and total phosphorus). Public health risk focused on pathogens (*Escherichia coli* and helminth eggs). An understanding of the risk arising from treating, disposing and reuse of faecal sludge, thus important, in ensuring sustainability of the environment and water resources (SDG 6) and public health (SDG 3).

MATERIALS AND METHODS

Study area

The study was carried out in five unplanned settlements in Mzuzu City in Malawi namely Salisbury Lines, Luwinga, Katoto, Chibanja and Chibavi (Figure 1). Based on settlement categorization for Mzuzu, the settlements fell under medium density areas (Luwinga), high density permanent areas (Katoto and Chibanja), high density traditional areas (Chibavi) and informal areas (Salisbury Lines). All the settlements were not getting waste collection services from

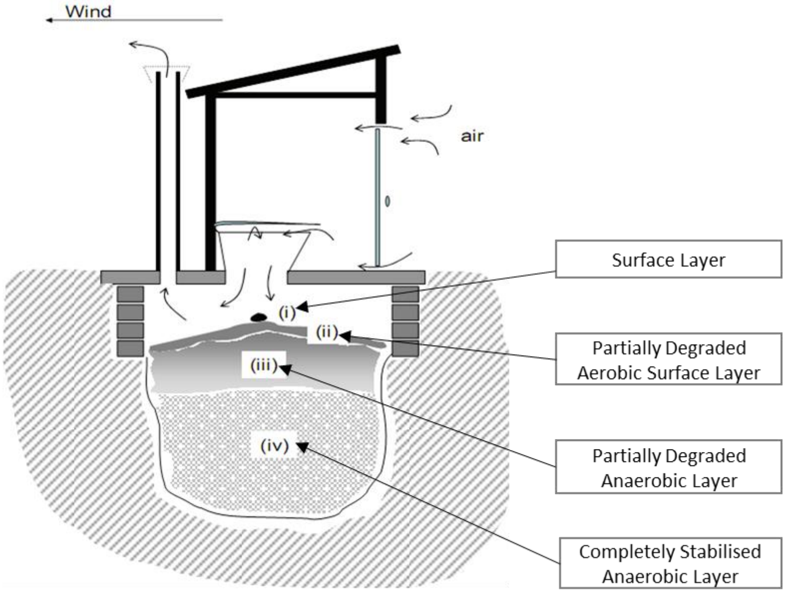

Figure 2. Theoretical categorization of sludge in pit latrine.
Source: Bakare et al. (2012).

Mzuzu City Council (Mzuzu City Council, 2013).

Sampling

Sludge samples were obtained using grab sampling from a total of 20 pit latrines in these informal settlements in October 2014. The sampling was done in conjunction with an established pit latrine emptier and generally followed the procedure utilized by the emptier when engaged to empty filled-up pit latrines. Verbal informed consent to obtain sample from a household latrines was obtained from the head of the household. No identifiable information was collected in relation to the households from whose pit latrine sampling was done. Purposive sampling was employed in the study whereby only latrines with a minimum column depth of 1.5 m of sludge that were viscous enough to be sucked by a vacuum tanker were included. Depth and viscosity of the pit latrine sludge were determined by driving a marked wooden plank into the sludge. In each latrine, sludge samples were collected at four depths (the surface, 0.5, 1 and 1.5 from the sludge surface). This sampling scheme was informed by the theoretical classification of layers occurring in pit latrine as proposed by Bakare et al. (2012) and illustrated in Figure 2. The underlying reasoning in the framework is that sludge characteristics vary by layers as a result of differences in predominant chemical and biological processes in individual layers. Thus, the sampling targeted a wider variation of sludge in the latrines. Sludge samples were preserved and transported to the Malawi Polytechnic Laboratory in plastic sample transport box filled with ice. At the polytechnic laboratory, the samples were kept at 4°C in the refrigerator.

Documentation review of studies at local and global level was done to get parameter values in wastewater. Major studies informing wastewater characteristics for Malawi included Sajidu et al. (2005), Chipofya et al. (2010) and Chipofya et al. (2011).

Laboratory analyses

In the laboratory, the pit latrine sludge was characterized for organics (biochemical oxygen demand and chemical oxygen demand), nutrients (total ammonia nitrogen and total phosphorus) and pathogens (*E. coli* and helminth eggs). Chemical oxygen demand and biochemical oxygen demand were determined through titration (BS 6068, 1988). Total ammonia nitrogen, total phosphorus and *E. coli* were analyzed using standard methods in AOAC (2000). Total ammonia nitrogen was determined by titration, total phosphorus (TP) by colorimetric method and *E. coli* by membrane filtration. Helminth eggs were quantified using the modified USEPA Method (Schwartzbrod, 1998). Each analysis was duplicated for each sample with the average taken as the final result. One sample t-test, at 0.05 significance was performed in Microsoft Excel to compare mean parameter values and calculate the comparative risk of pit latrine sludge and wastewater.

RESULTS

Organics

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) levels in sludge samples from the 20 latrines and wastewater are presented in Figures 3 and 4, respectively. Both BOD ($t = 21.3$, 79 d.f., $p < 0.00001$) and COD ($t = 24.8$, 79 d.f., $p < 0.00001$) were higher in pit latrine sludge than wastewater. BOD levels in latrine sludge ranged from 1437 to 5563 mg/L with an average of 3011 mg/L. The mean BOD comparative risk was 3.7. COD levels in pit latrine sludge ranged from

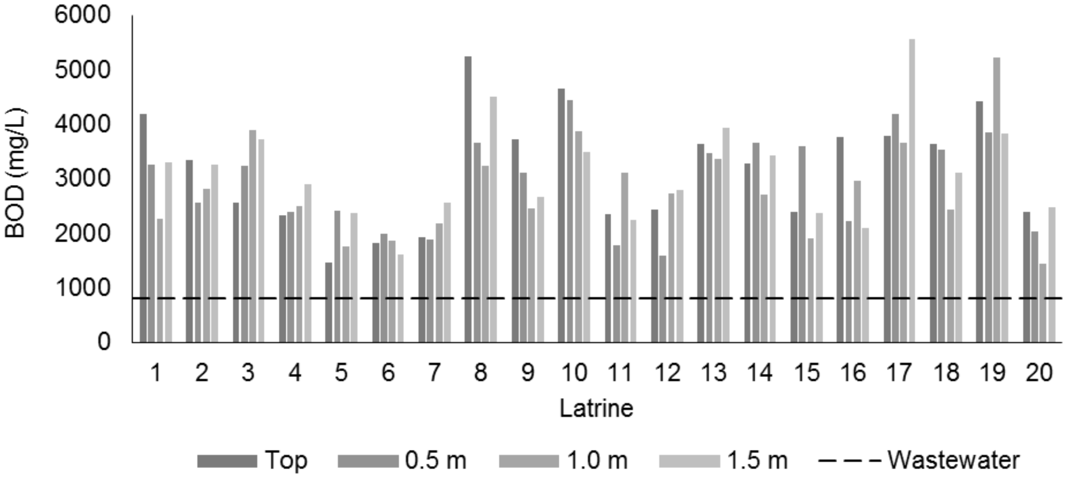

Figure 3. Biochemical oxygen demand in pit latrine sludge and wastewater.

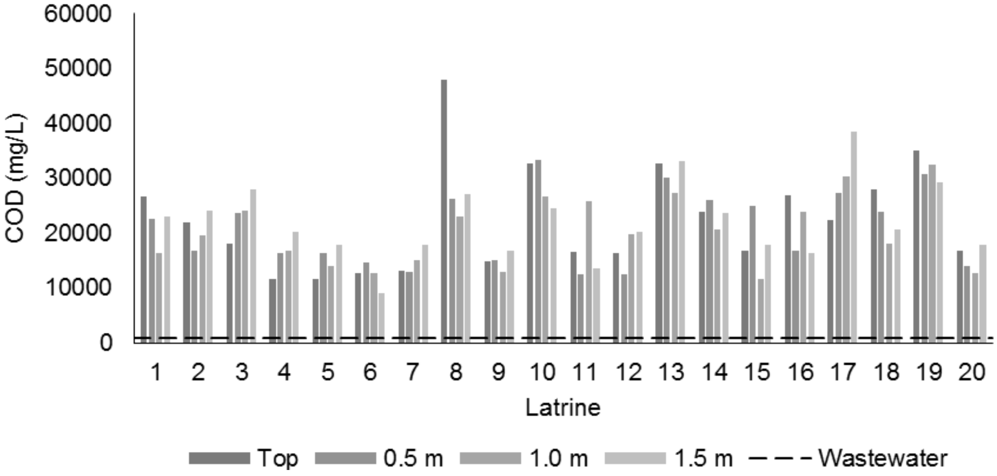

Figure 4. Chemical oxygen demand in pit latrine sludge and wastewater.

9072 to 48021 mg/L with a mean value of 21317 mg/L. The mean comparative risk for COD in pit latrine sludge as compared to wastewater was 26.

Nutrients

Figures 5 and 6 present data on total ammonia nitrogen (TAN) and total phosphorus (TP) content, respectively. Levels of both TAN ($t = 7.88$, 79 d.f., $p < 0.00001$) and TP ($t = 24.5$, 79 d.f., $p < 0.00001$) in pit latrine sludge were higher than levels in wastewater. TAN in pit latrine sludge ranged from 0 to 1284 mg/L with a mean value of 273 mg/L. This gave a mean TAN comparative risk of 22.8. TP ranged from 105 to 590 mg/L with a mean value of 331 mg/L. The mean TP comparative risk for pit latrine sludge in relation to wastewater was 62.5.

Pathogens

E. coli and helminth egg counts results are presented in Figures 7 and 8, respectively. *E. coli* counts in pit latrine sludge were lower than counts found in wastewater ($t = 294.9$, 79 d.f., $p < 0.00001$). The *E. coli* counts in pit latrine sludge ranged from 2700 to 71200 cfu/100 mL

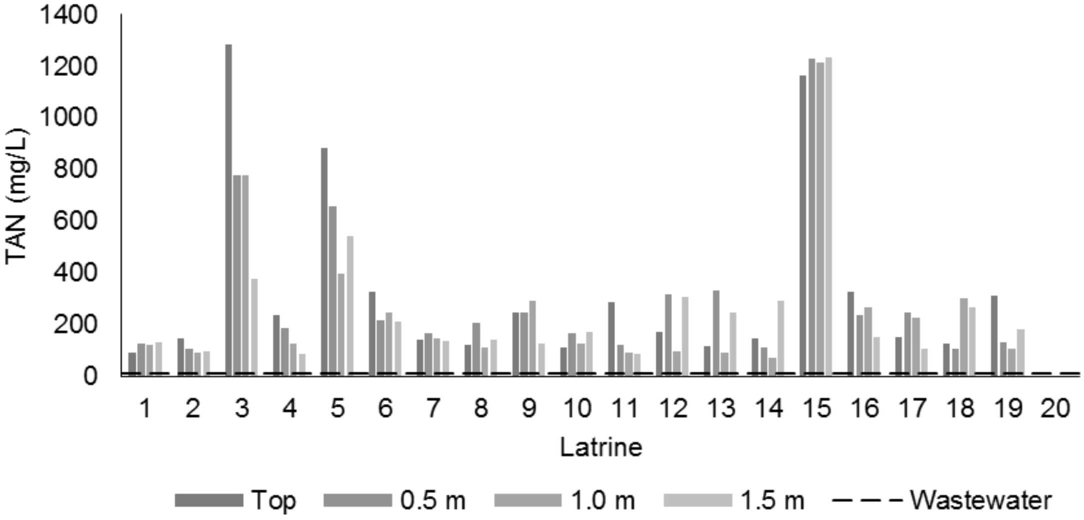

Figure 5. Total ammonia nitrogen content of pit latrine sludge and wastewater.

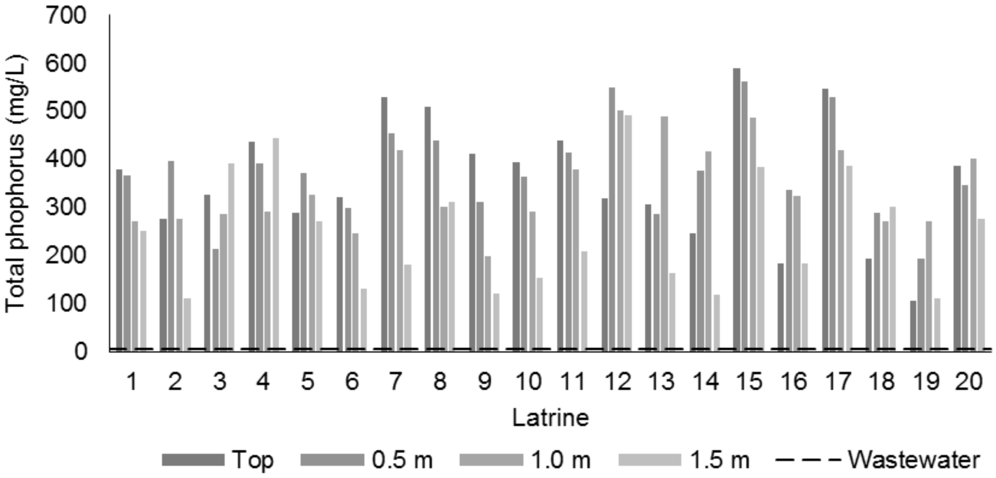

Figure 6. Total phosphorus content of pit latrine sludge and wastewater.

with a mean count of 24798 cfu/100 mL and a mean comparative risk of 0.04. Helminth egg counts in pit latrine sludge did not differ from wastewater ($t_= 1.4$, 79 d.f., p = 0.165). The helminth egg counts ranged from 0 to 2091 eggs/g TS with a mean count of 126 eggs/g TS. The helminth egg comparative risk of pit latrine sludge to wastewater was 1.7.

DISCUSSION

The higher levels of organics and nutrients in pit latrine sludge as compared to wastewater can be explained by the dilution in wastewater whose major constituent is water. In addition, the disposal of solid waste and use of additives in pit latrines, which is unlikely to happen in the wastewater stream, could also be attributed to the difference (Kalulu et al., 2016; Chiposa et al., 2017). The major forms of solid waste thrown into pit latrines included paper, cobwebs and vegetative waste. Common additives used in the latrines include greywater, commercial products (co-trimoxazole granules and sodium hypochlorite) ash, soap, used engine oil and paraffin. These additives are used for odour control,

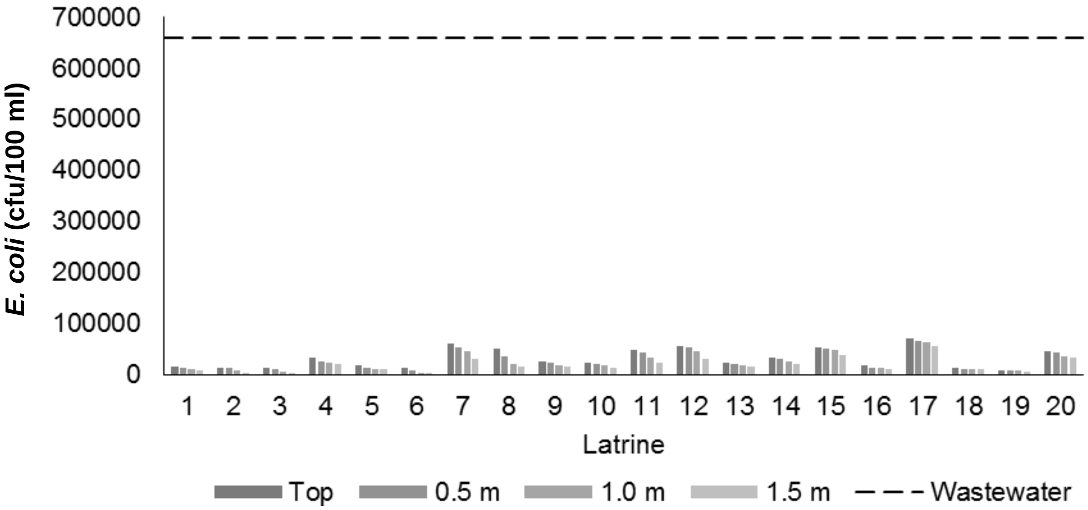

Figure 7. *E. coli* counts in pit latrine sludge and wastewater.

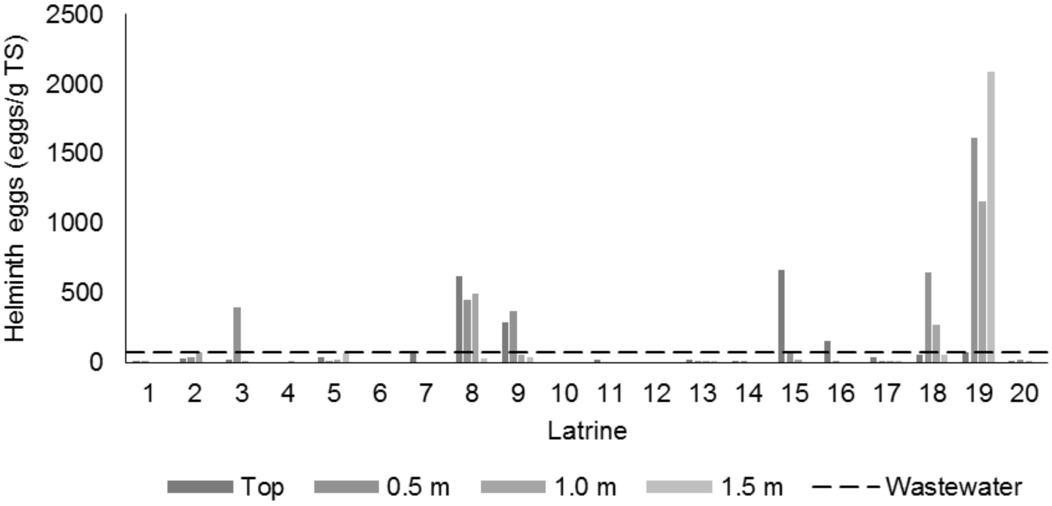

Figure 8. Helminth egg count in pit latrine sludge and wastewater.

latrine fill-up rate reduction and killing flies and germs in latrines.

The comparative risks from this study were generally lower as compared values (37.8 for COD, 31.0 for BOD and 54.2 for TAN) deduced from literature (Doku, 2002; Metcalf et al., 2003; Koné and Strauss, 2004; Bassan et al., 2013; Strande et al., 2014). Since wastewater characteristics display low variability, the higher comparative risk values level in literature could be explained by higher levels of organics and nutrients in pit latrine sludge investigated in these studies in comparison to sludge from Mzuzu. Latrine use habits and diets, and sludge retention period in the latrine could be some of the reasons for this difference (Bassan et al., 2013). Only TP had a higher comparative risk (62.5 than the global value of 21.2) which could be attributed to low utilization of detergents and other cleaning materials in wastewater streams in developing countries like Malawi.

Despite the fact that pit latrine sludge pose more risk than wastewater for organics and nutrients, the study showed that faecal sludge did not pose significantly greater public health risk than wastewater. Lower *E. coli* counts in the sludge could be attributed to die-off as a result of exposure to high levels of ammonia, sludge retention time and predation within the latrines (Montgomery and Elimelech, 2007; Arthurson, 2008; Niwagaba et al., 2009). The insignificant difference between helminth eggs in wastewater and pit latrine sludge could be explained by the eggs in the pit latrine sludge not being exposed long enough to harsh conditions to lead to significant die-off. Helminth eggs are very resistant and are known to take a subjection to unfavourable conditions ranging from several months to years to be inactivated (Jimenez et al., 2006; Strande et al., 2014).

Based on the study design, the comparative risks obtained in the study might not give the best picture on the ground. The study did not characterize wastewater in Mzuzu City as such values used could be different from the actual parameter levels in the city. Considering that faecal sludge is at present co-treated with wastewater, the actual risk faecal sludge poses to the urban environmental might not be high due to dilution of faecal sludge by wastewater. A better picture could be obtained by improving the current design by characterizing influent faecal sludge and wastewater before mixing them in the treatment plant. The products (effluent and sludge) from the co-treatment should also be characterized and used to calculate the comparative risk. Additionally, volumes of faecal sludge and wastewater being co-treated need to be considered to obtain the actual comparative risk.

Conclusions

This study gives a picture of comparative risk between pit latrine sludge and wastewater within a localized setting. The study demonstrated that pit latrine sludge was riskier in terms of organics and nutrients. However, pit latrine sludge did not pose a higher risk than wastewater in terms of pathogens.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors thankfully acknowledge the financial support from Water Research Commission SA through the Sanitation Research Fund for Africa (SRFA) Project. Special thanks to The Polytechnic, University of Malawi for providing laboratory space and equipment as well as administrative support during the research study. They are grateful to the technician team from the Department of Physics and Biochemical Sciences at The Polytechnic. Consortium for Advanced Research Training in Africa (CARTA) is also acknowledged for capacity building of the corresponding author in research and publication.

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