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Table of Contents: Volume 10   Number 9   September 2016

ARTICLES

Full Length Research Paper

The use of magnetic susceptibility measurements to determine pollution of agricultural soils in road proximity

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This research work presents a study on the application of magnetic susceptibility measurements and geochemical analysis for mapping or assessing heavy metal pollution in the agricultural soil in road proximity. The research work was also done to check any runoff of heavy metals pollution to the Owabi dam which serves as the main water sources to catchment areas and the whole of Kumasi Metropolis. This research work was conducted along the asphalt road closed to Amamfrom Community in the southern part of Ghana. The study revealed that magnetic susceptibility measurements can be used as a proxy and fastest method of determining heavy metal pollution in agricultural soils. The results showed three most important trends: 1) the samples collected near the road have higher values of magnetic susceptibility and mean heavy metals content than those collected far from the road exhaust; 2) some of the sample areas undisturbed by erosion and weathering have significant magnetic susceptibility and heavy metals contents; 3) some of the sample areas washed away by erosion are believed to be deposited in Owabi Dam due to their low ground reliefs. Therefore, future research should concentrate on Owabi Dam which may be polluted by the runoff from these heavy metals.

Key words: Magnetic susceptibility, heavy metal, pollution, road proximity.

INTRODUCTION

Soil is a crucial component of environment that supports crops and plants growth and land management is the main key to soil quality. Soil nutrients, are been affected, disturbed or washed away by human activities like mining, industrial and factory wastes, manufacturing wastes and the use of synthetic product which accumulate heavy metals into the agricultural soil over a period of time. Heavy metals also occur naturally in agricultural soil by erosion activities, plate tectonics activities, earthquakes, old landfill sites, old orchards that used insecticides containing arsenic as active ingredient and field that had past application of waste water and municipal sludge. Excess heavy metals accumulation is very toxic to human and other animals due to food chain

transfer and toxic level of these heavy metals in agricultural soil are best investigated using magnetic susceptibility meter and X-ray spectrometer.

Magnetic minerals present in soils may either be inherited from the parent rocks (lithogenic origin) formed during pedogensis (pedogenic origin) or may stem from anthropogenic activities (secondary ferromagnetic materials). Hematite and magnetite are common minerals that occur as primary and secondary minerals in soil and solid wastes and provide a major sink for pollutants such as heavy metals in soils. They have been known as major minerals contributing to the magnetic susceptibility of a soil. In addition to the presence of these minerals, the content of Fe, Mn, Cr, Co and Ni also affect magnetic susceptibility of the soil.

Magnetic susceptibility is a measure of the ability of any substance to be magnetized. In geology, magnetic susceptibility is one characteristic of a mineral type. The term "heavy metal" refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. The use of magnetic measurements as a representation of chemical methods is largely approved because pollutants and magnetic particles are related (Hanesch and Scholger, 2002). The magnetic susceptibility technique has been utilized in a variety of soil science researches such as soil genesis and morphology. Recently, the technique was adopted as a tool for mapping environmental pollutant distribution (Wang and Qin, 2005). Magnetic susceptibility measurement has been considered as a rapid and cheapest screening tool for the determination of spatial distribution of contamination level of heavy metals in soils. The use of magnetic measurement as a proxy for chemical method is possible because pollutant and magnetic minerals are genetically related (Hanesch and Scholger, 2002).

Heller et al. (1991) and Bityukova et al. (1999) reported close relationships of magnetic susceptibility with heavy metal contamination in soil which was proven by combined analyses of chemical and magnetic data. Magnetic susceptibility thus provides an indicator of heavy metal contamination of soils. Hoffmann et al. (1999) successfully measured road traffic pollution by evaluating the spatial distribution of magnetic susceptibility in the nearby soils. Only a fraction of the pollutants was airborne.

Recently, there is a growing interest in using magnetic techniques for monitoring environmental pollution. Many studies have reported excellent relationships between soil magnetic susceptibility and the contents of some heavy metals in street dust or industrial/urban soils. Non-destructive and rapid magnetic techniques seem promising in monitoring soil pollution. Some recent studies have successfully applied soil magnetic susceptibility mapping as a tool for preliminary pollution monitoring and mapping areas polluted by industrial

emissions (El Baghdadi et al., 2012). Heavy metals constitutes a group of inorganic chemical hazards, and those most commonly found at contaminated sites are lead (Pb), chromium (Cr), cadmium (Cd), copper (Cu), arsenic (As), zinc (Zn), mercury (Hg) and nickel (Ni) according to GWRTAC (1997). Soils are absorbers of heavy metals released into the environment by the human activities and unlike organic contaminants which are oxidized to carbon (iv) oxide by microbial action, most metals do not undergo microbial or chemical degradation (Kirpichtchikova et al., 2006), and their total concentration in soils persists for a long time after introduction (Adriano, 2003). Heavy metal contamination of soil may pose risks and hazards to humans and the ecosystem through direct ingestion or contact with contaminated soils, the food chain (soil-plant, human or soil, plant-animals-human), drinking of contaminated water, reduction in food quality (safety and marketability) via photo toxicity and reduction in land usability for agricultural production causing food insecurity (McLaughlin et al., 2000). The adequate protection and restoration of soil ecosystems contaminated by heavy metals require their characterization and remediation.

This paper investigates the relationship between heavy metal contamination and magnetic susceptibility and further confirms the fact that magnetic susceptibility is a representation of heavy metal concentration which can be used for the rapid identification of contaminated areas. This will allow subsequent geochemical sampling and analysis to be focused on smaller areas, thereby decreasing costs and time considerably.

MATERIALS AND METHODS

Description of study area

This project was carried out along the asphalt road closed to Amanfrom Community in the southern part of Ghana where two parcels of land A and B on latitude 6° 45'35.95"N, longitude 1° 40' 51.40" W and latitude 6° 40' 45.57" N, longitude 1° 40' 45.78'' W respectively can be found. Geology of the study area (Figure 1) and the region is dominated by the middle Precambrian rocks and forms part of the Eburnean plutonic suite, where it mainly composes of the biotite, granite and minor granodiorite and K-feldspar porphyritic rocks. Kumasi granitoid complex dominates much of the basin area and contains large proof pedants of metasedimentary schists (Kesse, 1972). The soils have a fairly high moisture holding capacity. The common parent materials found in the Parcel B consists of hematite and magnetite that provides a major sink for pollutants such as heavy metals in soils. They have been known as major minerals contributing to the magnetic susceptibility of a soil. The nature of soil materials in Parcel A is made up of loose oxide materials rich in organic matter. The type of road along these parcels of land ply by commercial and private cars is asphalt. It takes every 1-2 min for a car to ply on the road.

Soil sampling and characterization

The study was conducted with two topsoil parcels, A and B; with
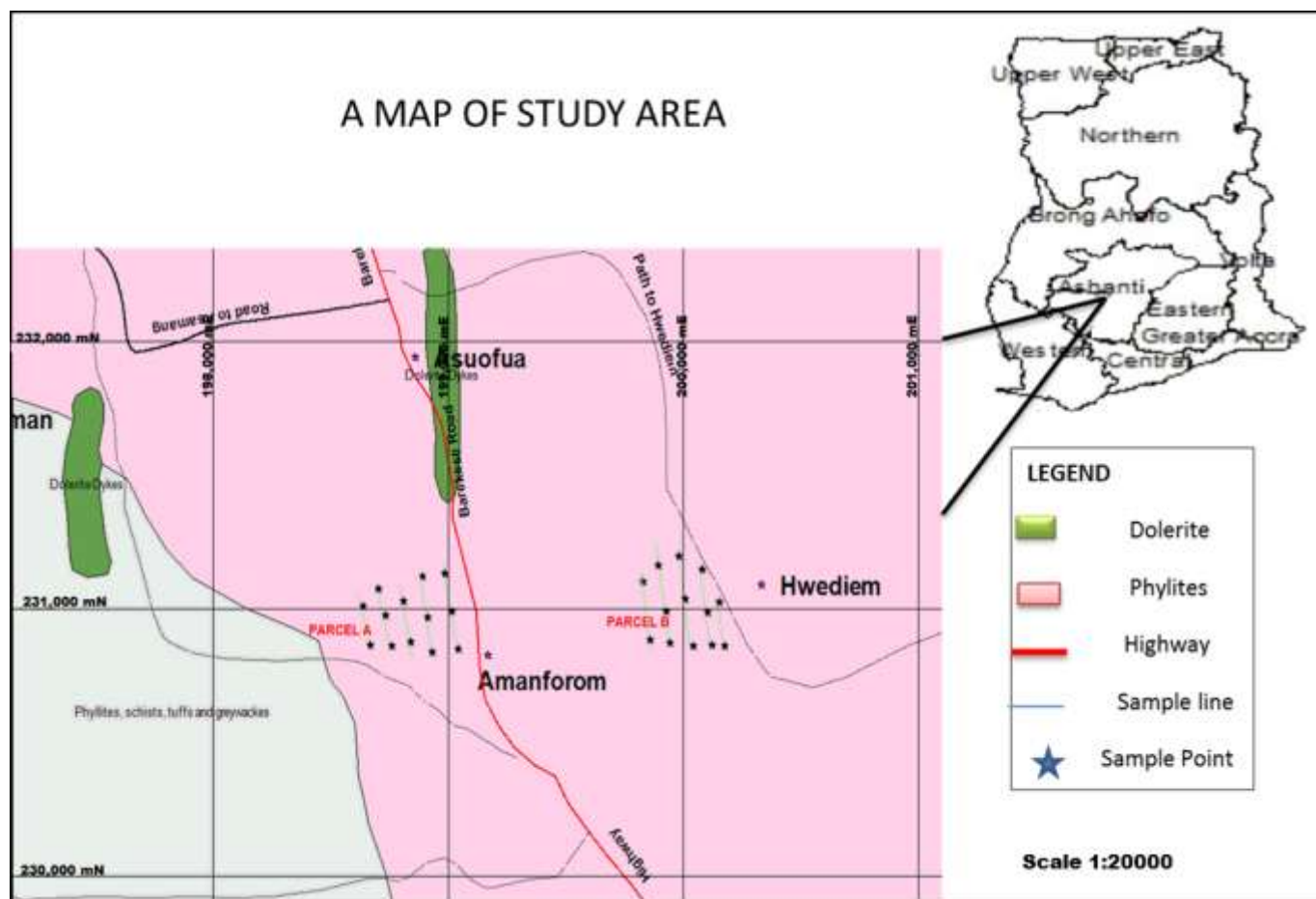
Figure 1. A map and geology of the study area.

distances of 6.5 and 231.8 m respectively from the road exhaust. Five (5) soil samples from each line in the parcels were picked at a depth of 6 cm. Distances between lines and sampling points on a row were 10 and 5 m, respectively. Laboratory measurements of the magnetic susceptibility and elements in samples were obtained using the MS2B dual frequency sensor and X-ray fluorescence spectrometer respectively. Soil samples from each line on land parcels, A and B were mixed, air dried and sieved to reduce the biasing effect of air, water and pebbles. The soil samples with less than 2 mm diameter were stored in a polyethylene bottle for further chemical, mineralogical analysis and magnetic measurement. The mineralogical composition of the soil samples was determined with an X-ray diffractometer. The magnetic susceptibility of the soil samples were also determined using magnetic susceptibility meter.

Magnetic susceptibility measurements

The samples were fed into sample containers and placed within the sensor of the MS2 magnetic susceptibility system. The sensor generates a magnetic field in the test coil which interacts with the minerals of the soil and displays the corresponding magnetic susceptibility value. Measurements were performed with an operating frequency of 0.465 KHz and sensitivity of 10^{-5} SI. A

measurement represents a mean of three readings to avoid measurement error.

Measurement of heavy metals content in soil

The prepared soil samples were analyzed for their heavy metal concentrations using X-ray fluorescence (XRF) Spectrometer. 4 g of soil from each sample container was taken using an electronic balance, after which it was homogenized by mixing the 4 g soil sample with a wax. The mixed soil samples was then fed into a mould and placed in a hydraulic press, after which a weight of 80000 N was applied to change the mixed samples into round pellets. The pellets are placed in the X-ray fluorescence spectrometer and readings were taken from the computer connected to the spectrometer.

RESULTS AND DISCUSSION

Tables 1 and 2 show the results of magnetic susceptibility and concentration of heavy metals content in parcel A and parcel B, respectively. The heavy metals content

Table 1A. Magnetic susceptibility and concentration of heavy metals in parcel A.

Distance from road (m)	Magnetic susceptibility $(\times 10^{-5} SI)$	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)	Sr (mg/kg)	Zr (mg/kg)	Pb (mg/kg)	Ti (mg/kg)	Cr (mg/kg)
6.5	112.1	17.4±1.6	10.1±0.7	64.3±1.5	4.6±0.6	44.7±0.5	379±12	1.0±0.1	3703±34	302±14
14.1	87.6	20.0±1.6	9±0.7	40.9±1.3	8.0±0.7	21.1±0.4	648±15	1.6±0.1	4466±38	484±16
24.1	106.4	16.4±1.4	4.8±0.4	23.3±0.9	6.7±0.6	14.1±0.3	604±14	0.0±0.0	3852±34	455±15
35.9	159.2	13.8±1.3	7.0±0.5	30.9±1.0	4.7±0.5	35.1±0.4	629±14	0.0±0.1	3270±31	980±19
46.5	164.4	17.9±1.4	5.4±0.5	32.5±1.0	6.3±0.6	17.8±0.3	713±14	0.4±0.1	3728±33	572±16

Table 1B. Magnetic susceptibility and concentration of heavy metals in parcel B.

Distance from road (m)	Magnetic susceptibility $(\times 10^{-5} SI)$	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	As (mg/kg)	Sr (mg/kg)	Zr (mg/kg)	Pb (mg/kg)	Ti (mg/kg)	Cr (mg/kg)
231.8	145.2	26.6±1.7	8.9±0.7	21.8±0.9	5.7±0.6	18.1±0.4	624±14	0.0±0.0	3357±31	518±16
237.7	153.6	24.0±1.6	7.3±0.6	23.0±0.9	10.4±0.6	23.4±0.4	713±15	1.6±0.1	3632±31	411±14
243.1	122.3	22.7±1.5	7.2±0.6	23.1±0.9	11.0±0.6	24.6±0.4	662±14	0.8±0.1	3469±30	421±14
249.5	160.8	28.3±1.6	10.9±0.8	27.2±1.0	9.4±0.6	26.0±0.4	652±14	1.2±0.1	3893±33	444±15
256.3	154.8	23.5±1.5	12.5±0.8	30.1±1.0	10.5±0.6	29.3±0.4	826±15	1.6±0.1	3664±32	345±13

Table 2A. The mean, maximum, minimum and standard deviation of heavy metals in parcel A.

mg/kg of soil	Magnetic susceptibility $(\times 10^{-5} SI)$	Ni	Cu	Zn	As	Sr	Zr	Pb	Ti	Cr	Total
Mean	125.94	17.10	7.26	38.38	6.06	26.56	594.60	0.60	3803.80	558.60	5052.96
Max	164.40	20.00	10.10	64.30	8.00	44.70	713.00	1.60	4466.00	980.00	
Min	87.60	13.80	4.80	23.30	4.60	14.10	379.00	0.00	3270.00	302.00	
Standard deviation	34.02	2.26	2.27	15.78	1.43	12.88	127.11	0.69	430.60	254.90	847.94

present in agricultural soil of the study areas include: Ni, Cu, Zn, As, Sr, Zr, Pb, Ti and Cr.

Statistical analysis of soil magnetic susceptibility

Magnetic susceptibility of parcel A ranges from 87.6 to 164 $\times 10^{-5}$ SI while parcel B ranges from 122.30 to 160.80 $\times 10^{-5}$ SI. Agricultural topsoil at parcel B (far away from road) shows consistent enhancement or even distribution of magnetic susceptibility when compared with parcel A closed to the road. Parcel A recorded highest value of magnetic susceptibility in the last line of the sample points (as compared to parcel B) but not consistent to the first four sample lines. This is due to the fact that by visual inspection, parcel A had undergone numerous physical, chemical and biological processing, which include intense weathering with associated erosion. On the other hand, topography of parcel B showed uniform

Table 2B. The mean, maximum, minimum and standard deviation of heavy metals content in parcel B.

mg/kg of soil	Magnetic susceptibility $(\times 10^{-5}\,\mathrm{SI})$	Ni	Cu	Zn	As	Sr	Zr	Pb	Ti	Cr	Total
Mean	147.34	25.02	9.36	25.04	9.40	24.28	695.40	1.04	3603.00	427.80	4820.34
Max	160.80	28.30	12.50	30.10	11.00	29.30	826.00	1.60	3893.00	518.00	
Min	122.30	22.70	7.20	21.80	5.70	18.10	624.00	0.00	3357.00	345.00	376.74
Standard Deviation	15.06	2.34	2.31	3.49	2.15	4.10	79.79	0.67	204.41	62.42	
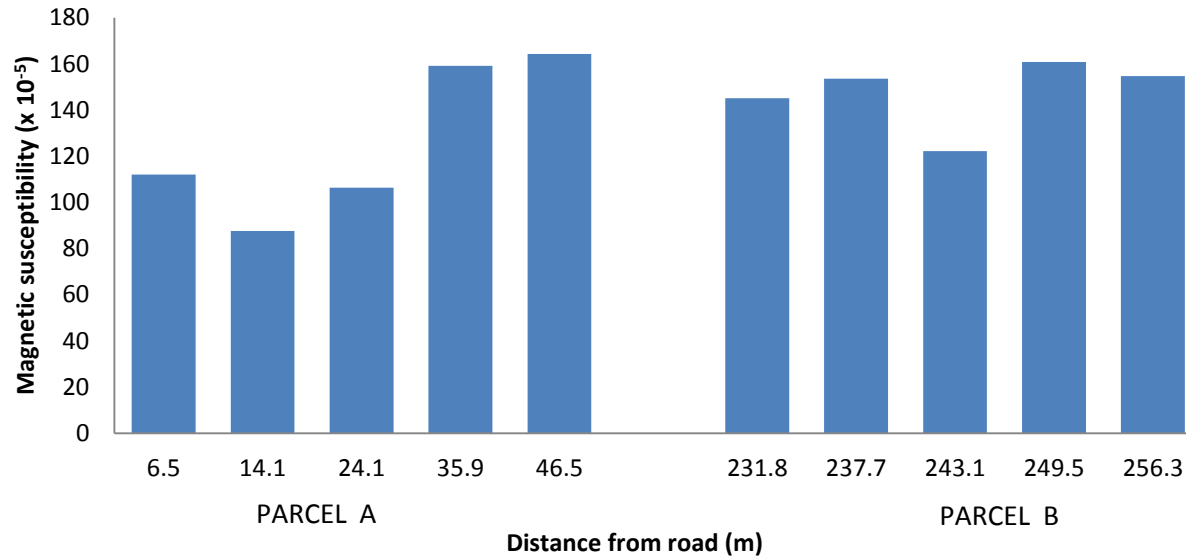
Figure 2. Magnetic susceptibility and distance from the road.

landscape with highly goethite materials covering the near subsurface of the earth, hence, even distribution of magnetic minerals. Because parcel A recorded highest value of magnetic susceptibility and partly undergone chemical and biological processes, it can be concluded that magnetic susceptibility of agricultural soil closed to the road is higher than one far away from the road (confirming what early researchers had proposed).

In order to show the strength of magnetic susceptibility with respect to distance on the road side, histogram distribution of magnetic susceptibility and distance is shown in Figure 2.

In parcel A, magnetic susceptibility shows inconsistent values with highest peak at 46.5 m from the road with standard deviation of 34.2×10^{-5} SI. Similarly, in parcel B, magnetic susceptibility distribution is slightly homogeneous with standard deviation of 15.06×10^{-5} SI. Reasonably, high magnetic susceptibility values suggested that top

Parcel A
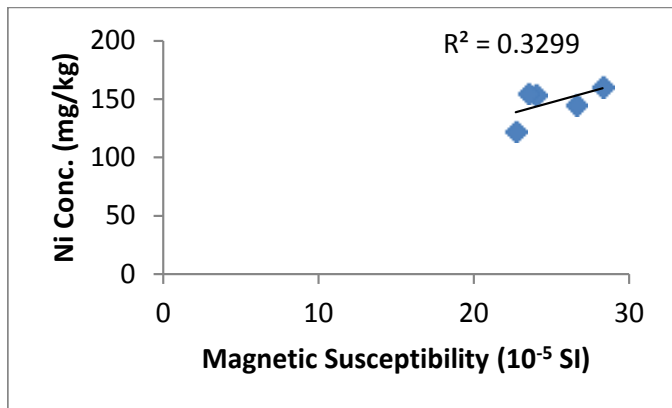
Parcel B
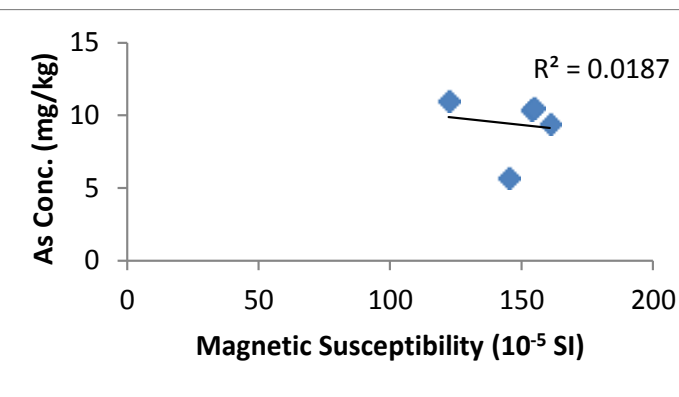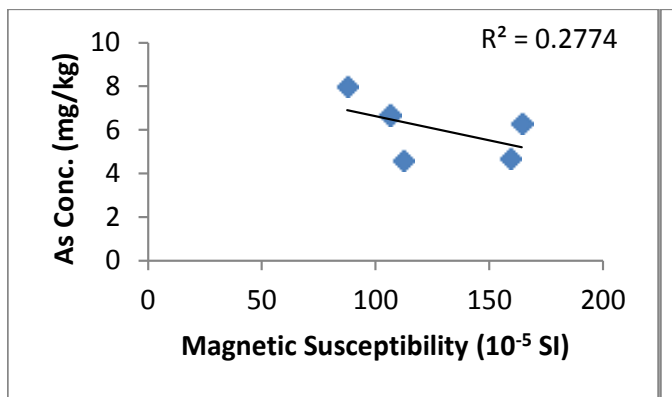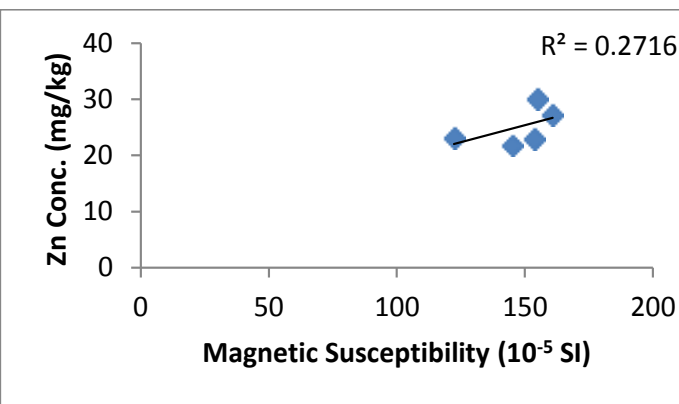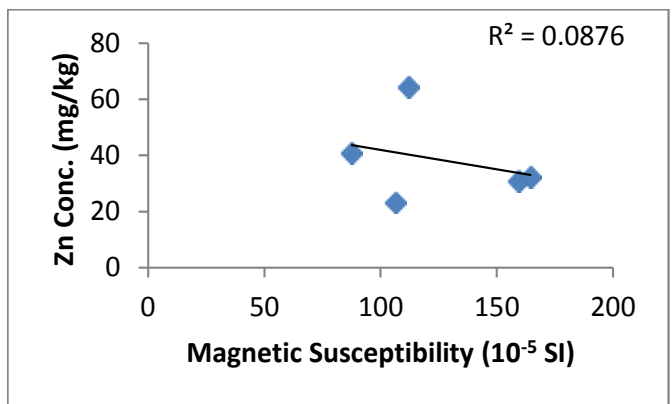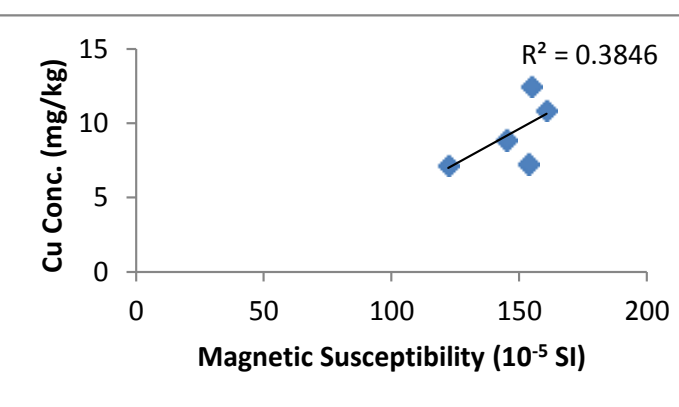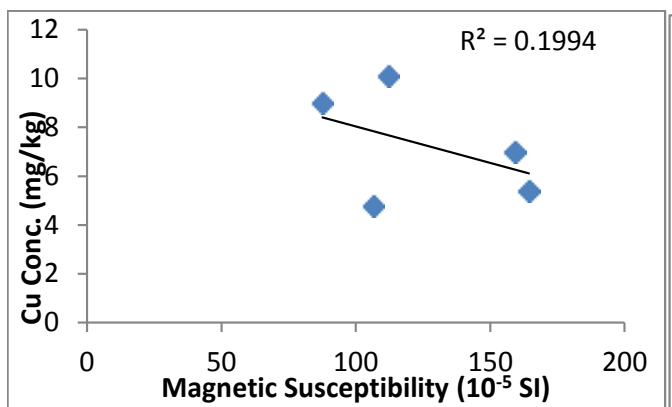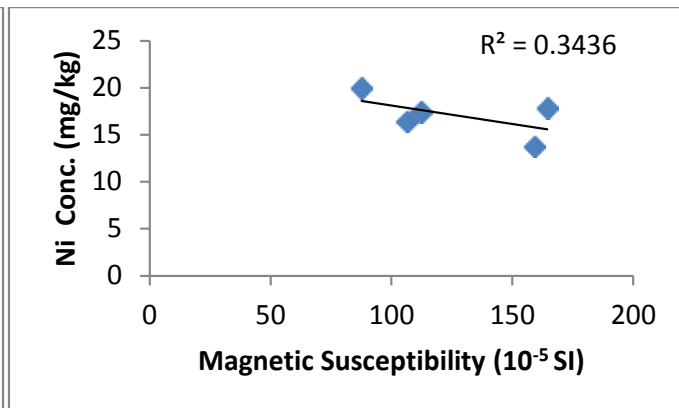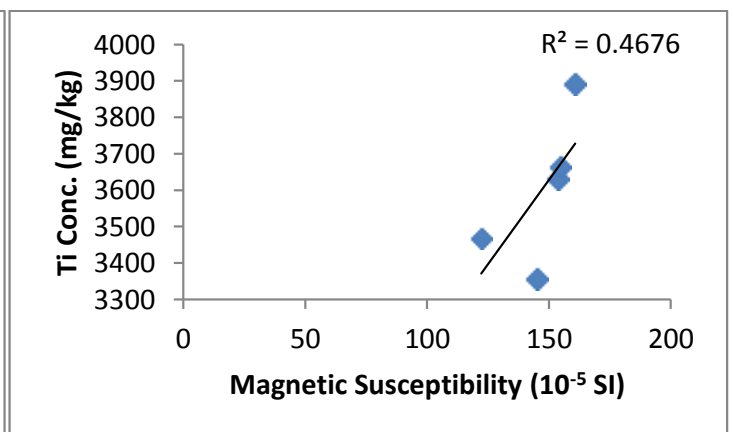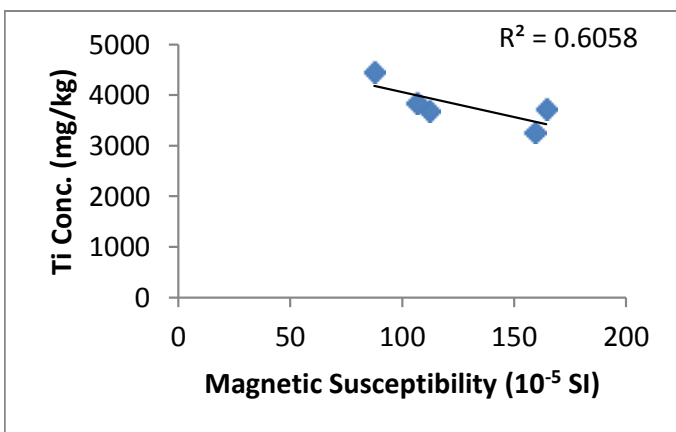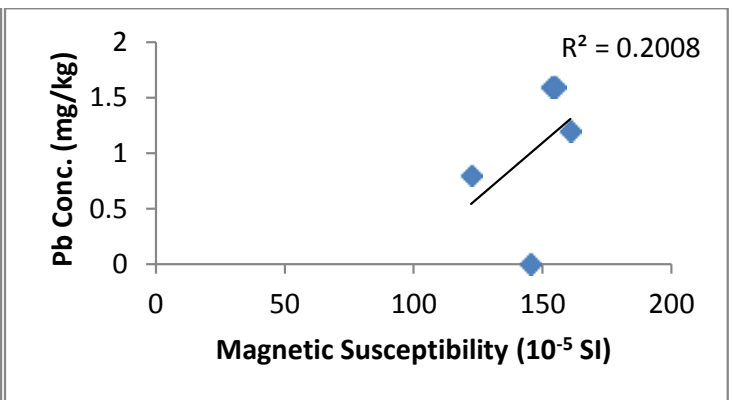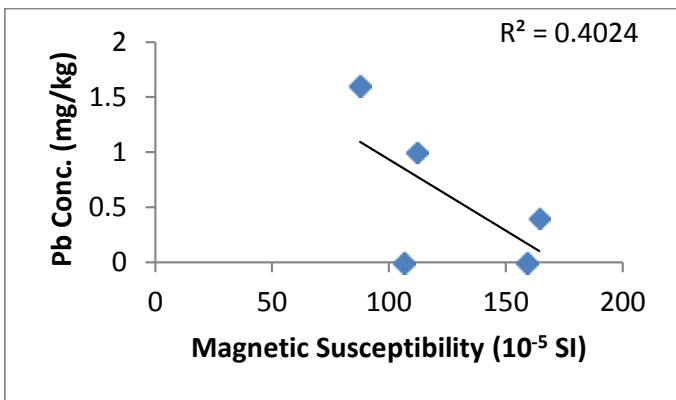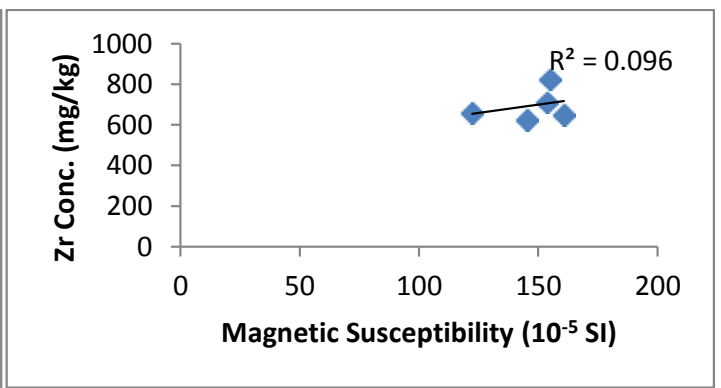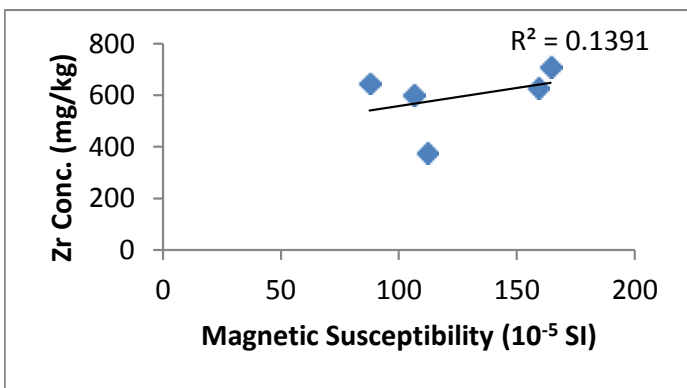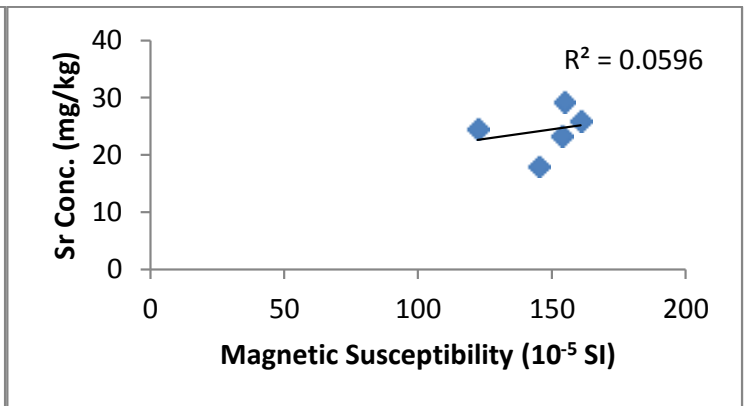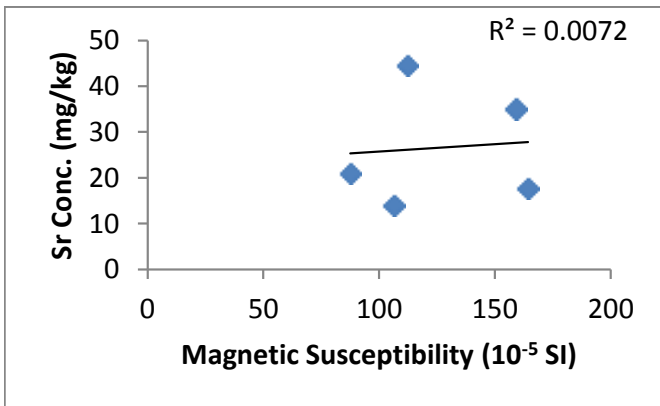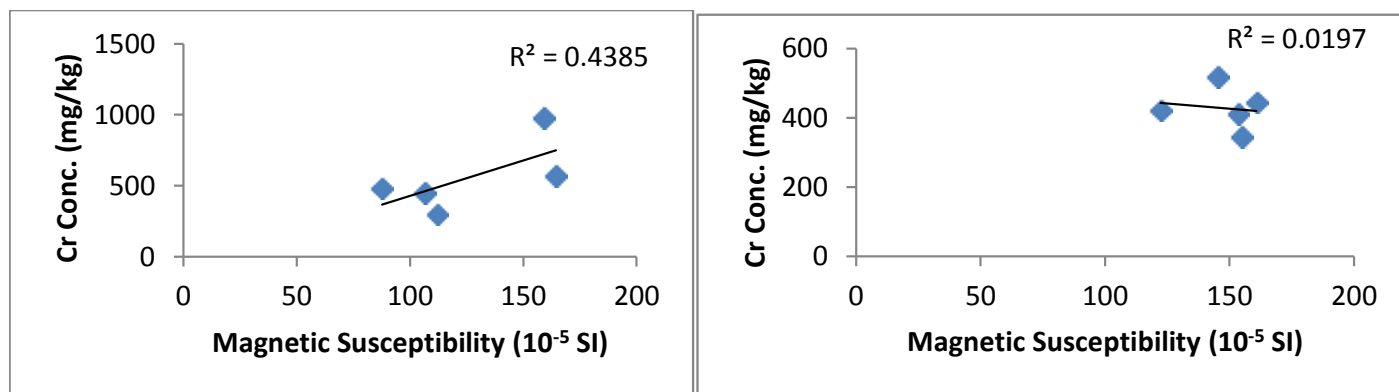
Figure 3. Scatter diagrams of the concentration of heavy metals and magnetic susceptibility values for parcels of agricultural soils.

soil is enriched with ferri/ferro-magnetic materials as a result of vehicular emission, anthropogenic activities and repeated application of fertilizer in the soil.

Statistical analysis of heavy metals in soil

In parcel A, the mean concentration of Ni, Cu, As, Sr, Zr, Pb, Ti and Cr content in top soil were 17.10, 7.26, 38.38, 6.06, 25.56, 594.60, 0.60, 3803.80 and 558.60 mg/kg, respectively. In parcel B, the mean concentration of Ni, Cu, As, Sr, Zr, Pb, Ti and Cr in top soil were 25.02, 9.36, 25.04, 9.40, 24.28, 695.40, 1.04, 3603.00 and 427.80 mg/kg, respectively. As a common element, the concentration of Fe is missing throughout the two agricultural soils. Parcel A contains 51.18% of the total heavy metals content measured as compared to 48.82% of heavy metals content in soils measured in parcel B away from the road. The results indicate that top soils near the road have higher concentration of heavy metals than top soils away from the road due to vehicular emission and anthropogenic activities.

Correlation between magnetic susceptibility and heavy metal content in soil

A graph of each heavy metal contents present in each parcel of agricultural soils is plotted against magnetic susceptibilities measured in the same parcels of soils. Correlation coefficient, R^2 for each heavy metal of agricultural soils are calculated and analyzed. According to correlation analysis of each parcel of soil, all heavy metals analyzed show positive correlations with magnetic susceptibility values (Figure 3). Heavy metalcontent, Ti in both parcels of soils show relativity strong positive correlation coefficients (0.60) with magnetic susceptibility as compared to the rest of other heavy metals. Heavy metals such as Ni, Cu, Pb and Cr showed significant

values (< 0.50) of correlation coefficient with magnetic susceptibilities in both parcels. The rest of the metals such as As, Sr, Zn and Zr gave inconsistent values (≤0.02) of correlation coefficient with magnetic susceptibilities in both parcels.

Conclusion

Accumulation of lead (Pb) content closed to the road (parcel A) may be from vehicular (traffic) emission. Enrichment of Ni, Cu, Zn, As and Ti in Parcel A may be due to anthropogenic activities rather than influence of vehicular exhausts. It seems that slightly higher magnetic susceptibility values in Parcel A in comparison with Parcel B, are result of physical, chemical and biological processing rather than influence of transport. Correlating magnetic susceptibility measurement with heavy metals content can give a better insight into environmental management. Preventing heavy metal pollution is critical because cleaning contaminated soils is extremely expensive and difficult. This study shows that magnetic susceptibility can be used as a proxy for mapping high concentration of heavy metals in agriculture top soils. It was also discovered that washing away of the top soils in Parcel A are likely to settle in Owabi Dam, which serves as water sources to catchment communities and Kumasi Metropolis. Hence further research is recommended on the Owabi Dam to check heavy metals pollution.

RECOMMENDATION (FUTURE PROSPECTS)

Further research work is recommended to be carried out in the nearby streams or dams to check if the top soils believed of washing away by erosion or weathering processes are clearly deposited in the nearby streams or dams which serve as water sources for inhabitants of

Kumasi Metropolis and surrounding villages.

Conflict of Interests

The author has not declared any conflict of interests.

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REFERENCES

Adriano DC (2003). Trace Elements in Terrestrial Environments: Biogeochemistry, Bioavailability and Risks of Metals. 2nd edition, Springer, New York, USA.

Bityukova L, Scohlger R, Birke M (1999). Magnetic susceptibility as indicator of environmental pollution of sols in Tallin. Phys. Chem. Earth 24(9):829-835.

El Baghdadi M, Barakat A, Sajieddine M, Nadem S (2012). Heavy metal pollution and soil magnetique susceptibility in urban soil of Beni Mellal City (Morocco). Environmental Earth Sciences, 66(1):141-155.

GWRTAC (1997). Remediation of metals-contaminated soils and groundwater, Tech. Rep. TE-97-01, GWRTAC, Pittsburgh, Pa, USA, GWRTAC-E Series.

Hanesch M, Schloger R (2002). Mapping of heavy metal loadings in soils by means of magnetic susceptibility measurements. Environ. Geol. 42:857-870.

Hoffmann V, Knab M, Appel E (1999). Magnetic susceptibility mapping of road side pollution. J. Geochem. Explor. 66:313-326.

Heller F, Strzyszca Z, Magiera T (1998). Magnetic record of industrial pollution in forest soils of Upper Silesia, Poland. J. Geophys. Res. 103:17767-17774.

Kesse OG (1972). The geology of sheet 165, Sekodumasi, SW Ghana, Geological Survey Department. Bull. P 41.

Kirpichtchikova TA, Manceau A, Spadini L, Panfili F, Marcus MA, Jacquet T (2006). Speciation and solubility of heavy metals in contaminated soil using X-ray microfluorescence, EXAFS spectroscopy, chemical extraction, and thermodynamic modeling, Geochimica et Cosmochimica Acta 70(9):2163-2190.

McLaughlin MJ, Hamon RE, McLaren RG, Speir TW, Rogers SL (2000). Review: a bioavailability-based rationale for controlling metal and metalloid contamination of agricultural land in Australia and New Zealand, Aust. J. Soil Res. 38 (6):1037-1086.

Wang ZS, Qin Y (2005). Correlation between magnetic susceptibility and heavy metals in urban topsoil: a case study from the city of Xuzhou, China. Environ. Geol. 49:10-18.

Full Length Research Paper

Co-composting of sewage sludge and *Echinochloa pyramidalis* (Lam.) Hitchc. & Chase plant material from a constructed wetland system treating domestic wastewater in Cameroon

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Trials were conducted at the Cité-Verte domestic wastewater treatment station (Yaoundé-Cameroon) in order to assess the effect of three sewage sludge: Macrophyte ratios on the co-composting process and compost quality. The ratios were T1: 25 kg of plant material (*Echinochloa pyramidalis*) and 75 kg sludge; T2: 50 kg of plant material and 50 kg sludge, and T3: 75 kg of plant material and 25 kg of sludge. The assessment parameters of the co-composting process included the daily evolution of temperature, the pH and water content for each month. The quality of the mature compost obtained was analysed based on their C/N ratio, Ca, Mg, P, K, trace elements and helminth eggs content. During co-composting, maximum temperatures ranged from 45.3 ± 4.7°C (T1) to 70.77 ± 2.76°C (T3). Mature co-compost was obtained after 3 months (T1), 4 months (T2) and 5 months (T3). Mean pH and C/N ratio of co-composts respectively ranged from 7.26 to 7.62 and from 10 to 15. In mature compost, the average values of organic matter, N and P respectively were 3323 ± 405 mg/kg, 165 ± 32 mg/kg and 36 ± 5 mg/kg for T1; 2945 ± 128 mg/kg, 152 ± 30 mg/kg and 27 ± 6 mg/kg for T2; and 228 ± 103 mg/kg, 105 ± 48 mg/kg and 7 ± 1 mg/kg for T3. K content was 1 mg/kg in all three co-composts. Heavy metals were found at trace levels. Helminth eggs concentration in compost was 0.2 ± 0.03 egg/g (T1), 0.1 ± 0.02 egg/g (T2) and 0.007 ± 0.01 egg/g (T3). All these co-composts did not present a significant hygienic risk with regards to WHO guidelines (2006) for safe reuse of faecal matter or faecal sewage in agriculture (less than 1 egg/g TS). For a given amount of plant harvested, it was concluded that the quickest way to produce a compost safe of parasites will be to mix them with 3/4 of sludge from the digestion tank.

Key words: Co-composting, Cameroon, compost quality, *Echinochloa pyramidalis*, hygienic risk, sewage sludge.

INTRODUCTION

All over the world, people in rural and urban areas have been using human excreta for centuries to fertilize fields and fishponds as well as to maintain or replenish the soil organic fraction, that is, the humus layer. Till date, in both

agriculture and aquaculture, this practice is still common (Strauss et al., 2003; Fabián et al., 2012). Reuse activities have led to a strong economic link between urban dwellers (food consumers as well as waste producers), and urban farmers (waste recyclers and food producers). Chinese peri-urban vegetable farmers have reported that customers prefer excreta-fertilized vegetables to chemically fertilized ones (Wang, 1991). Thus, vegetables grown on excreta-conditioned soils are sold at a higher price (Wang, 1997). In developing countries, natural wastewater treatment systems in replacement of conventional systems such as activated sludge treatment systems are considered nowadays as a viable alternative (Koné et al., 2007; Kengne et al., 2008; Tanveer and Guangzhi, 2012). Meanwhile, despite their good purifying performances, these systems are most often associated to the production of important by-products (sludge scum, plants, treated water, grit refuse etc.). Some of these products such as sludge scum can constitute organic amendments for the improvement of soil fertility (Strauss et al., 2003; Whautelet, 2011). Indeed, they contain nutrients (N, P, K, etc.) required for plant growth (Olufunke et al., 2009; Luna et al., 2011; Nogueira, 2013). This particular by-product generally undergoes a finishing treatment in order to limit sanitary and environmental risks linked to its discharge and or reuse in agriculture (Blaszkow et al., 2010; Bouzid and Djadi, 2015), because the latter is generally biochemically unstable and liable to contain pathogenic organisms and heavy metals (Olufunké et al., 2009).

In Cameroon, a two stage subsurface flow (SSF) constructed wetland was set up since 2012 for the treatment of domestic wastewaters for a population equivalent of approximately 5000 at the Cite-Verte neighbourhood. The system consists of an up-flow anaerobic pre-treatment with a screen/grit removal chamber, an anaerobic settling tank, an oil removal chamber and two gravel filters. This is followed by a two-stage subsurface flow (SSF) constructed wetlands. The process produces approximately 1 ton of sludge/week, collected as scum at the level of the anaerobic settling tank, which requires careful management. Several techniques such as incineration, composting and/or co-composting have been mentioned in literature as potential procedures for sludge transformation (Moumeni and Boutekrabt, 2001; Blaszkow et al., 2010) with regards to their cost and their level of technological mastery (Olufunké et al., 2009; Koné et al., 2007). Among these techniques, composting and co-composting are the most recommended because of their low cost and easy realisation.

Many studies have reported that sewage sludge alone produces compost of poor quality due to its high moisture content and low air permeability. In addition, this sludge contains a high concentration of nitrogen. It is therefore necessary to mix with other ingredients including bulking agents such as rice straw, sawdust, grass or leaves. These bulking agents are used to adjust the C/N ratio between 25:1 to 50:1, regulate the moisture content and maintain inter-particle void dispersion, thus allowing for adequate air and water exchange within the composting mass (Petric and Selimbasic, 2008; Iqbal et al., 2010).

Maturity is an important concept that is closely related to the quality of compost. Simply put, mature compost has decomposed enough to promote plant growth. Experienced producers and users of compost often evaluate maturity using subjective indicators such as colour, smell, and feel (Kuo et al., 2004). Dark brown, earthy smelling, moist, and finely divided composts that lack sour or ammonia off-odours are expected to be of adequate maturity to promote plant growth. However, more quantitative measures are required to better enable end-users to determine the optimal rate and frequency of compost application. A good compost in terms of the physicochemical constituents include an optimal C:N ratio ranging between 10-20:1, EC (<2.0 mmo), pH (6.0-7.5), the presence or absence of contaminants like human pathogens, physical contaminants (plastics), weed seeds, heavy metals, and pesticide residues (Walker, 2001).

Besides the production of sewage sludge at the Cite-Verte station, the frequent harvesting of plant materials generate huge amounts of grass and leaves which could serve as bulking agents for the composting of sludge produced. However, the appropriate mixing ratio for the best output of the process is not yet known. Therefore, the present study was conducted to assess the effect of three plant/sludge ratios on the co-composting process and the quality of compost obtained.

MATERIALS AND METHODS

Material preparation

The experiment was conducted at the Cité-Verte wastewater treatment plant in Yaounde (Cameroon); located at latitude 3° 40'N and longitude 11°29' E, 761 m above the sea level. The treatment system is made up of a vertical flow anaerobic pre-treatment with a screen/grit removal chamber, an anaerobic settling tank, an oil removal chamber and two gravel filters. This is followed by a two-stage subsurface flow(SSF) constructed wetlands.

The study was conducted at pilot scale in order to gain scientific and technical knowledge, skills and experiences in co-composting of macrophyte *(E. pyramidalis)* and sewage sludge. Plant material

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and sewage sludge both originated from maintenance operations of the Cité- Verte wastewater treatment plant. Scum collected from pre-treatment settling tanks served as sewage sludge, while macrophytes were harvested from planted beds at the end of their life cycle (five to six months). About 2 m[3] of sewage sludge with an average total solid (TS) content of 25 to 30% was loaded on top of an unplanted drying bed and allowed to dewater for one to two weeks, depending on climatic conditions. Thereafter, harvested plant materials were manually chopped with a cutlass into small fractions of about 2 to 3 cm to increase microbial surface contact and to ease of handling.

Plant material and sludge mixing ratios for co-composting

Based on the available bulking material; three different mixing ratios (treatments) of plant material and sewage sludge were set up as follows:

1. T1: 75 kg of sludge + 25 kg of *E. pyramidalis;*
2. T2: 50 kg of sludge + 50 kg of *E. pyramidalis;*
3. T3: 25 kg of sludge + 75 kg of *E. pyramidalis*.

Three heaps were prepared per treatment by measuring a total corresponding weight of both dewatered sewage sludge and plant materials in their respective ratios. The heaps were randomly set up. These materials were thoroughly churned up with a shovel to obtain a uniform mixture. They were then heaped into windrows of about 1.10 m long, 0.7 m wide and 0.35 m high. The windrows were manually overturned periodically using shovels. Where necessary, 3 to 7 L of tap water was added when returning the heaps to adjust their moisture content to an optimum of 50 to 60% (Tiquia et al., 2002; Mckinley et al., 1986 Suler and Finstein, 1977). In order to protect the windrows from bad weather and especially favour aerobic fermentation as required by composting, they were covered with black polyethylene plastic paper on which aeration holes had been made.

Turning frequency and co-composting process

Using a shovel and a pitch fork, the heaps were turned every three days for the first 15 days. The frequency was then reduced to once a week for one month and then once every two weeks when temperature approached ambient conditions. The turning ensured that the entire compost mass was subjected to optimum conditions of aeration, temperature and moisture during composting. The high turning frequency in the early stages was to enable all parts of the heaps to be heated sufficiently for efficient pathogen inactivation and also to aerate heaps for the necessary aerobic conditions. This is because oxygen consumption is generally highest during the early stages of composting. The leaps were watered each time they were turned, except when the moisture content was enough. During each composting cycle, 2 samples were taken from the inner layer and 3 from the outer layer of the heaps and thoroughly mixed with a shovel. About 500 g of this mixture was filled into a polyethylene bag for sampling and immediately transported in an ice bag to the laboratory for analysis. The transportation time of the samples from the field to the laboratory was about 15 min. These samples were kept at -20°C before analysis.

Physicochemical and parasite characterisation of composting feedstock and compost

Assessment of co-composting process

To assess the co-composting process, samples were taken after 0,

4, 8, 12 and 16 weeks of composting and analysed in the laboratory of Biotechnology and Environment at the University of Yaoundé I. The parameters measured were temperature, moisture content and pH. The ambient temperature and specific temperatures of the different heaps were measured three times a day respectively at 8 am, 12 pm (mid-day) and 4 pm. Measurements were made at five points on the composting heaps by inserting a HANA thermometer at a depth of 40 cm into the heaps. The average temperatures of the heaps were obtained and used to verify the number of days for which the piles were subjected to temperatures above 55ºC. This served as a basis for the elimination of pathogens present in the sewage sludge (US EPA, 1984). The pH was measured in the supernatant suspension of 1:5 compost/distilled water using a Hach pH-meter model HQ11d. Moisture content was determined by weight loss upon drying 50 g of sample at 105°C in an oven for 24 h. The difference in weight was established as the water content and was used to determine the moisture fraction of the sample.

Assessment of sewage sludge, plant material and compost quality

The sewage sludge, plant material and final compost obtained were analysed in terms of their physicochemical (Carbon, TKN, Ca, Mg, P, K) and parasitological (helminth eggs) characteristics, as well as their heavy metal content (Pb, Cd, Zn, Cu, Cr and Fe). To assess the sewage sludge and compost quality, Carbon, Total Kjeldahl nitrogen (TKN), Ca, Mg, P, Na and K were analysed for their fertilizing value. TKN was assayed through wet acid digestion of 0.5 g samples followed by distillation in Bucchi K-350 distiller and back titration with H_2SO_4 0.1N. Total P was measured colorimetrically using a Hach DR. 3900 spectrophotometer. Organic matter (%) and organic carbon (%) were determined by igniting an oven dried sample overnight in a Carbolite® muffle furnace at 550°C for 6 h. Nutrient content (Ca, Mg) were determined by EDTA titration while (K, Na) were determined using a Jenway® flame photometer; these values were expressed as % dry weight.

The safety (hygienic quality) of the compost thus depended on its heavy metal and helminth eggs content. Helminth eggs were included in this safety investigation because they are extremely resistant to most of the sludge stabilization treatments. Many epidemiological studies for humans revealed a significant health risk associated to nematode eggs due to the high survival rate of helminth eggs in the environment and their low infective doses (Feachem et al., 1983). The assessment of helminth egg levels in the compost was done in compliance with the US EPA protocol (1999) modified (Schwartzbrod and Banas, 2003). Sulphuric acid extracts of the compost sample was finally used for the determination of heavy metals content (Pb, Cd, Zn, Cu, Cr and Fe) using a Hach DR. 3900 spectrophotometer.

Statistical analysis

One-way analysis of variance (ANOVA) was used to compare mean values from different samples. The significant differences were obtained and individual means were tested using the least significance difference test ($P < 0.05$).

RESULTS AND DISCUSSION

Physicochemical and microbial characteristics of composting feedstock

Chemical characteristics of sewage sludge and plant

Table 1. Nutrient, heavy metal and helminth eggs in sewage sludge and plant material (n=3).

Parameter	Sewage sludge	Plant material (*E. pyramidalis*)
Moisture (%)	63 ± 0.5	43.5 ± 0.8
TOM (%)	60.45 ± 0.11	46.22 ± 9
C (%)	30.22 ± 0.07	23.11 ± 0.001
N (%)	1.30 ± 4	0.18 ± 0.006
P (%)	0.07 ± 0.02	0.01 ± 0.001
K^+ (%)	0.02 ± 0.002	0.17 ±0,7
Ca^{2+} (%)	0.05 ± 0.003	0.01 ± 0.03
Mg^{2+} (%)	0.05 ±0.001	0.13 ± 0.009
Na^+ (%)	0.49 ±0.02	0.06 ± 0.005
C/N	23.24 ± 1.7	128.38 ± 3.8
Cd (mg/L)	5.78 ± 0.7	0
Cr (mg/L)	343.75 ± 12.4	0
Cu (mg/L)	600 ± 21	0
Fe (mg/L)	3150 ± 11	0.7 ± 0.1
Pb (mg/L)	0	0
Zn (mg/L)	175 ± 5	0
Helminth eggs (eggs /Kg) D.M.)	3770 ± 34	0

material used in the experiment are shown in Table 1. The analyses of samples (sludge, plant material) revealed average contents of essential nutrients notably organic matter, nitrogen (N), phosphorus (P), potassium (K) and exchangeable cations (Ca^{2+}, Na^+, K^+ and Mg^{2+}) which are required for plant growth. Hence, it can constitute an organic amendment for the improvement of soil fertility. Similar results were mentioned by Strauss et al. (2003), Olufunke et al. (2009) who found faecal sludge and sewage sludge to be good sources of organic matter and nutrients. The C/N ratio of sludge (23.24) was lower than suitable values for composting process, hence, do not respect the range (30-35) for required composting material as suggested by the literature (Petric and Selimbasic, 2008; Iqbal et al., 2010). It is therefore necessary to apply bulking materials with high C content like plant material. Many studies have reported that sewage sludge alone produces poor compost quality due to its high moisture content and low air permeability. It is therefore necessary to mix with other ingredients including bulking agents such as rice straw, sawdust, grass and leaves (Petric and Selimbasic, 2008; Iqbal et al., 2010).

These bulking agents are used to adjust moisture content and maintain inter-particle void dispersion, which provides adequate air and water exchange within the composting mass (Eftoda and McCartney, 2004; Petric and Selimbasic, 2008; Iqbal et al., 2010), and also provides optimal initial carbon-to-nitrogen (C/N) ratio to enhance the decomposition rate (Kalamdhad and Kazmi 2009). Hence, the plant material used in this study can constitute a good bulking agent given its high C/N ratio

(128.38). The sludge-plant material mixture proved to be necessary for the reduction of the C/N ratio and the induction of biological activity in co-composting swaths. It may also result in maximum stability, highest fertilizer value, and minimum potential environmental pollution, corroborating with Ndegwa and Thomson (2000) who reported similar advantages in a C/N ratio of 25:1 for starting materials in the vermicomposting process of sewage sludge.

Heavy metal elements were also present in sludge, but their concentration was low. The concentration of helminth eggs in sewage sludge is above the French norms (NFU-44 051). Therefore, it must undergo a polishing treatment in order to limit sanitary risks linked to their discharge and or reuse in agriculture.

Effect of plant material and sludge ratio on the evolution of co-composting temperature

The evolution of temperature directly reflects the microbial activities during composting (Golueke, 1991); it may be considered as a good indicator of the bio-oxidative phase. Stentiford (1996) suggested that temperatures higher than 55°C maximised sanitation; those between 45 and 55°C maximised the biodegradation rates, and between 35 and 40°C maximised microbial diversity in the composting process. The ambient temperatures ranged from 22 to 28°C throughout the experimental period. Temperature development in the T1 and T2 piles between days 6 and 19 differed considerably from that in T3 (Figure 1). The
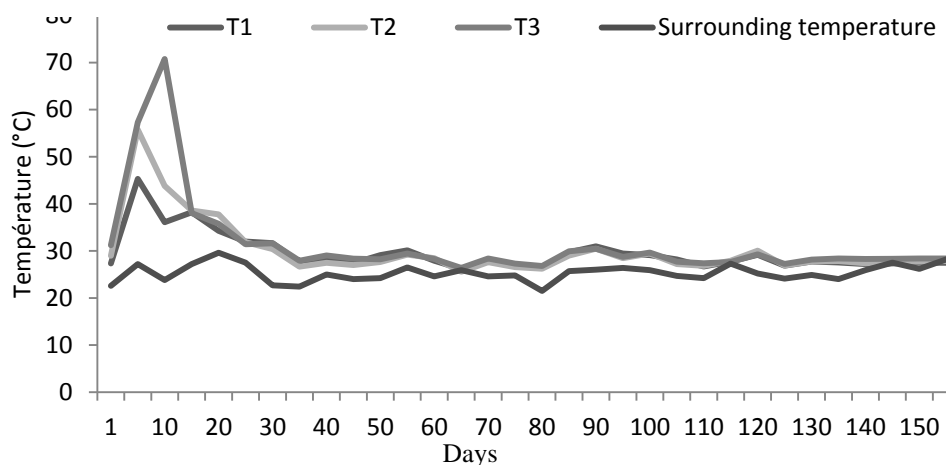
Figure 1. Temperature change of different heaps during co-composting.

piles showed an abrupt increase in temperature from day 5, with core temperature reaching 40°C in T1, 43°C in T2 and 47°C in T3 at mean ambient temperature of 23°C. The thermophilic (40 to 70°C) and mesophilic (40 to 25°C) phases could be seen as the bio-oxidative phase reported by Kuo et al. (2004). The temperature profile of the three piles had a similar pattern and the duration of the thermophilic phase was evaluated to be from about 5 days in T1, 9 days in T2 and 12 days in T3. These results are in line with the recommendation of the United States Environment Protection (USEPA) that the temperature of the compost pile should be higher than 40°C and maintained thus for at least 5 days, in order to ensure the elimination of pathogenic microorganisms (USEPA, 1984). This statement is also supported by Venglovsky et al. (2005). After the thermophilic stage, temperatures of all treatments rapidly declined until day 15, and then gradually decreased up to the ambient temperature. Subsequently from day 25 onwards, temperatures remained ambient until the end of the composting process, indicating the maturation phase in the sense of Diaz and Savage (2007) who showed that the color of composting materials changes from more intense to loose as observed in this study. The increased temperature observed in all treatments seven days after the beginning of the process may be due to delayed microbial growth stemming from pile turning and moisture content adjustment on day 6. Generally, pile turning could reactivate the composting process due to an increase in oxygen availability to microorganisms present during composting (Cayuela et al., 2006) thereby increasing the microbial metabolism and subsequent release of heat. On another hand, the evolution of temperature during the first week in the different treatments could be the result of a strong microbial activity induced by the presence of biodegradable organic matter such as mentioned by

Compaoré and Nanéma (2010). The heat generated accelerates the decomposition of proteins, fats and complex sugars like cellulose and hemicelluloses contained in *E. pyramidalis*. The strong reduction in temperature observed in all treatments at the cooling phase could be explained by a slow-down of the activity of microorganisms due to the exhaustion of easily biodegradable organic matter as confirmed by Compaoré and Nanéma (2010). The stabilisation of temperature observed at the maturation period could be due to the stop of fermentation (release of gases) and the elimination of phytotoxicity (presence of ammonium ions, acetic acid, etc.) able to deteriorate soils and organisms that live therein as suggested by Fancou et al. (2008).

Effect of plant material and sludge ratio on water content of piles during co-composting

The initial moisture content of the three piles was not very similar at the beginning of the process (Figure 2).

Water content (WC) decreased progressively in all treatments during the co-composting. It changed from 58.08 ± 3.57% (T1), 63.18 ± 3.06% (T2) and 48.26 ± 0.74% (T3) at the beginning of co-composting, to 27.3 ± 3.71 % (T1), 28.81 ± 1.69 % (T2) and 29.91 ± 3.95 % (T3) at the end of the experiment. These values of WC in treatments 1 and 2 were significantly higher than those of treatment 3 within the first month of co-composting. Generally, the least values of water content were recorded in the swaths of T3, while the highest were recorded in those of T1. Nevertheless, at the 5th month of the process, water contents presented slightly higher values in T3 than in T1 and T2, even though the differences were not statistically significant (Figure 2). The decrease of moisture could be explained by the
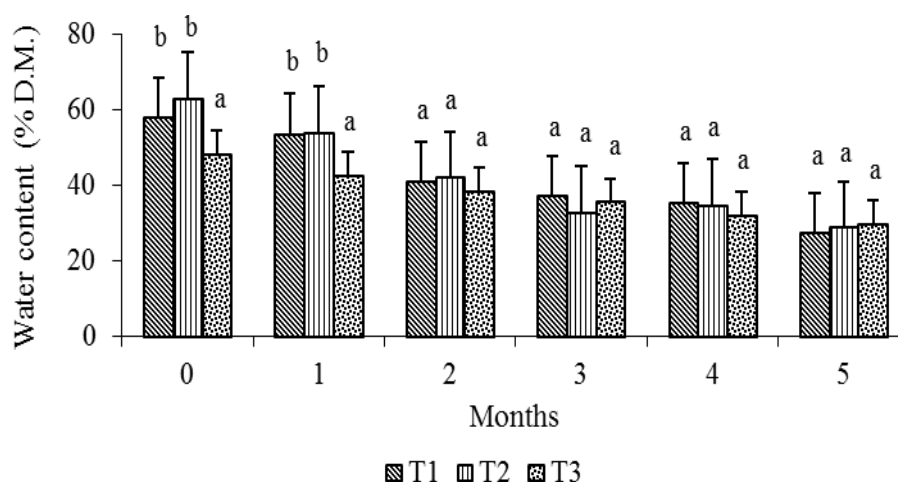
Figure 2. Water content variation of co-composts during co-composting process.
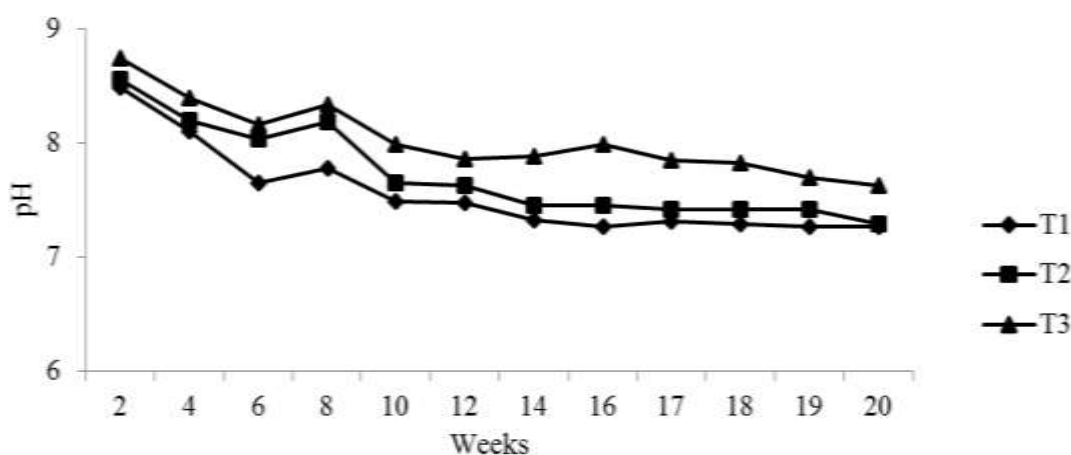
Figure 3. Changes of pH in different treatments during co-composting.

evaporation of water due to a thermal effect and by the combined action of overturning and aeration. According to Francou et al. (2008) part of the calorific energy radiated during the composting process provokes an evaporation of water leading to the drying off of matter while Compaoré and Nanéma (2010) attributed water loss in the form of vapour as a result of the different overturns carried out during composting.

Effect of plant material and sludge ratio on pH values during co-composting

The pH variation in the different treatments is presented in Figure 3. A regression of pH was noticed in the swaths of all treatments. Despite this regression, pH remained basic with values ranging from 8.49 ± 0.03 to 8.74 ± 0.10

at the beginning of co-composting to 7.26 ± 0.04 to 7.62 ± 0.04 at the end. A slight pH peak was observed between the 6th and the 10th week in all treatments with values of 7.78 ± 0.13 (T1), 8.18 ± 0.35 (T2) and 8.33 ± 0.27 (T3). This increase in pH of all compost piles was due likely to the metabolic degradation of organic acids and the ammonification process taking place during organic matter degradation as reported by Satisha and Devarajan (2007) as well as Mahimairaja et al. (1994).

The pH values in T3 remained higher than those in T1 and T2 throughout the process, with lowest values recorded in T1. At the end of co-composting, pH oscillated between 7 and 8 in all treatments. The increase of pH and the slight differences recorded during co-composting could be attributed to the initial composition of substrates (sewage sludge and plant material mixture). Indeed, Compaoré and Nanéma (2010) affirmed that the

Figure 4. Change of colour and physical characteristics of co-composts. a: Swath of treatment 1; b: Swath of treatment 2; c: Swath of treatment 3.

substrate could influence the evolution of pH during composting. Furthermore, the highest pH in T3 could be explained by its highest plant material quantity (*E. pyramidalis*) as compared to sludge. The decrease of pH from 8.74 to 7.26 observed at the beginning of co-composting is different from literature results. In fact, Cayuela et al. (2006) observed that at the beginning of composting of olive mill wastes, an increase in pH from 7 to 9 was generally recorded. These differences can be due to the type of organic matter used, the period of experimentation and the composting methods. The pH peak recorded between the 6th and the 10th week in all treatments should be associated to the degradation of short chain fatty in proteins and the liberation of ammonia during ammonification. Furthermore, the stabilisation of pH at the end of the process in all treatments could be attributed to the oxidation of ammonium by bacteria and the precipitation of calcium carbonate as mentioned by Chakroune et al. (2005). The final pH values (7.26, 7.29 and 7.62 respectively) obtained are in the range of those of Olufunke et al. (2009) in composts of different sources of organic matter (faecal sludge, animal dung, household refuse), after pH ranged from 7.1 to 8.6. After 2 weeks of composting, the pH values of all composts prepared gradually declined from 8.0, 8.3 to 6.9 and 7.3.

Effect of plant material and sewage sludge ratio on the maturity of co-composts

Co-composts were considered as ready when they had the odour of humid ground, a brown or dark colour, with a charred feel upon touch and when their temperature at the end of co-composting became stable and close to the external surrounding temperature without exceeding 30°C (Chakroune et al., 2005). However, the differences in colour only appeared at the beginning and the end of co-composting with colours that moved from black, dark brown and brown for T1, T2 and T3 respectively to deep black, black and dark brown after 150 days of co-composting (Figure 4).

The black, dark brown and brown colours respectively observed in T1, T2 and T3 at the first period of co-composting of sewage sludge and plant material could be explained by the composition of the initial mixture. Indeed at the beginning, the colour of sludge was dark and plant material was green. The black colour (T1 and T2) and dark brown (T3) of composts obtained should be due to the presence of humus contained resulting from the total mineralisation of co-compost materials, also indicating their maturity. Indeed, Mbuligwe et al. (2002), characterise mature co-compost by its deep black colour,

Table 2. Heavy metals contents and helminth eggs content of co-compost obtained (n = 3).

Parameter	Treatment			
	T1	T2	T3	French Norms (NFU-44 051)
Cd (mg/kg)	1.06 ± 0.07[a]	1.19 ± 0.05[a]	1.32 ± 0.08[b]	3
Cr (mg/kg)	95 ± 5.00[a]	84.58 ± 8.87[a]	228.33± 11.61[b]	120
Cu (mg/kg)	141.67 ± 19.09[a]	237.50± 45.07[b]	270.83± 19.09[b]	300
Fe (mg/kg)	2237.50 ± 625.37[a]	2166 ± 190.94[a]	2550 ± 43.30[a]	nd
Helmintheggs (eggs/g DM)	0.2 ± 0.03[c]	0.1 ± 0.02[b]	0.007 ± 0.01[a]	Absent in 2 g of raw material

To move from milligrams per kilogramme (mg.kg^{-1}) to percentages (%), divide by 10^2; nd = not determined. Values followed by the same letter are not significantly different from each other following Student Newman Keul's test (p < 0.05).

while the World Health Organization characterizes it by it black or dark brown colour.

The nauseating odour that emanated from the various treatments during the first weeks of co-composting could be associated on one hand to the unpleasant odour of sewage sludge from the wastewater treatment plant, and on the other hand to the anaerobic conditions inside the swaths at the beginning of the experiment. Indeed, the high water contents in swaths at the beginning of co-composting should obstruct aeration interstices, creating anaerobic conditions as confirmed by Agendia et al. (1997). The rapid diminishing of these odours after the 5th week of co-composting could be explained by the drop in water content and more by the presence of plants which should have conferred a good aeration to the swaths. In fact, Francou et al. (2008) mentions that it is essential to compost sludge from waste treatment stations with a dry carbonated structuring agent because this optimisation favours the creation of gaps, which are obligatory for a good aeration.

Effect of plant material and sewage sludge ratio on compost characteristics

Heavy metals and helminth eggs content of co-composts obtained

The analyses of final composts revealed the presence of some heavy metals (Cd, Cr, Cu, and Fe) and helminth eggs in lowest quantities compare to sewage sludge (Table 2). These quantities are statistically different in treatments T1 and T2 compare to T3 for Cd, Cr, and Cu.

Heavy metals contents of the final composts were below the French norms NFU-44 051. Meanwhile, the chromium content of T3 (228.33 ±11.61 mg/kg) is largely above the limit value (120 mg/kg MS) (Table 3). The heavy metals (HM) contents of all composts are lower than those of the sludge used for co-composting, and Zn which was present in sludge (175 mg/kg) is no longer present in final composts. These results shows that these

latter do not constitute any danger to be used as agricultural amendment. The HM values are weak as compared to those obtained by Agendia et al. (1997) and Compaoré and Nanéma (2010) in Yaoundé and Ouagadougou respectively. These values are high as compared to those obtained by Swati and Vikram in Burkina-Faso (2011). The differences observed could be due on one hand to the nature of wastes used and on the other hand to the co-composting technique and the methods of analyses as suggested by Compaoré and Nanéma (2010). The HM concentrations of co-composts are largely inferior to those obtained in sludge used for co-composting. Hence, co-composting should have contributed to the reduction of these concentrations in co-composts obtained. The reduction of HM could be attributed to the co-composting method and to the presence of molluscs like leeches and earthworms in swaths placed for co-composting. In fact, several authors, like Swati and Vikram (2011) confirm that molluscs are generally used as metallic pollution indicators because they are excellent bio-accumulators.

The low quantities of helminth eggs of co-composts obtained as compared to the initial sludge should be the result of the elimination of the latter during the co-composting process under the action of high temperatures. Actually, Venglovsky et al. (2005) showed that temperature higher than 55°C enable compost hygienisation. Furthermore, Venglovsky et al.(2005) mentioned that temperature maintained between 55 and 60°C during three consecutive days is require to eliminate a maximum of pathogenic elements in a compost pile. The final compost do not constitute a risk for being used as agricultural amendment because the helminth egg values present in the composts are in conformity with French norms (absence of eggs in 2 g of raw material).

The odour of humid ground, the deep black and brown colours as well as the temperatures close to the ambient temperature allow for the consideration of final composts as mature. In fact, all these parameters are taken into considerations by several authors (Olufunké et al.,

Table 3. Physical parameters of co-composts obtained (n = 3).

Parameter	Treatments			
	T1	T2	T3	Compost quality standards (WHO,1993)
Weight (Kg)	55.67 ± 3.06^a	66.67 ± 5.69^a	79 ± 7.55^b	nd
Conductivity (µS/cm)	639 ± 36.17^a	589 ± 54.25^a	806.33 ± 178.30^a	nd
'water' pH	7.26 ± 0.04^a	7.29 ± 0.03^a	7.62 ± 0.04^b	6-9
'KCl' pH	7.71 ± 0.02^a	7.68 ± 0.05^a	7.8 ± 0.02^b	6-9
Temperature	27.47 ± 0.06^a	27.87 ± 0.55^a	28.4 ± 0.95^a	nd
WC (%DM)	27.30 ± 3.71^a	28.81 ± 1.61^a	29.91 ± 3.95^a	nd

nd = Not determined. Values followed by the same letter are not significantly different according to Student Newman Keul's test ($p < 0.05$). Values followed by the same letter are not significantly different with each other with regards to Student Newman Keul's test ($p < 0.05$).

Table 4. Chemical parameters of co-composts obtained (n = 3).

Parameter	Treatment			
	T1	T2	T3	Compost quality standards (WHO,1993)
TOM (% DM)	33.23 ± 4.05^b	29.45 ± 1.28^b	22.8 ± 1.03^a	10-30
C (%DM)	16.61 ± 2.02^b	14.97 ± 0.21^b	11.4 ± 0.51^a	nd
N (% DM)	1.65 ± 0.32^a	1.52 ± 0.30^a	1.05 ± 0.48^a	0.1-1.8
P (% DM)	0.36 ± 0.05^b	0.27 ± 0.06^b	0.07 ± 0.01^a	0.1-1.7
K^+ (% DM)	0.01^a	0.01^a	0.01^a	0.1-2.3
Ca^{2+} (% DM)	0.24 ± 0.05^b	0.06^a	0.08 ± 0.01^a	nd
Mg^{2+} (% DM)	0.03 ± 0.01^a	0.02 ± 0.01^a	0.04 ± 0.01^a	nd
Na^+ (% DM)	0.49^a	0.49^a	0.46 ± 0.06^a	nd
C/N	10.20 ± 1.08^a	10.69 ± 0.97^a	10.16 ± 2.96^a	10-15

nd = Not determined. Values followed by the same letter are not significantly different according to Student Newman Keul's test ($p < 0.05$).

2009; Mbuligwe et al., 2002).

Physical parameters of composts obtained

The evaluation of mean weights values of the obtained composts showed that those of T3 were significantly higher than those of T1 and T2. However, temperature and water content did not follow similar pattern (Table 3). The highest conductivity values were recorded in composts T3 and the least in co-composts of T2 but they did not present significant differences. The pH values in all treatments were slightly basic both for 'water' pH and for 'KCl' pH. Globally, the physical parameters of all obtained composts were in the range of World Health Organisation (WHO, 1993) for agricultural use.

Chemical parameters of final composts obtained

The concentrations of TOM, C and P are significantly higher in final composts of T1 and T2 as compared to

those of T3 (Table 4). These contents were in the range of WHO (1993). Nutrients (N, K, Mg^{2+} and Na^+) do not present significant differences in all composts obtained and the C/N ratios (up to 10) are in the range of compost quality standards of WHO (between 10 and 15). Exchangeable cations (K^+, Na^+, Ca^{2+} and Mg^{2+}) concentrations are low in all composts but the only difference observed was notice in composts of T1 which have a Ca^{2+} content that is significantly higher than those of T2 and T3. These results could be explained by the initial composting feedstock ratio and the composting procedure used.

Elements such as N and P are found in higher quantities in the co-composts of T1 and T2 as compared to initial sludge. However, the co-composts of T1 are on the whole richer in nutrients than those of T2 and T3. The determination of total soluble fertilizing elements permits the forecasting of the fertilizing effect of co-composts which is an important aspect of the quality of the compost.

The chemical element contents of final composts are slightly lower than those obtained by Agendia et al.

(1997) in Yaoundé, during the compost production from *Pistia stratiotes* biomass generated by a macrophytic sewage treatment system. They are also below those obtained by Compaoré and Nanéma (2010) in Ouagadougou during the composting of urban solid wastes. According to FAO norms, final composts obtained have high TOM and N contents with a low C/N ratio; but weak concentrations of P, K, Na^+, Ca^{2+} and Mg^{2+}. Meanwhile, compared to the AFNOR norms, these composts were very rich in TOM, N, P, with very low C/N ratios. The obtained results could be explained by the nature of initial organic substrates and the composting procedure used. The sludge and *E. pyramidalis* plants ratios could explain the differences in nutrient contents of the obtained composts as well as the strongest TOM and mineral elements concentrations in the T1 composts. Indeed, Raj and Antilb (2011) affirmed that mineral elements contents found in composts are depending to the nature of wastes and tributary to their major initial elements. The C/N ratios (< 13) found in obtained composts may confirmed their richness in nitrogen as confirmed by Agendia et al. (1997). The pH values (between 6 to 8) of the composts are favourable to microbial activity according to the compost quality standards of WHO (1993).

Conclusion

This study revealed that sewage sludge and plant material from wastewater treatment plant can be used to produce compost for agricultural purpose. The richness observed in organic matter, nutrients (C, N, P, and K) and exchangeable cations (Ca^{2+}, Na^+ and Mg^{2+}) in sewage sludge and plant material shows that these by-products can be used for agricultural purposes. However, the concentration of helminth eggs and heavy metals (Cd, Cu, Cr, Fe, and Zn) found in sewage sludge could limits it reuse. In other to improve the hygienic quality of sewage sludge for it safe agricultural reuse, composting process was achieved in combination with plant material. During the co-composting period, similar evolution tendencies were observed in all treatments for each monitored parameter. Temperatures, pH and WC in all piles were sufficient for the mineralisation of organic matter, change of colour and the elimination of parasites. The mixture of plant material and sewage sludge contributed to reduce heavy metal content (Pb, Zn, Cu, Cr, Cd, and Fe) and helminth eggs concentrations while increased nutrient (N, P, Ca, Mg Na and K) content of final composts. These heavy metals and helminth eggs concentrations in final co-composts are in the range of WHO, US EPA and French guidelines for compost. The concentration of nutrient were higher in Treatment 1 (75 Kg sludge and 25 Kg plant material) and it duration of co-composting was the lowest (3 moths). According to these observations,

the above treatment can be recommended for the co-composting of sewage sludge and plant material coming from the wastewater treatment plant of Cité-Verte. However further researches about the effect of other different type of bulking materials and sewage sludge from this wastewater treatment plan for co-composting are recommended.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Agendia PL, Kengne NIM, Fonkou T, Mefenya R, Sonwa DJ (1997). Production de compost à partir de la biomasse de *Pistia stratiotes*. Cahiers Agric. 6:15-19.

Blaszkow F, Filali R, Fournier A, Gu S, Sadaka K (2010). Valorisation énergétique des boues de station d'épuration. Compost Science and Utilization. 4(2):1-26.

Bouzid M, Djadi A (2015). Revaluation of activated sludge and chicken manure through composting by aerobic process. Afr. J. Agric. Res. 10(52) :4831-4836.

Cayuela ML, Sanchez-Monedero MA, Roig A (2006). Evaluation of two different aeration systems for composting two-phase olive mill wastes. Process. Biochem. 41(3):616-623.

Chakroune K, Bouakka M, Hakkou A (2005). Incidence de l'aération sur le traitement par compostage des produits dérivés du palmier dattier contaminés par *Fusarium oxysporum* f. sp. *albedinis*. Can. J. Microbiol. 51:69-77.

Compaoré E, Nanéma LS (2010). Compostage et qualité du compost de déchets urbains solides de la ville de Bobo-Dioulasso, Burkina Faso. Tropicultura. 28(4):232-237.

Diaz LF, Savage GM (2007). Factors that affect the process. In: Diaz L F, De Bertold, i M, Bidlingmaier W, Stentiford E. (ed) Compost Science and Technology in Waste Management, 8th edition. Elsevier, Amsterdam . pp. 49-65.

Fabián F, Langen C, Edmundo RJ ,Pineda-Pineda, Antonio V, Luís AM, Gaudencio C, Joaquín M, Fernando L, and Luc D (2012).Growth and development of common vetch (Viciasativa L.) in a gasoline-polluted soil amended with organic or inorganic amendments. Afr. J. Agric. Res. 7(8):1259-1267.

Francou C, Linères M, Derenne S, Villio-Poitrenaud ML, Houot S (2008). Influence of green waste, biowaste and paper–cardboard initial ratios on organic matter transformations during composting. Bioresour.Technol. 99:8926-8934.

Golueke CG (1991). Principle of Composting. The staff of Biocycle Journal of Waste Recycling.The art and science of composting. JG Press, Pennsylvania. pp. 32-55.

Iqbal MK, Shafiq T, Ahmed K (2010). Characterization of bulking agents and its effects on physical properties of compost. Bioresour. Technol. 101(6):1913-1919.

Kengne NIM, Amougou A, Soh EK, Tsama V, Ngoutane PMM, Dodane PH, Koné D (2008). Effects of faecal sludge application on growth characteristics and chemical composition of *Echinochloa pyramidalis* (Lam.) Hitchc. and Chase and *Cyperus papyrus* L. Ecol. Eng. 34:233-242.

Koné D, Olufunke C, Christian Z, Katharina G, Daya M, Silke D, Martin S (2007). Helminth eggs inactivation efficiency by faecal sludge dewatering and co-composting in tropical climates waters. Water Res. 41:4397-4402.

Kuo S, Ortiz-Escobar ME, Hue NV, Hummel RL (2004). Composting and compost utilization for agronomic and container crops. Available at: www.ctahr.hawaii.edu/huen/ composting_compost_util.pdf.

Luna ZHS, López WW, Solís OM, Vera A (2011). Effect of compost made with sludge from wastewater treatment plants on field of corn (Zea mays L.) and arbuscularmycorrhizal fungi density. Afr. J. Agric. Res. 6(5):1233-1240.

Mahimairaja S, Bolan NS, Hedley MJ, Macgregor AN (1994). Losses and transformation of nitrogen during composting of poultry manure with different amendments: an incubation experiment. Bioresour. Technol. 47:265-273.

Mbuligwe SE, Kassenga GR, Kaseva ME, Chaggu EJ (2002). Potential and constraints of composting domestics solid waste in developing countries: findings from a pilot study in Dar es Salaam. Resour. Conserv. Recycl. 36:45-59.

McKinley VL, Vestal JR, Eralp AE (1986).Microbial activity in composting. In: The Biocycle Guide to In-vessel Composting. JG Press Inc., Emmaus Pennsylvania. pp. 171-181.

Moumeni L, Boutekrabt A (2001). Valorisation des boues résiduaires urbaines et d'ordures ménagères par compostage conjoint. Rev. Energ. Ren. : Production et valorisation-Biomasse. pp. 79-82.

Ndegwa PM, Thomson SA (2000). Effect of C to N ratio on vermicompostiong of biosolids. Bioresour. Technol. 75(1):7-12.

Nogueira TAR, Franco A, He ZL, Braga VS, Firme LP, Abreu-Junior CH (2013). Short-term usage of sewage sludge as organic fertilizer to sugarcane in a tropical soil bears little threat of heavy metal contamination. J. Environ. Manage. 114:168-177.

Olufunke C, Doulaye K, Silke R, Daya M, Chris Z (2009). Co-composting of faecal sludge and organic solid waste for agriculture: Process dynamics. Water Res. 43:4665-4675.

Petric I, Selimbasic V (2008). Composting of poultry manure and wheat straw in a closed reactor: optimum mixture ratio and evolution of parameters. Biodegradation 19(1):53-63.

Raj D, Antilb RS (2011). Evaluation of maturity and stability parameters of composts prepared from agro-industrial wastes. Bioresour. Technol. 102:2868-2873.

Satisha GC, Devarajan L (2007). Effect of amendments on windrow composting of sugar industry pressmud. Waste Manage. 27:1083-1091.

Schwartzbrod J, Banas S (2003). Quantification and viability determination for helminth eggs in sludge (modified EPA method 1999), University of Nancy.

Stentiford ET (1996). Composting control: Principles and practice. In: DeBertoldi M, Sequi P, Lemmes B, Papi T. (Eds.), the Science of Composting. Chapman & Hall, pp. 49-59.

Strauss M, Drescher S, Zurbrügg C, Montangero A (2003). Co-composting of faecal sludge and municipal organic waste. A Literature and state of knowledge review, pp. 17-22.

Suler DJ, Finstein MS (1977). Effect of temperature, aeration and moisture on CO_2 formation in bench-scale, continuously thermophilic composting of solid waste. Appl. Environ. Microbiol. 33:345-350.

Swati P, Vikram R (2011).Heavy metals remediation from urban waste using three species of earthworm (Eudrilus eugeniae, Eisenia fetida and Perionyx excavates). J. Environ. Chem. Ecotoxicol. 3(14):345-356.

Tanveer S, Guangzhi S (2012). A review on nitrogen and organics removal mechanisms in subsurface flow constructed wetlands: Dependency on environmental parameters, operating conditions and supporting media. J. Environ. Manage. 112:429-448.

Tiquia SM, Wan JHC, Tam NFY (2002). Microbial population dynamics and enzyme Activities during composting. Compost Science and Utilization. 10:150-161.

USEPA (1984). Use and Disposal of Wastewater Sludge, E.P.A. 625/1-84-003.

Venglovsky J, Sasakova N, Vargova M, Pacajova Z, Plachai I, Petrovsky M, Harichova D (2005). Evolution of temperature and chemical parameters during composting of pig slurry solid fraction amended with natural zeolite. Bioresour. Technol. 96:181-189.

Wang B (1991). Ecological waste treatment and utilisation systems on low-cost, energy- saving/generating and resources recoverable technology for water pollution control in China. Water Sci. Technol. 24(5):9-19.

Wang MJ (1997). Land application of sewage sludge in China, The science of the total environment. pp. 149-160.

Walker JM (2001). U.S. Environmental Protection Agency Regulations Governing Compost Production and Use. Chapter 18 in: P. Stofella and B. Kahn (eds.). Compost Utilizaton in Horticultural Systems. CRC Press. Boca Raton, Florida.

WHO (1993). Urban Solid Waste Management, Ed. 1985 and 199-1993.

Full Length Research Paper

Geochemical assessment of toxic metals stocking in top-soil within the area of limestone quarry in Gombe of North-eastern Nigeria

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This work presents an assessment of geochemical toxic metal stocking in top-soil within the area of a limestone quarry in Gombe State. Samples of topsoil from the area of a limestone quarry in Gombe (North-eastern Nigeria) were collected to analyse levels of hazardous substances such as of Hg, Fe, Zn, Ni, Mn, Cu, Cr, Cd and Pb. A total of 24 topsoil samples were collected around the radius of 0.5 km from the blasting arena. Additionally, six background samples were also collected from an unexploited reserved area that was ~6 km far from the main sampling location. Two rocks of limestone samples from blasting area were also collected and analysed for heavy metals as a reference. All the samples were processed and extracted with nitrate acid solution and analysed using smart spectrophotometer methods. The results suggested varying organic contents in soil, sand, silt, clay and pH. All these parameters are correlated with those of unexploited samples. Limestone rocks samples displayed a high concentration of Fe and Mn improvement. Toxic metals concentrations (mg/kg) in top-soil with background levels were discovered in Hg, Fe, Mn, Ni, Zn, Cd, Cu, Cr and Pb. Residual phases exhibited the lowest enrichment for most metals possibly, because of high loamy sand content. The situated enrichment advocates influence from mining activities. The results especially geoaccumulation index assessment exhibit below detected limit to 0.20 mg/kg for Pb which is uncontaminated by Lead when compared with the USA threshold limit of particulate metal concentration. Conversely, the other hazardous metals ranged from 1 to 2, indicating the area is contaminated moderately. The exposure to dust containing high silica in quarry workers leads to deterioration of pulmonary function and hence suggesting a need for protective measures of the quarry workers.

Key words: Top-soil, heavy toxic metal, limestone quarry, air pollution.

INTRODUCTION

Limestone quarrying from subsurface deposits is an early technological activity that has been in place since the ancient time (Gbadebo and Bankole 2007). The Romans and Egyptians present early examples of limestone used

in the construction of the large pyramids, monuments and temples. Quarrying activity is still common and 112800 metric tonnes is quarried annually according to Ashaka cement Plc annual report (unpublished). The company has the intention to increase its capacity by the end of 2017.

Quarrying activities also bring many adverse effects to ecosystems (Evans, 1989; NISA, 1997; Madhaven and Sanjay, 2005; Effiong and Gilbert, 2012; Abah et al., 2014) and to the health of human beings (Ugbogu et al., 2009; Morton et al., 2010; Ololade et al., 2015). For example, dust from quarrying affects the growth and flowering of crops because it settles down on the leave's surface and affects photosynthesis. Human exposure may occur directly by ingestion, inhalation, or dermal contact (Evans, 1989; Adewuyi and Osobamiro, 2016).

Silicosis is another dangerous disease in quarry miners that happens due to inhalation of silica containing dust material within 0.1 to 150 µm size range (Evans, 1989; Loska et al., 2003; Hamad et al., 2014). Skin diseases and other respiratory problems have also been reported in quarry workers (Ugbogu et al., 2009; Ololade et al., 2015). For example NISA (1997) and Safrudin et al. (2014) stated that inhaled limestone dust can increase the level of IL-8 serum of limestone mining workers after work. Toxic metals contamination of the locality from acid mine channel occurred from exposure to some minerals like sulphide minerals mostly arsenopyrite and pyrite in water and air of both abandoned and active mine areas. Zuhairi et al. (2009) found that, the concentration of some elements (Zn, Pb, Mn, Fe, Cu and As) in surface soil, water and mine tailings passed regulatory levels. Recently, a quarried limestone in the United State was discovered to contain exposure of hazardous limits of Hg metal (Safrudin et al., 2014; Adewuyi and Osobamiro, 2016).

According to Jibiri and Okorie (2006), because of the increase in demand for limestone as raw material in Nigeria, surface mining methods for limestone extraction have increased in recent times. For example, Gbadebo and Bankole (2007) reported a similar research in Shagamu, North-Western Nigeria, whose results generally show the elevated concentration of all the elements when compared with the USA threshold limit of particulate metal concentration, e.g., Pb ($1.5g\ m^{-1}$); Cd ($0.004 - 0.026\ g\ m^{-3}$), in the surrounding air. These elements in the airborne dust may pose a great threat to the health of plants, animals and residents in and around the factory and also to workers and visitors to the factory (Gbadebo and Bankole, 2007; Ajala et al., 2014). Gamma radiation and radionuclides where also detected in selected quarries of limestone in Ibadan, Nigeria (Evans, 1989). In Nigeria, there is a dearth of research

information on the effect of quarrying limestone and some mineral explorations on the environment in regarding of toxic metals contaminations. There is serious need to carry out research on baseline levels of concentration of heavy metals in the quarry environment. With this, a database on pollution status would be produced of the heavy metals around the area of mining and used as reference material for research in future and comparison. Therefore, this work aims to quantify the concentration levels of hazardous substances such as Mercury (Hg), Iron (Fe), Zinc (Zn), Nickel (Ni), Manganese (Mn), Copper (Cu), Chromium (Cr), Cadmium (Cd) and Lead (Pb) in top-soil of a limestone quarry in Gombe, North-Eastern Nigeria.

METHODOLOGY

Study area

The studied stratigraphic succession in the study area (Ashaka area) begins with the Bima Sandstone, the Bima Sandstone is categorised in both the Dumbulwa-Bage High and Wuyo-Kaltungo High. It also occurs on the floor of the research area (Ashaka Cement Quarry section) and is divided from the overlying Pindiga Formation (Kanawa Member) by a thin ferruginous crust without the transitional Yolde Formation. The Yolde Formation is almost absent in the research area. According to Zarborski et al. (1998), the Yolde Formation wedges out in the western part of the Dumbulwa-Bage High where syn sedimentary uplift also resulted in the attenuation of the "Middle and Upper Bima Sandstones"; Carter et al. (1963) referred to the equivalents of the Pindiga Formation to the Gongila Formation and Fika Shales. Zaborski et al. (1998) subdivided the Pindiga Formation into Kanawa - Dumbulwa - Fika members in the area. Like the Yolde Formation, the overlying Kanawa Member has been eroded over the large part of the Ashaka area.

Ashaka cement limestone quarry was chosen as the research area. This is because it is the only active limestone quarry in the region of North-eastern Nigeria (Figure 1). The research area is located on 10° 56′ 10″N and 11° 27′ 20″ E. The stratigraphy and geologic setting of the research area which is part of the Benue trough evolved during the opening of the Atlantic which separated Africa and South America in the carboniferous as a result of continental rifting (Walkey and Black 1934). The Gongola Basin along with the Yola Basin forms the upper Benue trough, trending South West to North East for about 800 km and is about 150 km wide containing up to 6000 m of Cretaceous to Tertiary sediments that have been uplifted, faulted and folded.

Collection of samples and their chemical analysis

A total of 24 samples were systematically collected from the upper 0 to 10 cm depth within 0.5 km radius from the zone of blasting as shown in Figure 2. Another 4 top-soil samples were also collected around the quarry pit area and stand as samples at zero meters. Another 4 samples of the topsoil each were collected also within the radii of 100, 200, 300, 400 and 500 m distance from the blasting area as shown in Figure 2. All the above mentioned samples added

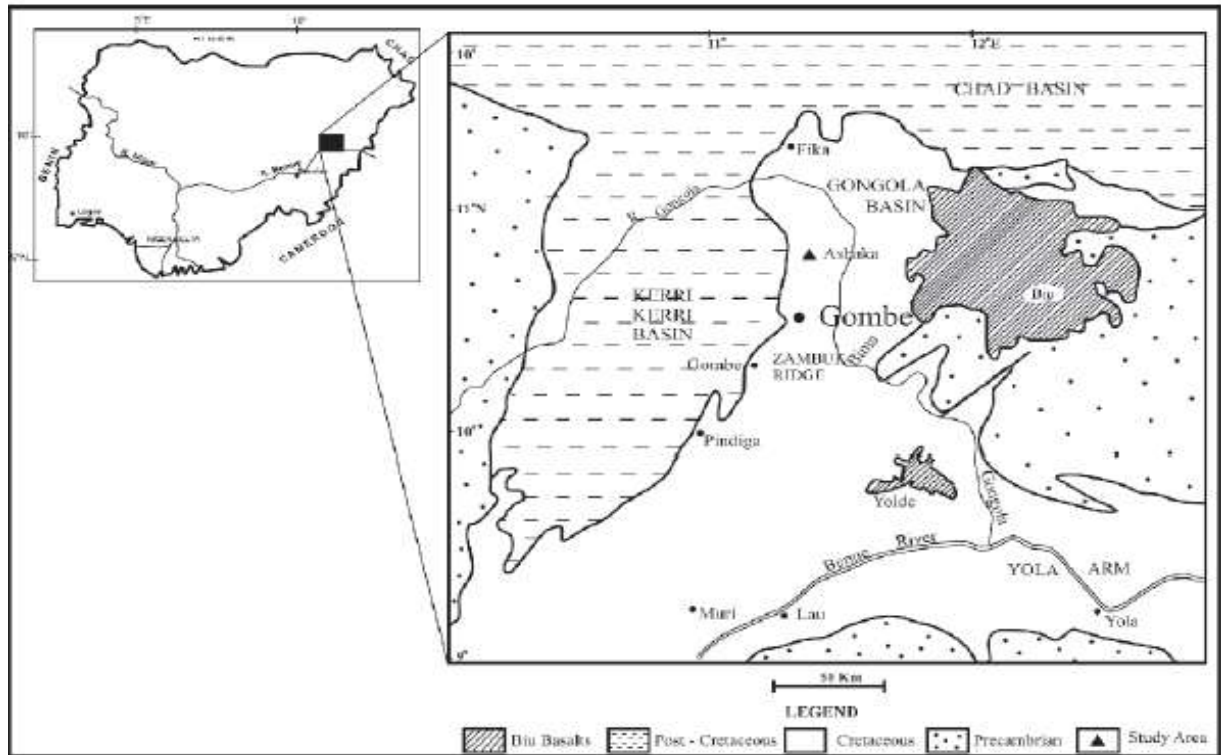*Corresponding author. E-mail: attaayya@gmail.com. Tel: +2347032161990.

Figure 1. Map of Nigeria showing the geological map of the study area location (Ashaka, Gombe state, North-eastern Nigeria).
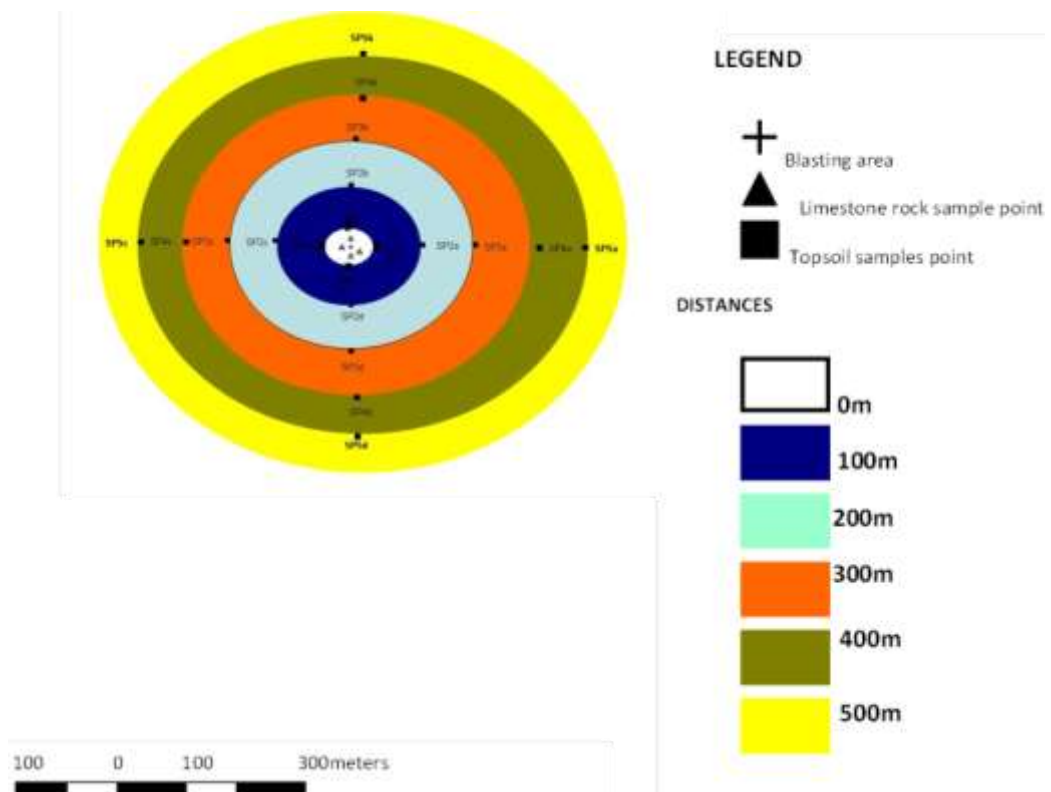

Figure 2. Top-soil sampling points at study area: Samples were collected up to half kilometre from blasting point at 100 m interval.

Table 1. Average concentration (mg/kg) of heavy metals in top-soil sample around the area of a limestone quarry pit.

Sample Code	Distance from quarry(meter)	Hg	Fe	Mn	Ni	Zn	Cd	Cu	Cr	Pb
SP 1	0	0.05 ± 0.02	1.01 ± 0.02	2.93 ± 0.03	0.95 ± 0.05	0.13 ± 0.01	0.10 ± 0.01	0.77 ± 0.02	0.09 ± 0.01	0.2 ±0.01
SP 2	100	0.09 ± 0.03	1.65 ± 0.01	1.19 ± 0.01	1.23 ± 0.01	0.07 ± 0.01	0.13 ± 0.01	0.77 ± 0.01	0.05 ± 0.00	nd
SP 3	200	0.16 ± 0.03	1.32 ± 0.02	1.00 ± 0.02	0.10 ± 0.01	0.18 ± 0.02	0.25 ± 0.01	0.90 ± 0.01	0.12 ± 0.01	nd
SP 4	300	0.04 ± 0.03	1.45 ± 0.02	0.66 ± 0.02	0.29 ± 0.02	0.06 ± 0.01	0.02 ± 0.01	0.92 ± 0.02	0.11 ± 0.01	nd
SP 5	400	0.07 ± 0.02	1.31 ± 0.02	0.40 ± 0.02	0.04 ± 0.01	0.12 ± 0.02	0.04 ± 0.01	0.56 ± 0.02	0.14 ± 0.01	nd
SP 6	500	0.17 ± 0.14	1.33 ± 0.01	0.53 ± 0.38	0.05 ± 0.01	0.09 ± 0.01	0.02 ± 0.00	1.03 ± 0.02	0.13 ± 0.01	nd
Background	Unexploited	0.02 ± 0.01	1.34 ± 0.02	0.46 ± 0.01	0.65 ± 0.02	0.04 ± 0.02	0.28 ± 0.01	0.91 ± 0.01	0.24 ± 0.01	nd
LR 1	-	0.15 ± 0.04	1.52 ± 0.02	0.60 ± 0.01	1.12 ± 0.03	0.04 ± 0.01	0.31 ± 0.02	0.74 ± 0.01	0.17 ± 0.01	nd
LR 2	-	0.16 ± 0.02	1.34 ± 0.01	1.90 ± 0.02	0.38 ± 0.02	0.02 ± 0.01	0.00 ± 0.00	0.72 ± 0.02	0.18 ± 0.01	nd

nd: not detected.

to a total of 32 samples. At each sampling points, samples were picked randomly and added up to produce composite samples. All the topsoil samples that were collected were labelled as SP_1 (0 m), SP_2 (100 m), SP_3 (200 m), SP_4 (300 m), SP_5 (400 m) and SP_6 (500 m). Four background samples from the unexploited area were also collected about 6 km from research area.

Four limestone samples were also collected from different sections of the quarry. There are two types of limestone deposits in the quarry based on their colour; brownish and greyish. A clean plastic trowel was used to spoon the samples and immediately they were preserved in clean polyethylene bags and conveyed to the geochemical laboratory for immediate pre-treatment and chemical analysis. Samples were safely conveyed to the geochemical laboratory and arranged on a pre-cleaned surface. During the sample preparations and analysis, sampling implements and other work surface were always thoroughly cleaned between samples. Soil samples were put in oven at room temperature for 24 h to air-dry, and grinded using agate mortar. All the samples for heavy metals analysis were sieved using hand sieve with 0.5 mm mesh size.

Geochemical analysis of heavy metal and soil properties determination

pH of soil samples was analysed by using the potentiometric method. The method involved taking the pH of 1:2.5 (soil: deionised water) extracts using a calibrated pH meter. Organic content was analyzed in the soil samples using Walkley and Black wet oxidation method Walkey and Black (1934). The heavy metals were extracted by weighing 5.0 g of 2 mole of nitrate acid (HNO_3). The solution was covered in a conical flask and transferred to a hot plate at 30°C for 2 h. Agitation of all the samples solution after every 20 min was carried out to make sure all soil particles were exposed to complete leaching. All the samples were cooled for 2 h and Whatman No 1 filter papers were used for filtration, extracts from all the soil solution samples were kept in plastic bottles in the fridge.

For the determination of heavy metal, spectrophotometer (American model 2000) was used. The operation of smart spectro was controlled by a micro-processor; the micro-processor is programmed with menu driven software. Samples containing all reagents except the soil samples (blank samples) were carried through all methods, analyzed and subtracted from the sample, for the purpose reagent confirmation.

Risk determination

Geoaccumulation index (I_{geo}) was applied to assess the pollution level of heavy metals of the topsoil within the environment of the research area. Muller (1969) used the I_{geo} as a tool to assess the level of toxic metal of the soil with regards to background concentration levels. The I_{geo} is mathematically expressed as:

$$I_{geo} = \log_2 [C_n/1.5 \times B_n] \qquad (1)$$

Where C_n and B_n are the average concentrations of heavy metals in the on-site soil and background location respectively, while 1.5 is an empirical coefficient.

RESULTS AND DISCUSSION

Assessment of toxic metals

Table 1 presents the average concentrations of Hg, Fe, Mn, Ni, Zn, Cd, Cu, Cr and Pb in the top-soil of the Ashaka cement quarry samples. The concentration level of the various heavy metals exhibits a little range of alteration with fickle pattern in the order: Fe > Mn > Cu > Ni > Cd > Cr > Zn > Hg > Pb (Figure 3). Therefore, Fe is the most dominated toxic metal in the study area while Pb is the least represented. The major effect of Fe from a health perspective of the quarry worker is on pulmonary function (Madhaven and
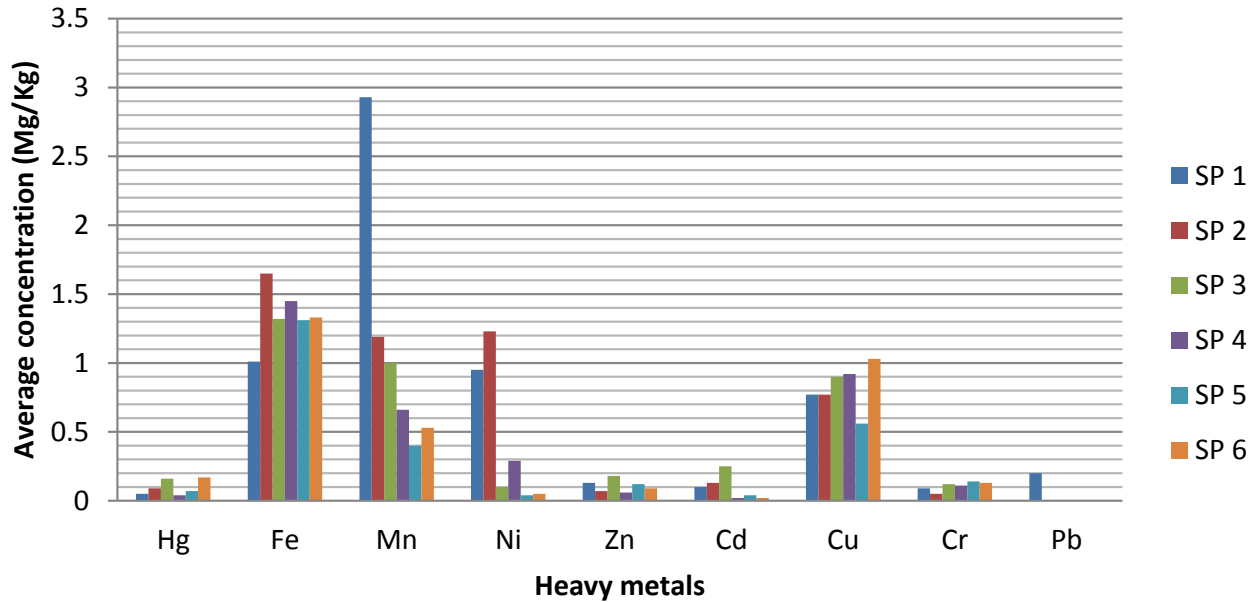
Figure 3. Average concentration of heavy metal in the topsoil samples of the study area.
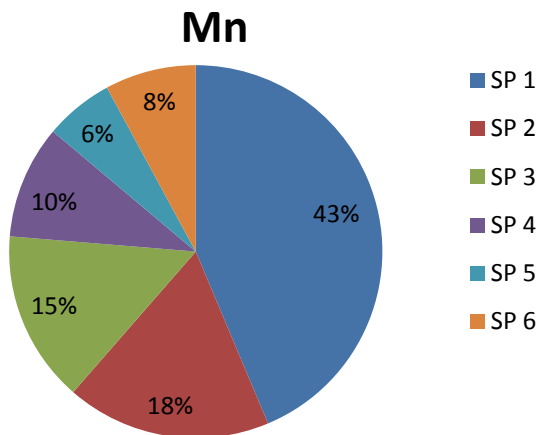
Figure 4. Concentrations level of manganese (Mn) in the study area topsoil samples.

Samjay, 2015). There is no specific pattern in variation for each heavy metal with an increase in distance from quarry blasting area as except for Mn and Zn as shown in Figure 3. This evidenced that the distribution of heavy metals from the origin could have been bulk by a wind which dispersed quarry dust containing heavy toxic metals in all corners at various time, space and magnitude.

Most of the samples between 0 and 200 m seem to display greater concentrations for most metals than samples from 300 to 500 m; this is because of the excavated overburden deposited in the locations and their proximity to the blasting area. Examination of the quarry limestone rocks (LR), which are classified as

Brownish and Greyish limestone chemically, displayed the conspicuously greater concentration of Fe as compared to other metals analyzed. The Fe concentration in top-soil samples analyzed up to 500 m (Table 1) away from the blasting area displayed a level almost similar to that of the unexploited area (background level), probably because of intense exposure of the limestone outcrop due to the erosion of the overburden in the area. Mn conspicuously showed high concentration at 0, 100 and 500 m from the blasting area, the high concentration of Mn at 500 m could be because of the excavated soil from the quarry pit which was dumped at 500 m distance, thus increasing the amount of soil containing Mn, this probably caused the high concentration of Mn compared to close sampling point at 400 m (Figure 4). It is believed that the origin of Mn in these three sampling locations is a non-point source. The soil properties, especially the sandy loam of the soil and organic content of topsoil samples in this research promote leaching, but pH values for all soil suggest that most heavy toxic metals might not be free in solution (Muller, 1969).

Properties of the top-soil

The outcome of the result analysis of soil properties within the vicinity of an Ashaka limestone quarry in North-eastern Nigeria is presented in Table 2. The pH ranged from 5.28 to 6.03 for the top-soil samples within the corners of half a kilometre away from blasting pit. The average pH of unexploited area (background) soil was 5.69 ± 0.62, while that of the quarried limestone

Table 2. Soil properties of top-soil samples around the area of limestone quarry pit.

Sample code	Percentage				pH in H_2O	EC
	Sand	Clay	Silt	Organic content	1:2.5	dscm^{-1}
SP 1	57.10 ± 4.5	10.40 ± 7.9	32.50 ± 5.1	0.72 ± 0.22	5.81 ± 0.70	0.69 ± 0.18
SP 2	56.87 ± 10.3	9.87 ± 5.2	32 .49 ± 3.2	0.60 ± 0 .14	5.70 ± 0.38	0.75 ± 0.02
SP 3	59. 60 ± 19.5	7.90 ± 3.50	32.50 ± 6.4	0.49 ± 0. 25	5.63 ± 0.52	1.06 ± 0.05
SP 4	64.60 ± 1.78	5.40 ± 2.5	30. 00 ± 23.1	0.64 ± 0.19	6.03 ± 0.82	0.87 ± 0.17
SP 5	57. 10 ± 23.2	10.40 ± 6.5	32. 50 ± 3.9	0.60 ± 0.30	5.55 ± 1.0	0.55 ± 0.03
SP 6	59.60 ± 15.1	12.90 ± 9.50	27.50 ± 23.1	0.51 ± 0.02	5.28 ± 0.44	0.71 ± 0.23
Background	69. 60 ± 5.3	12.90 ± 7.23	17.50 ± 5.5	0.43 ± 0.44	5.69 ± 0.62	0.36 ± 0.11
LR 1	N/A	N/A	N/A	N/A	6. 80 ± 0.49	N/A
LR 2	N/A	N/A	N/A	N/A	6. 64 ± 0.52	N/A

N/A: No answer; LR, limestone rock.

displayed as LR 1 and 2 in Table 2, was 6. 80 ± 0.49 for the brownish limestone and 6. 64 ± 0.52 for the greyish limestone, respectively. The pH value slightly reduced from 0 to 300 m while there is significant increase at 400 m probably because of dumping of top soils and shales associated with limestone bed by the quarry excavators at that distance. pH results of the soil samples were similar to that of the limestone rocks, where the pH of all the soil sample with the exception of sample at 400 m were more moderately acidic. This shows the influence from limestone rocks which are slightly acidic in nature. The similarity of pH values of limestone quarry's topsoil samples with pH value of background sample which is 6 km from the study are because of too much exposure of limestone rocks on the surface of the area which the leaching of some metals from the topsoil (background) affected.

Organic content of topsoil samples are presented in Table 2, which show a range from 0.49 to 0.72% compared with the average of 0.43 ± 0.44% for background samples. Determination of organic matter helps to estimate the nitrogen which will be released by bacteria activity for the next season depending on the climatic conditions, soil aeration, pH, type of organic material, and other factors. Soil organic matter is usually rich in humic materials with multiple functional groups. These functional groups have the ability to complex metals thereby absorbing them in the soil (Evans, 1989; Jibiri and Okorie, 2006; Effiong and Gilbert, 2012); therefore, the greater the soil organic content, the greater the ability of that soil to absorb or retain metals within it. The organic content in sandy loam soil samples were found to be absolutely low as presented in Table 2.

Particle size analysis of all top-soil samples showed 56.87 - 59.60, 27.50 - 32.50 and 5.40 - 10.40% for sand, silt and clay, respectively. All the samples compared with the unexploited background samples confirmed that they were from the same geographical region; these samples also displayed no or little interference from the activities of exploration.

Risk assessment

Table 3 shows the risk assessment based on geoaccumulation index (I_{geo}) rating. Here a factor of 1.5 is multiplied in each of the background samples in order to find the natural fluctuations of a given heavy metal in small anthropogenic influences and as well as the environment (ENS, 2007; Abah et al., 2014; Hamad et al., 2014). Rating of I_{geo} showed for all the top-soil from Ashaka limestone quarry ranged from   uncontaminated (< 0) to moderately contaminated (1 - 2). All the toxic metals displayed a significant enrichment from the limestone quarrying activities except that Pb input in the soil is related to the parent material that formed the soil or small anthropogenic non-point sources or other natural sources. Morton et al. (2010) reported that a slightly low spatial distribution of Ni in topsoil within an industrial area in Mexico has been studied to have contributed to the input from parental rocks in the area.

There is no similar research in this study area, but Effiong and Gilbert (2012) conducted similar work on risk assessment of topsoil samples at Ratcon limestone quarry in Oluyole, South-western Nigeria. The I_{geo} of these samples were compared with those estimated in our work this (Table 4). The I_{geo} rating results displayed that all samples of topsoil of Ratcon limestone quarry of Mn are <0, implying that the topsoil samples were clearly uncontaminated by Mn. However, I_{geo} of Mn is greater than zero for all the samples compared with Ratcon limestone quarry (Figure 5); suggesting moderate contamination by Mn of slightly high concentration level from 0 m while reducing as distance increases from the blasting point.

Criteria for soil quality

The average level for the soil sample heavy metals studied was within the limits provided by some countries and the European Union, except for Pb which is not

Table 3. Geoaccumulation index (I_{geo}) of heavy metals in top-soil samples around a limestone quarry.

Sample code	Hg	Fe	Mn	Ni	Zn	Cd	Cu	Cr	Pb
SP 1	0.50	0.15	1.28	0.29	0.65	0.07	0.17	0.08	-0.20
SP 2	0.90	0.25	0.52	0.38	0.35	0.09	0.17	0.04	Nd
SP 3	1.61	0.10	0.44	0.03	0.90	0.18	0.20	0.10	Nd
SP 4	0.40	0.22	0.29	0.09	0.30	0.01	0.20	0.09	Nd
SP 5	0.70	0.20	0.17	0.01	0.60	0.03	0.12	0.11	Nd
SP 6	1.71	0.20	0.23	0.02	0.14	0.01	0.23	0.11	Nd

Nd: Not detected.

Table 4. Comparative research findings of geoaccumulation index (I_{geo}) of Heavy metals in topsoil samples between Ashaka (NE, Nigeria) and Oluyole (SW, Nigeria) limestone quarry.

Present study										
Sample code	Hg	Fe	Mn	Ni	Zn	Cd	Cu	Cr	Pb	Co
SP 1	0.50	0.15	1.28	0.29	0.65	0.07	0.17	0.08	-0.20	-
SP 2	0.90	0.25	0.52	0.38	0.35	0.09	0.17	0.04	Nd	-
SP 3	1.61	0.10	0.44	0.03	0.90	0.18	0.20	0.10	Nd	-
SP 4	0.40	0.22	0.29	0.09	0.30	0.01	0.20	0.09	Nd	-
SP 5	0.70	0.20	0.17	0.01	0.60	0.03	0.12	0.11	Nd	-
SP 6	1.71	0.20	0.23	0.02	0.14	0.01	0.23	0.11	Nd	-
Similar research findings (Effiong and Gilbert, 2012)										
SL 1	-	0.97	-0.43	0.57	0.20	-0.64	1.31	1.08	0.31	0.50
SL 2	-	1.10	-1.89	0.26	0.16	-0.40	0.41	0.16	-0.42	-0.76
SL 3	-	1.38	-0.79	0.93	0.76	-1.32	3.28	1.06	-0.22	-0.36
SL 4	-	-0.01	-0.54	-0.54	-0.03	-1.56	1.12	-0.04	-0.22	-0.29
SL 5	-	-0.06	-1.09	-0.43	0.10	1.24	0.73	-0.25	-0.40	-0.89
SL 6	-	0.23	-1.09	0.20	0.01	1.94	0.19	0.56	0.45	-0.54

detected. The concentration of metals showed no potential toxicity associated with the mining of limestone in Ashaka quarry. However, other attributes such as more acidity, weathering of the rock, and pH, showed the possibility of the high infiltration potential of these toxic metals from the surface soil into subsurface soil and gradually into groundwater. The slightly moderate contamination of top-soil represented by I_{geo} rating as displayed in Table 3 is a direct confirmation that the blasting and other exploration activities promote some level of heavy metals onto the soil. These findings clearly suggest that continuous monitoring of the top and sub-soils is important to assess level of toxic metals.

CONCLUSIONS

The concentration of Fe, Zn, Ni, Mn, Hg, Cu, Cr, Cd and Pb in top-soil samples within the area of
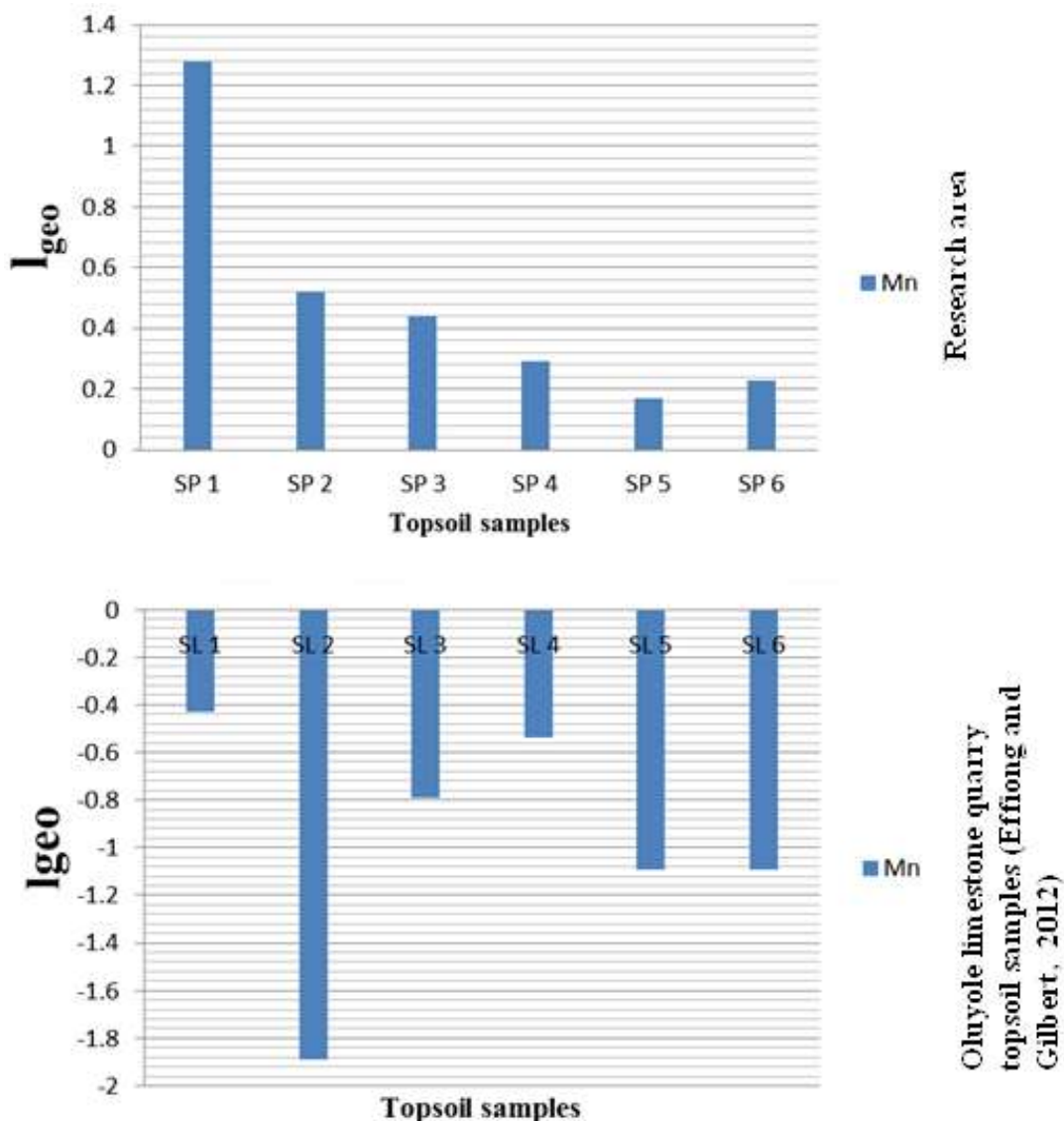
Figure 5. Comparative research findings for geoaccumulation index (I_{geo}) of Mn in topsoil samples between Ashaka (NE, Nigeria) and Oluyole (SW, Nigeria) limestone quarry in their topsoil samples.

Ashaka limestone quarry was analyzed. The acidity (pH) of the soil heavy metals falls between the range of moderately acidic. Properties of the organic content of soil and size of the particles freight support leaching of heavy metals from the top-soil. The organic content of Ashaka soils were found to be in low concentration. Pollution levels for all heavy metals according to I_{geo} rating ranged from uncontaminated to moderately contaminate. It is believed that Pb is related with parent material of topsoil as confirmed by I_{geo} for samples with a rating of <0 from 100 to 500 m indicating practically uncontaminated soil. All the heavy metals were found to be in line with the regulatory ranges, except the Pb that had the level far below the detecting limits when compared with other countries. Constant control of dust

and study of the limestone quarrying operations are significant to quantify the toxic level of hazardous substance, which could promote threat with active piling up of quarry dust on the soil and leaching by acid rain.

Conflict of Interests

The authors have not declared any conflict of interests.

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REFERENCES

Adewuyi GO, Osobamiro MT (2016). Chemical Speciation and Potential Mobility of Some Toxic Metals in Tropical Agricultural Soil. Res. J. Environ. Toxicol. 10:159-165.

Ajala LO, Onwukeme VI, Mgbemena MN (2014). Speciation of some trace metals in floodplain soil of Eke-Mgbom, Afikpo, Nigeria. Am. Chem. Sci. J. 4:963-974.

Carter JD, Barber W, Taite EA, Jones GP (1963). The geology of parts of Adamawa, Bauchi and Bornu provinces in Northern Nigeria. Bull. Geol. Surv. Niger. 30:99

Effiong UE, Gilbert UA (2012). Assessment of toxic heavy metal loading in topsoil samples within the vicinity of a limestone quarry in South Western Nigeria. Afr. J. Environ. Sci. Technol. 6(8):322-330.

Environment News Service (ENS) (2007). Mercury pollution discovered at Florida quarry, Published, 28-11-2007, TALLAHASSEE, Florida.

Evans LJ (1989). Chemistry of metal retention by soils. Environ. Sci. Technol. 23(9):1046-1056.

Gbadebo AM, Bankole OD (2007). Analysis of Potentially Toxic Metals in Airborne Cement Dust Around Sagamu, Southwestern Nigeria. J. Appl. Sci. 7:35-40.

Hamad SH, Schauer JJ, Shafer MM, Al-Rheem EA, Skaar PS, Heo J, Tejedor-Tejedor I (2014). Risk assessment of total and bioavailable potentially toxic elements (PTEs) in urban soils of Baghdad-Iraq. Sci. Total Environ. 494-495:39-48.

Abah J, Mashebe P, Njefu SAO (2014). Survey of the levels of some heavy metals in roadside dusts along Katima Mulilo Urban road construction, Namibia. Am. J. Environ. Protect. 3(1):19-27.

Jibiri NN, Okorie RO (2006). Radionuclide concentrations and gamma radiation dose rate levels in selected granite quarry sites in Ibadan. Nig. J. Sci. 40:1-2.

Loska K, Wiechuła D, Barska B, Cebula E, Chojnecka A (2003). Assessment of arsenic enrichment of cultivated soils in southern Poland. Pol. J. Environ. Stud. 12(2):187-192.

Madhaven P, Sanjay R, Budhpura (2005). Ground Zero'Sandstone quarrying in India, Study commissioned by India committee of the Netherlands, Netherlands. P 32.

Morton-Bermea O, Herna´ndez-A´lvarez E, Lozano R, Guzma´nMorales J, Martı´nez G (2010). Spatial distribution of heavy metals in top soils around the industrial facilities of Cromatos de me´xico, Tultitlan Mexico. Bull. Environ. Contamin. Toxicol. 85(5):520-524.

Muller G (1969). Index of geoaccumulation in sediments of the Rhine River. Geology J. 2:108-118.

National Industrial Sand Association NISA, (1997). Respiratory Health Effects of Crystalline Silica.

Ololade IA, Oloye FF, Adamu H, Oluwole OD, Oluyede OP, Folasade A, Ololade OO (2015). Distribution and potential mobility assessment of some hazardous metals in soil of mechanic workshops: A case study of Akoko Land in Nigeria. Int. Res. J. Pure Appl. Chem. 7:54-68.

Safrudin T, Moh RN, Inne AG, James S, Soedjajadi K, Ketut IS, Ririh Y, Mukono, Azizah R (2014). Effect inhaling of limestone dust exposure on increased level of IL-8 serum and pulmonary function decline to workers of limestone mining industry. Int. Refereed J. Eng. Sci.. 3(8):66-72.

Ugbogu OC, Ohakwe J, Foltescu V (2009). Occurrence of respiratory and skin problems among manual stone-quarrying workers, Mera. Afr. J. Respirat. Med. pp. 23-26.

Walkey A, Black IA (1934). An examination of the digestion method for the determination of soil organic matter and a proposed chromic acid titratio. Soil Sci. 37:29-38.

Wenzel WW (2005). Environmental factors affecting metal mobility, Abstracts of Workshop themed: Metal fluxes and stresses in terrestrial ecosystems held from October 15th – 20th, p.108. (Ed: Swiss Federal Institute for Forest, Snow and Landscape Resources, WSL, Birmensdorf), Switzerland.

Wright JB (1968). South Atlantic continental drift and Benue Trough. Tectonophys. 6(4):301-310.

Zaborski PM, Ugodulunwa F, Idornige A, Nnabo P, Ibe K (1998). Stratigraphy and Structure of the Cretaceous Gongola Basin, north – east Nigeria. Bulletin des Centre de Recherché Exploration – Production Elf-Aquitaine. 21:153-186.

Zuhairi W, Yaacob W, Syuhadah N, Pauzi M, Mutalib HA (2009). Acid mine drainage and heavy metals contamination at abandoned and active mine sites in Pahang. Geol. Soc. Malays. Bull. 55:15-20.

Full Length Research Paper

Comparison of community managed projects and conventional approaches in rural water supply of Ethiopia

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This study aimed to compare Community Managed Projects (CMP) approach with the conventional approaches (Non-CMP) in the case of Ethiopia. The data collection methods include a household survey (n=1806), community representative interviews (n=49), focus group discussions with district water experts (n=48) and observations of water systems (n=49). The data were collected from seven districts of two regions of Ethiopia. The study shows that CMP have a better platform to involve the community than non-CMP. In terms of reducing distances to water points, all approaches succeeded. However, the intended amount of water supplied is not achieved in all the cases: only 25% of CMP users and 18% of non-CMP users are able to get water according to the national standard, 15 L per capita per day. Fee collection in the approaches has a high disparity in favour of CMP. To keep long-lasting services, three requirements need to be particularly fulfilled: quantity, quality and accessibility.

Key words: Long-lasting services, rural water supply, Community Managed Projects (CMP), conventional, Ethiopia.

INTRODUCTION

The past few decades have significantly intensified the efforts to improve the coverage and access to potable water supply and sanitation worldwide. Yet, the situation has not been improved substantially in the Sub-Saharan countries. The access to water supply in the region only increased from 48% in 1990 to 64% in 2012 (WHO and UNICEF, 2014). Several factors such as population growth, climate change (Howard et at., 2010), high rate of

non-functional schemes (Harvey, 2008) and the lack of cost recovery systems or their ineffectiveness (Harvey, 2007) have contributed to the insufficient coverage of water supply, sanitation and hygiene (WASH) in the region.

Yet, national governments or donors alone cannot address the water demands of the alarmingly increasing population and the multi-faceted challenges of the sector in developing countries. Therefore, involving the user community is vital for long-lasting services. The participation of the community should be included in the planning and implementation the systems, contribution and utilization of investment funds, as well as operation and maintenance of the systems. Empowering of the users is essential since it is difficult to obtain adequate attention to repair and upgrade failed systems in countries with scarce resources. Thus, participating users from the beginning of a project is crucial in sustaining water service delivery (Rautanen et al., 2014). In the sustainable services, delivery quantity, good quality and a reasonable distance to water points are key monitoring indicators (UN, 2003). Moreover, the existence of the services mentioned above will boost the involvement of the users in the system management.

In addition to low success in improving coverage, non-functionality of systems has posed additional challenges in the sector. Many studies estimated that non-functionality of rural water supply schemes could reach 60% in sub-Saharan Africa (Harvey, 2008; Jones, 2011; Taylor, 2009). The causes of the service breakdowns could be under the technical, social, environmental or economic categories (Brunson et al., 2013). However, the technical and economic aspects usually override to shadow the others. For instance, financing is assumed to solve the problem of water supply. Of course, with money, a physical asset can be implemented; however, it will not bring a long-lasting result without the community involvement. Users are immediate stakeholders of a project and they could facilitate the achievement of functional schemes by tackling system-retarding factors. The customs of a community determine the process of change in institutions (North, 1990), in combating non-functionality. Contextualizing institutions with the local situation and involving users can increase credibility and the chance of institutional changes. Moreover, during implementation of new systems, paving ways for post-construction management is prominent in reducing non-functionality. Thus, to address water supply, it is crucial to deal with both implementation and post-implementation management.

In Ethiopia, four implementation approaches have been used in the rural water supply and sanitation sector. The first is the Woreda (District) Managed Project (WMP) approach that is administered and managed by the district water office. The second is the Non-Governmental Organization Managed project (NGO-MP) approach that

has similar nature with WMP in most cases – centralized administration. The third is the Community Managed Projects (CMP) approach, which decentralizes power to the community level; the user community controls the financials as well as project management. The last one is the self-supply approach, which is implemented by individual households or a group of a few households with only technical support from external actors (WIF, 2013).

WMP and NGO-MP projects are independent water supply implementation approaches owned by Government and Partner organizations, respectively. CMP is a bilateral project that is operated by the government of Ethiopia with technical assistance from the government of Finland. In the project, both countries have contributed cash for investment and capacity building.

WMP and NGO-MP have been practiced for long since the establishment of water sector development in the country and in this paper they referred to it as conventional approaches and represented by Non-CMP in this paper. However, CMP have evolved from Community Development Fund (CDF) in 2011 to finance projects in more decentralized ways (Behailu et al., 2015). Therefore, this paper aimed to compare CMP and non-CMP (WMP, NGO-MP) approaches in the context of long-lasting WASH services in Ethiopia. The self-supply approach is not included in this study as it is still in its initial stages.

The background of the research area

This study was conducted in Ethiopia, the second most populous country in Africa. The country has nine ethnically demarcated regions (Figure 1) and two administrative cities. According to the World Population Review (2016) estimate, the population of the country is approximately 99 million, out of which 84% live in rural areas (CSA, 2010). The study was carried out in two northwestern regions of Ethiopia; namely, Amhara and Benishangul-Gumuz (Figure 1), with the populations of 17.22 million (rural 15.11 million) and 0.78 million (rural 0.68 million), respectively (CSA, 2010). In the Amhara region, 36 districts were using the CMP financial mechanism in June 2012 (in 2013, the number increased to 40 districts in Amhara, and in 2014 to 72 districts in the country). The population of the districts varies from 35,000 to 2,250,000 in the study area.

The number of people served under a water supply system depends on the nature of sources and technologies used. For instance, deep wells could support more people than spring development. Moreover, hand-dug wells and shallow wells with hand pump are able to serve fewer residences than any other sources. Since the majority of water systems in the rural Ethiopia are hand-dug wells and spring developments, the
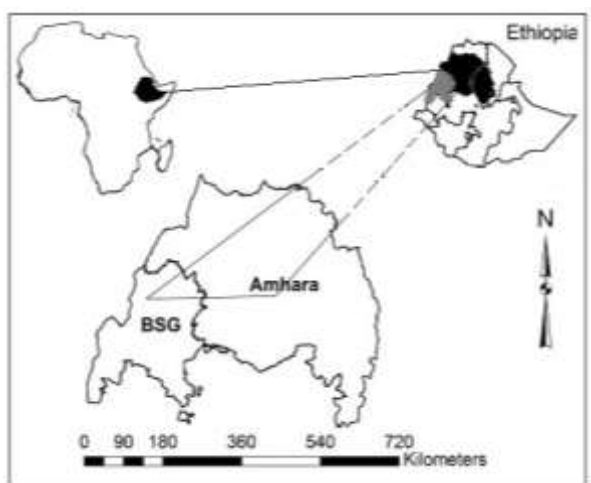
Figure 1. The map of the study area (drawn by the first author).

average population over a water point could reach 250 people (the equivalence of 50 households).

National standards

World Health Organization (WHO) has set minimum standards for per capita water supply (20 L) and distance to travel to collect water (1 km) (WHO and UNICEF, 2000). The government of Ethiopia has adopted a gradual improvement policy to reach these levels. Therefore, for the period from 2010 to 2015, per capita demand in rural areas was designated to be 15 lpcd (liters per capita per day and in a radius of 1.5 km (UAP, 2011). Moreover, a draft of the second growth and transformation plan (GTP2) has proposed 25 lpcd in a radius of 1.0 km for rural residences (GTP, 2015). In this paper, the former national standard is considered for analysis, since the research was carried out before the launch of the new plan, GTP-2.

Committee

Improved water sources are managed and operated by communities' representatives called WASHCO (short for WASH Committee). It consists of five to seven members depending on the approach. In this committee, a 50% involvement of women is mandatory as they are the ones who mainly suffer from the water and sanitation problems. In CMP, three out of five WASHCO members must be women. However, the composition and number of WASHCO members depend on national and regional interest. The role and responsibility of the committee do not vary between CMP and non-CMP except for the

arrangements of training and degree of empowerment.

METHODOLOGY

This study was conducted with both qualitative and quantitative approaches. Despite the difficulty in integrating the results of qualitative and qualitative data in mixed method, it is more practical to investigate a pragmatic nature of a social development, both from the perspective of service providers and producers (Bryman, 2006; Creswell, 2013). Thus, this approach is termed as a pragmatic approach and it is vital in studying the nature of different water and sanitation implementations and perceptions of the receiving community on the output (Bryman, 2006).

Methods employed in data collection were household surveys, focus group discussions and observations. The household survey was designed to collect information from the users. In the survey, users were asked about family size versus daily water use, distance travelled, queuing time, water quality perceptions, users' role in the implementation of the water scheme, water fee payment, the reliability of sources, feelings about the water schemes, and the trust that users have toward WASHCO members and their performance. The focus group discussions were done with water committees and district experts. Moreover, the focus of site observation is to synchronize the findings obtained by the other two methods with practical practices, accordingly the strategy of site observations was selected from the selected water schemes.

Data was collected from two regions of Ethiopia: namely Amhara and Benishagul-Gumuz regions. The reason for selecting these regions was the prior implementation of Community Managed Projects Approach (CMP) well in advance to the data collection period of this study. Data collection from Amhara region was done between December 2013 and June 2014, and from Benishangul-Gumuz between November and December 2012. Sampling process cascaded down from districts to water supply schemes and then to households to implement the above mentioned research methods. Thus, it has three stage sampling in agreement with the multilevel mixed methods sampling described by Teddlie and Yu (2007) (Table 1).

In the first stage of the sampling, districts were selected. Criteria of the selection were the presence of projects implemented by different approaches of CMP and Non-CMP. The second stage of sampling was selecting clusters of households based on the water supply schemes. Collected data can be used as individual household behavior and investigate perception of the users on implemented schemes (as a group of users), sticking to the scheme based clustering was considered appropriate in this study (Deaton, 1997). The cluster was also made for CMP and Non-CMP schemes to assist the comparison of the approaches.

The third stage of household sampling was also in agreement with Deaton (1997), selected with simple random technique from a fresh list prepared by water committee of the respective schemes. The reason for making the fresh list was the absence of organized record of users at each water supply scheme. In this sampling, at least a third of the households from a water supply scheme were surveyed with a repeated visit to missed households in the previous visit.

Moreover, the data collection process had two categories. The first one was conducting surveys of the selected households by the trained enumerators and the second was group discussions with district water offices staff, water committee and site observation by the first author. The data collection was made in district bases and all the above data collection processes were done in parallel. The first author was in the same district where data collection was active to facilitate the household survey and follow up the process while

Table 1. Sampled water schemes and households.

District	Number of water schemes	Surveyed households (CMP)	Surveyed households (Non-CMP)	Total households
First stage	Second stage		Third stage	
Dega Damot	20	102	52	154
Guangua	27	256	116	372
Fogera	32	212	12	224
Misrak estie	27	88	128	216
Dibate	25	142	61	203
Mandura	17	108	190	298
Pawi	31	312	27	339
Total	179	1209	597	1806

doing the side discussions and visits.

In addition to the household survey, focus group discussions were conducted with water committee (n=49) and district water offices of staff members (n=48). Moreover, field observations were made for water supply schemes where the focus group discussions were conducted (n=49). In the data collection, 179 water schemes were addressed. The schemes were implemented by different organizations such as Non-CMP (including Catholic Church, CISP Ethiopia, Comunita' Volontari Per II Mondo (CVM), Salini, UNICEF, CARE, Tikuret Legumuz, Tana Beles from local and international NGOs, Government implemented projects) and CMP. The analyses of the data are as follows:

1. The reported distance travelled is based on personal estimates. Since the users were unable to report the precise distance from their home to the water sources, they were asked to report estimate of the water scheme into the visible direction so that the enumerators made their estimates.
2. Time spent to collect water was estimated on the basis of many different questions. There were several questions that contributed for the calculation of time spent. These include the number of trips per day, waiting time at sources, and travel time from house to source and source to house for a single trip and calculated time for all trips per day. Finally, the sum of these is considered as time spent collecting water.
3. The water use was calculated from indirect inquiries. Family size, the number of the trips per day, and the type of container and its volume was considered during the interviews. Based on these elements, the per capita demand was analyzed using SPSS software.
4. For community involvements under each category of the imple-mentation approach, the users were asked if they were involved in the participation components. The users were considered involved if at least 50% of the responses from the same system confirmed their participation.

RESULTS AND DISCUSSION

Long-lasting services

The 1987 Brundtland Commission's definition of sustainability has a broader prospect in the time frame. However, in water supply and sanitation, putting a system into operation and maintaining its service at least for the design life of the facilities is challenging since some parts of the facilities may wear out earlier than others. Thus, replacing and repairing are inevitable to maintain the systems to serve the communities. However, the need for sustainability is crucial to WASH services, and operating systems in full capacity in the design period is top priority. Therefore, this paper prefers to use the phrase long-lasting services rather than sustainability.

Long-lasting services include both the physical and service functionality of the water supply and sanitation facilities. This study found two key elements that are necessary to maintain long-lasting services; adequate services and proper management (Figure 2).

Adequate service implies sufficient quantity, good quality and reasonable distance to water points. The systems that cannot fulfill any one of these conditions may fail due to conflicts caused by water shortages, be abandoned as a result of poor water quality, or unprotected sources may be used instead of travelling a long distance. Appropriate quality control activities are valuable during pre-implementation of the schemes in providing enough and desirable quality of water at a reasonable distance (Figure 2). The critical activities, which are deemed to be executed during the pre-implementation phase, were identified during the fieldwork. These activities include: sound planning, proper site selection, good design, supervision and construction monitoring. All these factors are required to be user-inclusive and drive for genuine community participation. These factors facilitate the user community engagement in the post-implementation management of the WASH schemes.

For proper management, external supporters should assist the users in fee collection, protecting systems from damage, operating, maintaining and rehabilitating until the community has developed a capacity to do these activities itself (Careter et al., 1999; Harvey, 2007). According to the discussions with the district staff members, some service breakdowns are due to repairable faults and misuse. This implies that sufficient support is not rendered to improve the capacity of the
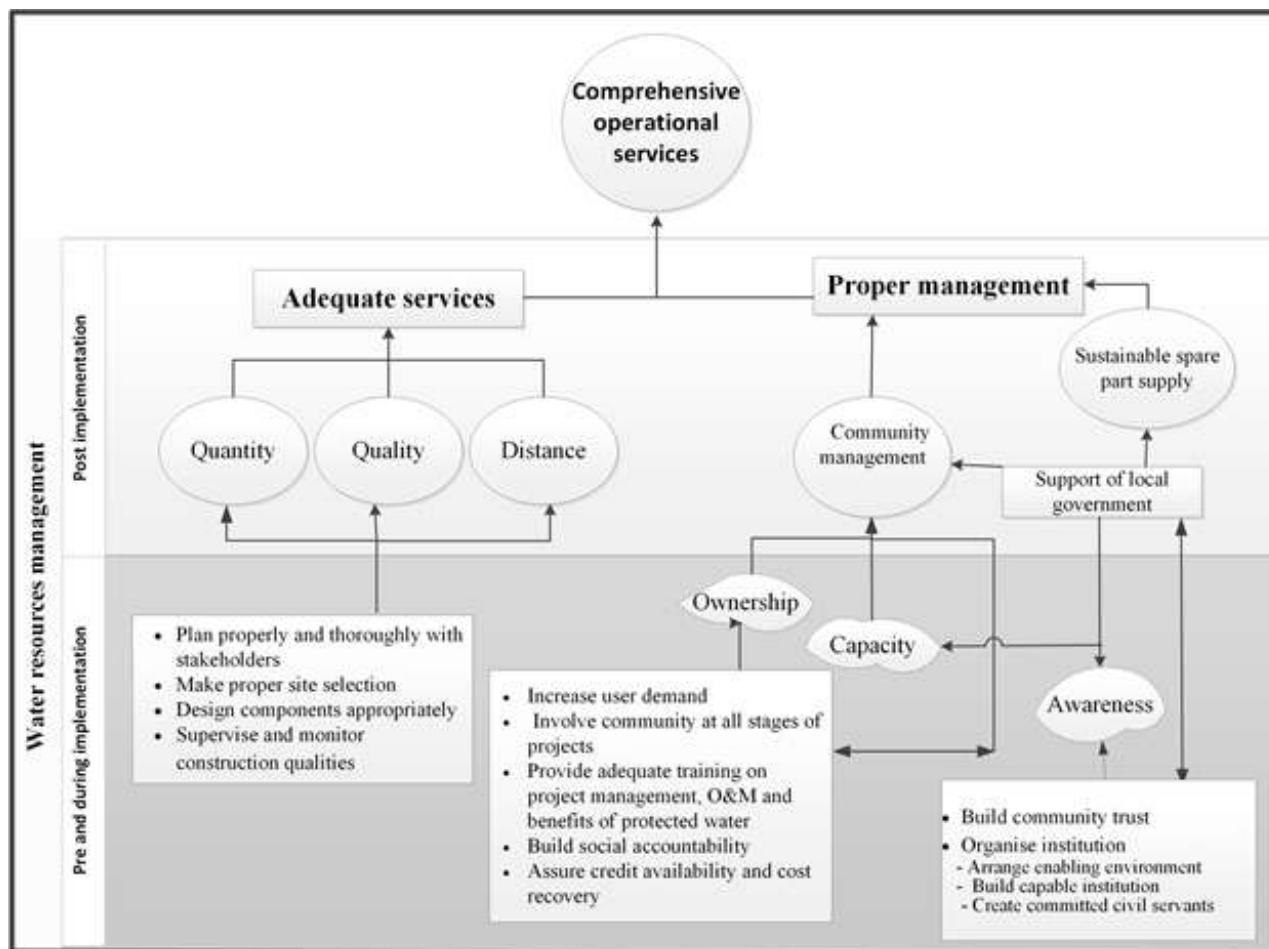
Figure 2. Framework for long-lasting services (by the first author).

user community, and so thoughtless mistakes lead to system failure. To mitigate the problem, user awareness and responsibilities in relation to the protection and management of the system should be established. Yet, it is obvious that a rural community cannot take care of the overall management without the support of the local governments, private actors and NGOs. These external supporters should establish an enabling environment for post-implementation management activities.

Provision of spare parts by Governmental Organizations (GOs) and Non-Governmental organizations (NGOs) is weakening the business opportunities of private suppliers. Based on the discussions with private spare part suppliers in two districts (Foger and Guangua) where suppliers exist, both users and suppliers were unhappy with the situation. The private suppliers were highly disappointed by the involvement of GOs and NGOs in the business, whereas the users complained about prices of private suppliers. The spare parts supplied by the organizations are neither sufficient nor do they encourage

private suppliers. Since the organizations offer the spare parts with lower costs than the market price, users prefer to rely on them. In this respect, the private business owners are forced to wait a long time until the donation has been consumed. As a result, when they do find the right market they sell their goods at higher prices to compensate. The users, on the other hand, feel inconvenienced regarding the costs when compared with the lower cost of donated spare parts. This imbalance affects the operation and maintenance activities of the water supply services in the study area.

Developing a more sustainable spare part system and community management is prominent in achieving long-lasting services; however, the appropriate role of local people and private suppliers must be taken into account. The local governments and external supporters have to enhance the technical and managerial ability of the community by building capacity and awareness and developing an ownership feeling at grass roots level (Figure 2).
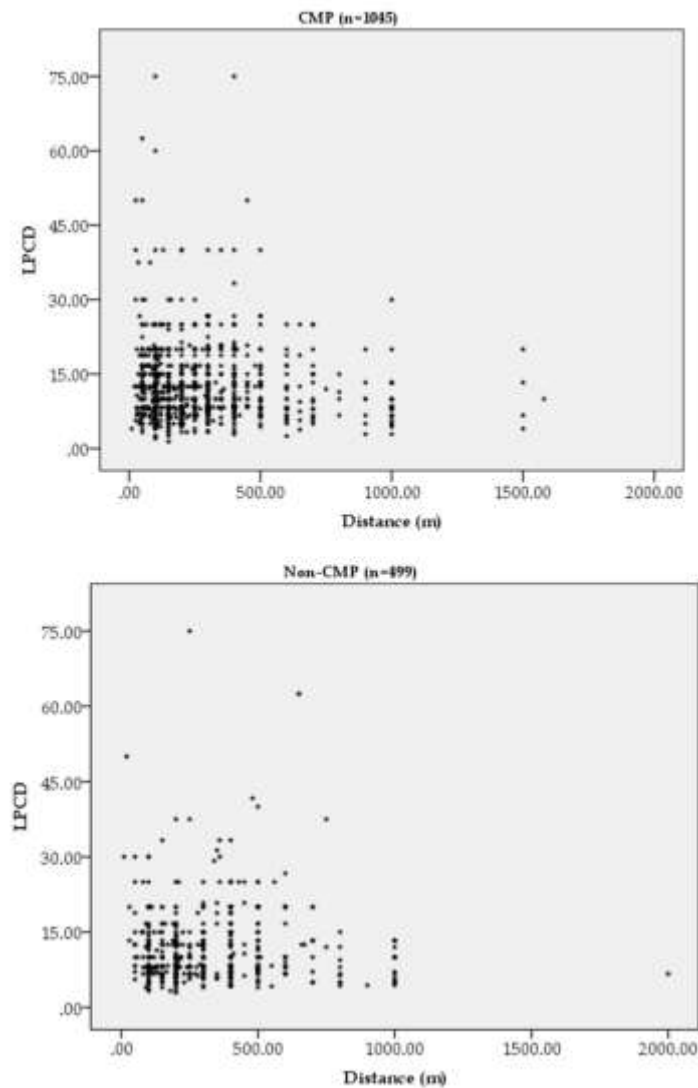
Figure 3. Water use (lpcd) versus travel distance (m) for CMP and non-CMP approaches.

Quality, quantity and distance as service indicator

Water quantity and distance to water sources

The quantities of water available at water points and the travel distance to fetch water determine the interest of people in using protected sources. If the distance is too long, or the available water supply is not adequate for daily consumption, the probability of users resorting to unprotected sources is high. The concept of a reasonable distance varies from country to country based on local conditions. For instance, fetching water from a distance of 0.5 km is a luxury in the rural Africa; luxury in countries with a developed economy is somewhat different

(Caircross and Valdmanis, 2006). Moreover, the UN recommendation for a reasonable distance is 0.2 km for urban dwellings (UN, 2000). Currently, the provision of water within a radius of 0.5 km in urban and 1.5 km in rural areas (UAP, 2011) are the short-term targets in Ethiopia. In addition, travel distance alone cannot ensure the intended outcome out of water services. If the yield of sources is too low to support all users, women and girls must wait for their turn at the sources. They sacrifice their productive time, schooling and social life in general. Therefore, the benefits hoped to be gained by improving water systems (Harvey, 2008) are unlikely realized.

Figure 3 shows that the average distance to improved water sources is 278 m (standard deviation 228 m) and
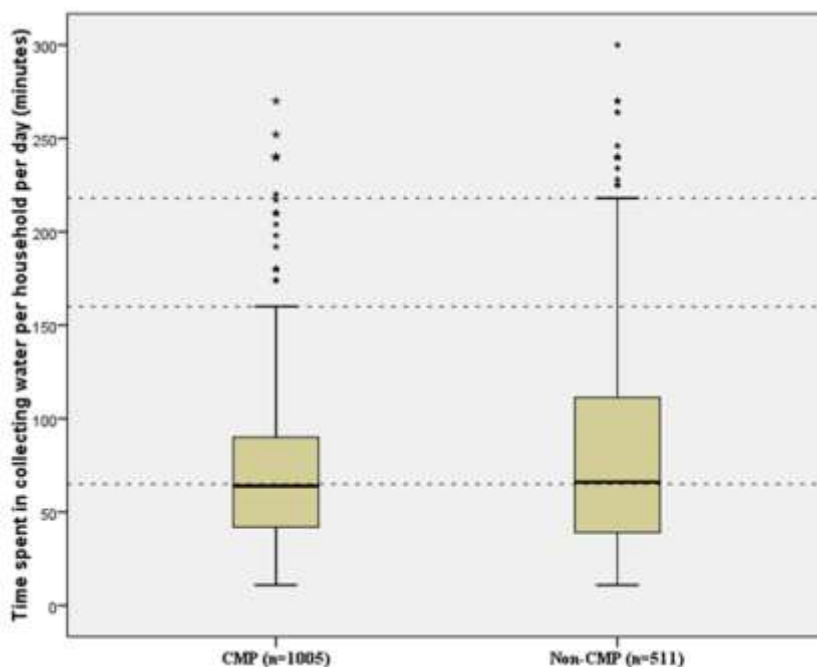
Figure 4. Time spent collecting water per household per day under non-CMP and CMP approaches (* = Outlier values; n is the number of households).

313 m (standard deviation 281 m) in the case CMP and non-CMP, respectively. In terms of the GTP-1 standard, maximum recommended distance to water sources is 1.5 km both for the schemes of CMP and non-CMP approaches. However, the daily water demand target of the country has not been achieved by the approaches, they have performed right in terms distances to water points. Only a few people consume over 20 lpcd as recommended by the UN. The pattern of consumption in Figure 3 indicates that the majority of the surveyed households consume between 10 and 15 lpcd regardless of the distance travelled to water points. Moreover, 82% of users who consume below 15 lpcd are traveling less than 400 m and 95% of them are in the range of 800 m. Contrary to the conclusion by Mellor et al. (2012), water quantity at source affects daily consumption more than the distance travelled. Therefore, distance is a secondary variable in determining the daily consumption of water when compared with the yield of sources in the study area.

As shown in Figure 4, the first two quartiles of the surveyed households spent less than sixty minutes collecting water both in the non-CMP (WMP and NGO-MP) and CMP users, whereas the fourth quartile is significantly different for both categories. In this quartile, CMP users spent up to three hours while non-CMP users could need four hours per day. In fact, the difference in collection time is observed in the upper quartile, which is due to a number of users per water point. The average

household size is 42 for CMP and 56 for non-CMP. The spent time refers to a round-trip travelling time including waiting time at the water source for all trips in a day.

In developing economies, the existence and functionality of water supply schemes usually seem to take precedence over supplying an adequate amount of water. If a scheme is working and has some kind of water flow, the users under the scheme are considered adequately served. In Ethiopia, most official figures on water supply coverage are based on the assumption that all users under a functional scheme are satisfied at least to regarding national standard. Such reporting, however, hides the deficiency of service even under functioning schemes. For instance, only 18% of non-CMP users and 25% of CMP users are getting at most 15 lpcd as shown in Figure 5. This corresponds quite closely with the finding by Rautanen et al. (2014) in Nepal. In the study area, the situation is even worse in the dry season when the wells run short of water. According to the survey of 66 water schemes, 83% experienced water shortages for 2.2 months per year on average.

One of the factors affecting water supply service is overpopulation. This means that the number of users on a water supply system is beyond its carrying capacity. This kind of situation can be due to extra users being made aware of the water point after its construction or constructed systems failing to provide adequate service to all users. These cases were observed during the fieldwork in the study area. It is obvious that knowing the
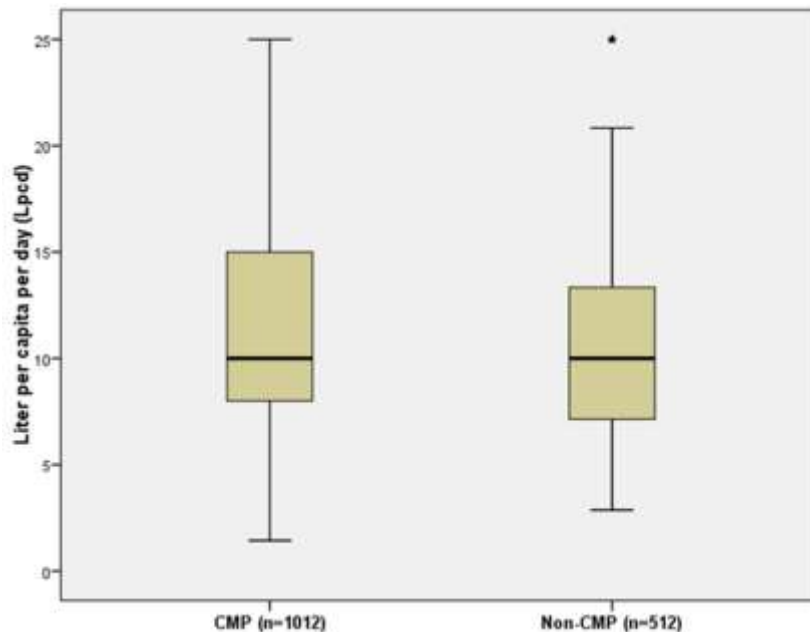
Figure 5. Water use under CMP and non-CMP approaches (* = Outlier values; n is the number of households).

size of the likely number of users during the planning stage is significant to design an adequate scheme. In the study area, the household is the unit of the population with the assumption of five people per family. Even though the five people family size is the national average, it is difficult to consider this figure for small-scale projects as it varies from place to place: in some areas, especially in the rural, the family size is much higher than the national average. Thus, household-based population representation and immigration into a community for different reasons are a few of the factors that overburden water systems. Immigrants may be seeking permanent residence or may just need to find water due to a service breakdown in neighbouring water schemes. Therefore, insufficient access to adequate water discussed above is not only because of lack of efforts in the sector, but also a lack of proper planning with local situations.

Another factor that contributes to the inadequate quantity of water supply is the yield of water sources. This factor depends on the technique and capability of yield determination before designing a system. In this aspect, local government (district) staff members, who had possible contact with such projects, have limited capacity to determine the yield, particularly for groundwater sources. This is not to undermine the individual; rather, institutions at the district level are not supporting the provision of skilled staff to carry out the yield determination. The number of beneficiaries needs to be determined before the project to estimate the yield of the sources that is enough for them. In the case of the

hand-dug wells, excavating to a depth that is sufficient to harvest the required amount of discharge is a solution. On the other hand, during spring development, neither the number of beneficiaries nor the yield is determined by the technical staff. This is because no household can be excluded from using a developed spring which they used to getting water from, and the yield of spring sources cannot be significantly improved. However, in the case of non-CMP, limiting the size of the beneficiaries of a water system is not an issue at the beginning of the projects, they serve all based on proximity. In this case, it is very difficult to achieve the quantity requirement.

Water quality

In the sub-Saharan region, 75% of improved water supply systems are not piped (WHO/UNICEF, 2014). The dominant schemes are hand-dug wells, protected springs and private wells. Similarly, the hand-dug wells with hand pumps and spring developments are common in the rural parts of Ethiopia, as they are simple technologies and affordable for sparsely settled rural communities. In the recent plans, hand dug wells and shallow wells have taken the line share in terms of number and budget allocation (OWNP, 2014; GTP, 2015). Thus, the water quality of these schemes depends on the protection of sources from animal interference, anthropogenic activities upstream of sources and stagnant water around a system; avoiding the point and non-point contamination

Table 2. Additional facilities to protect sources from contamination.

Approach	Functional Drainage	Fences	Cloth washes facility	Cattle watering through
CMP (n=90)	50%	73%	43%	30%
Non-CMP (n=45)	51%	66%	13%	9%

CMP- Community Managed Projects approach; Non-CMP- WMP project and NGO managed project.

of sources is crucial. Furthermore, quality problems that arise from the geological formation of an aquifer, such as arsenic and fluoride in the water, cannot be solved by the mentioned protection measures. In fact, fluoride is a serious problem for approximately 14 million Ethiopians in the central rift valley. Keeping this in mind, the study investigated the perception of the sample households and the provision of platforms to accommodate water quality issue by CMP and non-CMP.

As per the field observations and discussions with WASHCOs, water quality is mostly maintained in the study area by chlorination at the beginning of the system use (for hand pump wells). Otherwise, it depends on WASHCO members' consciousness and access to the district water office. Altogether, 39% of the water points visited (n=49) were applying chlorine every six months, while the rest did it once a year, biannually, or never after the first application right after completion of the system construction. The problems with this practice are that the application of chlorine in large quantities may alter the taste of the water at the beginning and that after the chlorine depletes the wells will be without chlorine for long periods. Moreover, neither of the implementation approaches has accounted for the hydrogeological contamination into their actions. They mainly focus on the water quality problem of the human and animal interferences. In this regard, both CMP and non-CMP have shown the same performance in providing adequate drainage facility and fencing the systems as indicated in Table 2. However, the approaches have differences in providing additional facilities, including cloth washing basins and cattle watering troughs.

The water quality issues are the same with all implementation approaches because of two important factors. First, the groundwater is assumed to have less contamination in rural areas. Second, the knowledge-ability in the community concerning water quality is poor: in some parts of surveyed areas, the traditionally flowing water has been considered potable if it tastes good and is clean to the eyes. The people of the study area were observed to use unprotected water although they have a protected source, especially in the highland areas where there are plenty of springs in the rainy season. Some communities are more concerned with water supply projects securing their water requirement during dry periods than what is the primary objective of protected sources. Similar attitudes were observed commonly

during the fieldwork at various places. This finding enforces the point by Caircross and Valdmanis (2006) who stated that the end users prioritize their accessibility to water sources over the health benefits of water supply schemes.

Community Involvement

As shown in Figure 2, the other key element needed to maintain a long-lasting water supply system is proper management. The prerequisite for realizing this target is to have strong community management and sustainable spare parts supply. This requires an interaction of external agents, like local governments, donors, partner organizations, etc., as well as the user community being involved in the implementation of water supply projects. The user communities may be eager to have the services; yet, they may not pay attention to the post management. On the other hand, the other stakeholders, external agents are expected to develop the sense of ownership of the water schemes to the communities, to capacitate for management, operation and maintenance of the water supply systems.

In principle, successful community management is achieved through community participation. According to Doe and Khan (2004), the participation could be in the service establishment, community meeting attendances, and ownership of services and community coherence. Furthermore, participation also contributes to the sense of ownership of systems. The clearer the vision of the participating community, the more the sense of ownership increases. According to Arnstein (1969), the ladder of citizen participation has eight levels that generally fall into three categories such as nonparticipation, tokenism and citizen's power as shown in Figure 6. The worst level, in this regard, is manipulation in which users reported as participated without their involvement and the ideal one is citizen control. In the citizen control, users have full authority to do or not to do things based on their preference. The others are intermediate indicators that gradually improve from the worst to the best scenario. Thus, Arnstein's classical ladder is used here to assess the WASH implementation approaches in Ethiopia. Based on the participatory discussions made with government employed staff (n=80) in Amhara region, community participation in CMP fell on the citizen power of 72% and
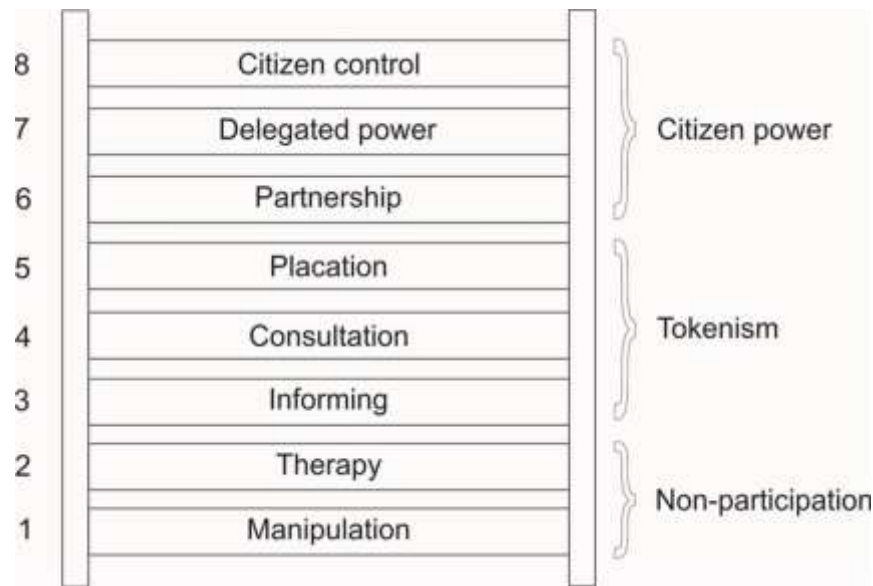
Figure 6. Ladder of citizen participation (Arnstein, 1969).

tokenism of 23%, whereas non-CMP placed between tokenism and non-participation (42 and 42%, respectively). In the discussion of the evaluation, the experts dominantly pointed out the reasons to assess the approaches in the mentioned way, based on the nature of community involvement in many aspects of a project.

Systematic involvement of users in all stages of a project cycle can ease the management process and result in a sense of ownership. In the Ethiopian context, community participation is a formal requirement for the implementation of public projects. Formally, the community should cover at least 10% of the project in kind, in cash, in labour or a combination thereof (UAP, 2008, p45). The same principle also applies to each approach in the country. However, the ways of implementation vary. Based on the experts' discussion, in non-CMP users seem to be manipulated, superficially consulted without their opinions showing up in the outcome, based on the participation ladder in Figure 6. The reasons are the same in both cases. The users' lower interest in participation may be due to their thinking that Governments and NGOs have enough resources to embark on the projects without the support of the community or the lack of awareness and appropriate consultation. In any case, the sense of ownership is debatable. The purpose of community involvement is to ensure a sense of ownership of the water supply systems. Yet, the level and ways of community involvement have an impact on the degree of sense of ownership among the users.

Another problem affecting effective community participation, for all approaches, is the multi-sectoral burden. For example, in the rural Ethiopia, citizens are asked to work for soil conservation, road construction, watershed management, community policing and attend frequent political meetings and other activities besides tending to their own business. Participation in all these activities is mandatory for community members since the by-laws of the local administration penalize non-participation. As a result, participation may easily be considered a burden. Therefore, community participation in water and other sectors to meet the 10% requirement is usually not successful in terms of creating an ownership feeling. The government has the power to push a community to participate, and the NGOs have the incentive to pay them for their participation. Both pretend to participate in order to meet the required level of participation (according to the view of the experts), whereas in reality, achieving genuine community participation requires an absolute involvement. In fact, since in CMP the members of the community request for the project themselves, they know the requirement of their participation. Thus, the ownership feeling in CMP is unique as compared to other approaches. Still, the communities need attention after the project completion.

The household survey (n=1806) revealed that there are disparities among different approaches to pre- and post-implementation support. As shown in Table 3, only a few of the approaches made the community involved in problem identification, site selection, consultation of the users on design options, and technology selection. The rate of participation in labour and cash is the same despite the differences in the timing and motivation of the contributions. Although, the differences are quite narrow,

Table 3. Community involvement in water supply and sanitation projects under different implementation approaches. The check mark (√) indicates that at least 50% of the respondents are involved in the various tasks.

Implementer	Non-CMP*										CMP
	Catholic Church (N=48)	CISP (N=55)	CVM (N=12)	Salini (N=20)	UNICEF (N=48)	CARE (N=96)	SLM (N=45)	Tikuret Legumuz (N=12)	Tana Beles (N=32)	WMP (N=52)	(N=1062)
Problem identification										√	√
Site selection	√				√	√					√
Design											√
Technology selection											√
Service level					√	√					√
Cash	√	√	√	√	√	√				√	√
Labour	√	√	√	√	√	√	√		√	√	√
Local material provision	√	√	√	√	√	√	√		√	√	√
Committee election				√	√	√	√		√		√
Procurement											√

*Organisations in the first nine columns are NGOs; CISP- A Canada based NGO; CVM - Comunita' Volontari Per II Mondo; CMP- Community Managed Projects approach; Non-CMP- WMP project and NGO manged Project; SLM – Soil and Land Management – a GTZ project; WMP- Woreda Manged Project.

the practicality and impact of participation are strong inCMP. The main difference between the CMP and non-CMP approaches is scheme handover. CMP works by empowering the community from the beginning so that the project assists the community in order to make them feel the project is their own; hence, no handover in CMP, whereas, Non-CMPs celebrate scheme handover after implementation. In the case of CMPs, users' committee elections and training take place before implementation. In the other approaches, including the district-managed projects, caretaker training and committee elections occur after implementation and during scheme handover.

Institutionalization and capacity building

A capacity building is the core component of long-lasting services. Thus, local staff and the community need to have the capacity and a compatible institution to run systems even in the absence of external support. Thus, the two basic requirements for the GOs and NGOs involved in the sector are to develop water systems and build the capacity to extend the services beyond the projects.

Many NGOs and governmental organizations have tried to create long-lasting services by incorporating the capacity building into the development of water supply schemes. Yet, very few have been successful and able to produce a true sense of development in the sector by doing physical construction and capacity building hand in hand. From this point of view, the CMP financial mechanism can be seen as a positive example among the approaches used in Ethiopia. Initially, Rural Water Supply and Environmental Programme (RWSEP)– the predecessor of CMPs was a conventional approach applying the government's financial mechanism. RWSEP was able to reshape itself through experiences to support the poor communities genuinely. Currently, the CMP approach is dependent on both technical and financial support.

In CMPs, a series of capacity building activities are performed at different levels of government to enhance smooth implementation and financing of rural water supply and sanitation. The project trains CMP technical staff out of regional and district government employees. The regional CMP technical staff members provide support in the form of capacity building, technical assistance, monitoring and supervision of district level staff members. The process of the capacity building is then cascaded down to the community level.

Functionality and effective implementation

In the study area, schemes are considered
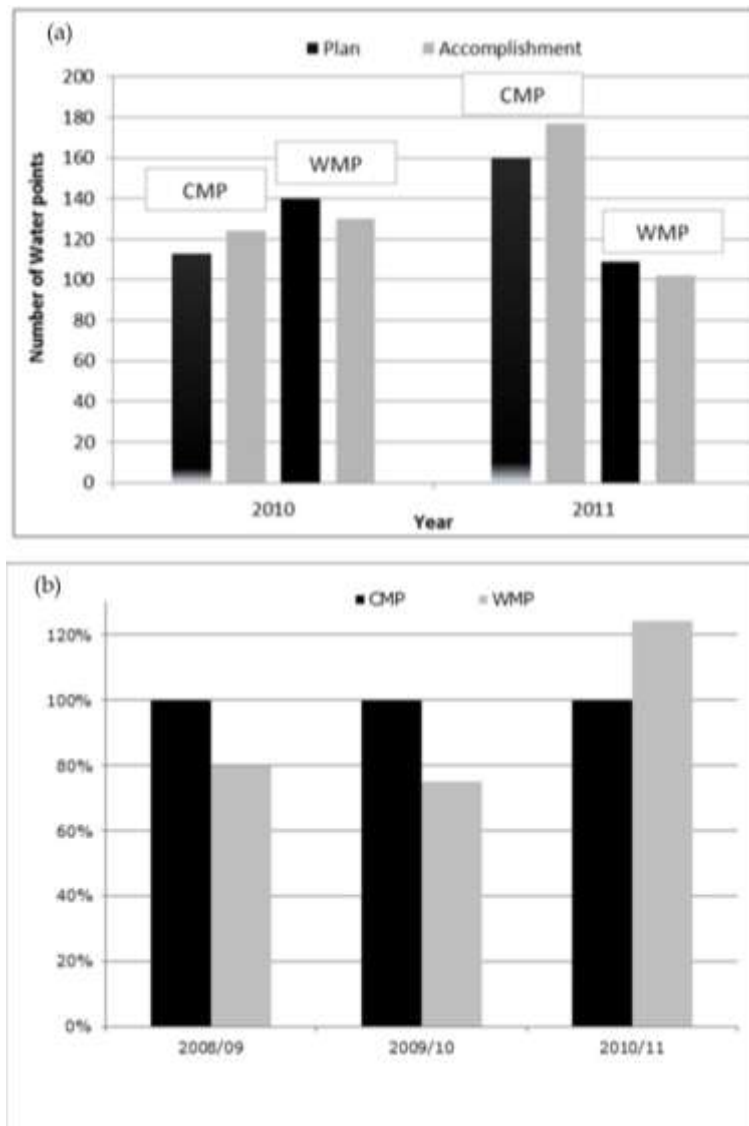
Figure 7. (a) Accomplishment versus plan, (b) annual fund utilization rates of CMPs and WMPs (Source: Tesfaye, 2012).

functional if they possess water regardless of its amount. However, the national targets of per capita demand and distance to water systems are seldom taken into account. Thus, the functionality of water schemes cannot guarantee that they provide adequate services. According to other studies made by different researchers in the same research project, the functionality rate ranges from 94 to 98% for schemes implemented using the CMP approach and from 84 to 92% for those implemented using a non-CMP approach (Mebrahtu, 2012; Sharma, 2012; Tesfaye, 2012). The results show that the CMP approach provided better protection and management than the non-CMP approach. However, these functionality

rates the actual services communities obtain. In both cases, approximately 25% of users under functioning water systems is satisfied with the national standard (15 lpcd).

Figure 7a shows that the CMP approach produced, at least, the number of planned water points while the WMP approach performed worse than planned. Moreover, in the case of the CMP approach, the implementation rate beyond the planned schemes indicates the efficient use of funds. In the two explored years, more water points were constructed with the allocated budget than planned. The efficiency of the CMP approach is also manifested by the fund utilization rate as indicated in Figure 7b. It was
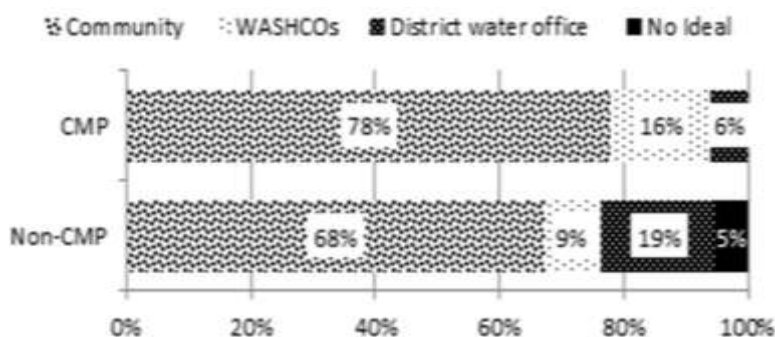
Figure 8. Perception of responsibility for scheme management in the CMP and non-CMP approaches.

almost 100% each year, while in WMP, it varied from 75to 80%. The 124% rate for District Managed Projects (WMP), which was realized in the third year, indicates that schemes started in the previous years were finalized in the third year, which increased the fund utilization rate of the year of completion. Thus, CMP is more effective and efficient than other approaches in utilizing funds and implementing plans.

Tariff collection

Water fee collection was observed to be quite different in CMP and non-CMP approaches. About 74% of the CMP respondents pay for their water (in addition to the operation and maintenance deposit made during project application) versus 43% of the non-CMP respondents. From this, it can be deduced that the communities in CMP approach are devoted to keeping their system operative. The national policy is to collect water tariffs to cover the O&M costs. The average tariff is 3.2 ETB (the standard deviation of 1.8 ETB), which is close to 0.13 euros per household per month. Since the number of households using a water point is 50 on average, the money collected through tariffs (160 ETB) is not enough to cover the O&M costs including the salary of the guards. CMP has proposed a minimum of 1,000 ETB as required for operation and maintenance of a system per year, excluding the salary of a guard; an average cost of a maintenance is 245 ETB according to Guangua district data (n=458). For non-CMP, the average tariff is 1.5 ETB (1.1 ETB), which is about half of that collected by CMPs.

The users in CMP approach seem to show the purpose of the collected tariff. Nearly 72% of CMP and 24% of non-CMP users responded that the money collected was used to cover maintenance costs and the salaries of the guards. However, 28% of the CMP users think they are paying a water tariff only to cover the guard's salary. In CMP, relatively modest awareness training about the purpose of the proper O&M could improve their

performance better than in the other approaches. Nevertheless, although the CMP approach is better in collecting tariff, the amount collected is not satisfactory to deposit for further component replacement of water supply systems.

The survey included the question "Who is responsible for protecting the water scheme?" to assess the perceptions of management by respondents and the result shown is in Figure 8. Service recipients of both CMPs and Non-CMPs assigned the first priority to the community that takes care of the water system (78 and 68%, respectively); second priority was assigned to WASHCOs in the case of CMPs and the District Water Office in the case of Non-CMPs (16 and 19%, respectively).

Conclusions and policy implications

The sustainability of water supply systems requires a series of actions for long-lasting services that can be ensured through proper maintenance and replacement of parts and systems. This means that after implementation, continuous investment is needed to keep the system operational and to repair any damages. In this regard, the communities that own the systems are responsible. Therefore, user groups should realize the importance of water points, and they should be trained to work with determination to keep the system functioning for as long as possible by replacing parts and systems when necessary.

To get the users genuinely involved, the services provided or produced should convince users that they are benefiting from the water system. For example, the distance to source and the quantity and quality of water should be within acceptable limits. Otherwise, community management will not work and cannot lead to the desired outcome. All implementation approaches used in Ethiopia have succeeded at least in attaining the target of reducing the travel distance to fetch water. However, the

country is a long way from providing an adequate quantity and quality of water. Therefore, much remain to be done in the sector.

As explained above, system management is assumed to be the responsibility of the community in all approaches. Yet, the success of community management depends particularly on the level of users' involvement in the project, and the way communities organize their activities and create a sense of ownership. Different approaches cause different behaviours as concerns community participation. Non-CMP is administering investment funds in the same manner. The project management responsibility is on the staff of the organizations, and the procurement process is also governed by the regulations of organizations– a process which takes weeks and even months to execute. Work is also contracted out to external contractors. These approaches are characterized mostly by delays in construction and a distant relationship with the user community. However, CMPs have recently delegated almost all their responsibilities to the communities. The project managers and procurement and contract officers of CMPs are community representatives. Moreover, the contractors are also artisans trained out of community members themselves. Therefore, execution of plans and the use of funds are more effective in CMPs than other projects due to the smooth financial flows and procurement process.

The difference between the senses of ownership felt by the users is clear in relation to the two categories of approaches (CMP and non-CMP). In the case of non-CMP approaches, the communities blamed the imple-menters for service breakdowns and the locations of water points. Moreover, the user committees are ineffectual or even non-existent. Water points implemented by CMPs are another issue. Although, all users do not pay a monthly fee, they usually contribute large sums when there is a system breakdown, and are also keen to protect their water system. However, the expectation that CMPs would collect a monthly water charge and deposit it in the local Micro Finance Institution is rarely realized. Therefore, this aspect needs to be given due attention in the future.

Conflict of Interests

The authors have not declared any conflict of interests.

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REFERENCES

Arnstein SR (1969). A ladder of citizen participation. J. Am. Institute Plan. 35(4):216-224.

Behailu BM, Suominen A, Katko TS (2015). Evolution of Community Managed Water Supply Projects (CMP) from 1994 to the 2010s in Ethiopia. Public Works Management and Policy 20(4):379-400.

Brunson LR, Busenitz LW, Sabatini DA, Spicer P (2013). In pursuit of sustainable water solutions in emerging regions: a Review paper. J. Water, Sanit. Hyg. Dev. 3(4):489-499.

Bryman A (2006). Integrating quantitative and qualitative research: how is it done? Qual. Res. 1:97-113.

Caircross S, Valdmanis V (2006). Water supply, sanitation, and hygiene promotion. In Jamison D. T. Breman TG, Measham A R, Alleyne G, Claeson M, Evans DB, Jeha P, Mills A, Musgrove P, 2nd eds, *Disease Control Priorities in Developing Countries*, World Bank, Washington DC. pp. 771-792.

Creswell JW (2013). Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications.

CSA (2010). *Population and housing census report*, Ethiopian Central Statistics Agency, Addis Ababa, Ethiopia, accessed at: www.csa.gov.et/newcsaweb/images/documents/surveys/Population% 20and%20Housing%20census/ETH-pop-2007/survey0/outputInformation/reports.html (12 April 2016).

Deaton A (1997). The analysis of household survey: A Microeconometric Approach to Development Policy. Published for the World Bank, The Johns Hopkins University Press, Baltimore and London.

Doe SR, Khan MS (2004). The boundaries and limits of community management: Lessons from the water sector in Ghana. Community Development Journal. 39(4): 360-371.

GTP (2015). Growthe and transformation Plan (GTP-2) for water sector, Ministry of Finance and Economic Development, Addis Ababa, Ethiopia.

Harvey PA (2007). Cost determination and sustainable financing for rural water services in sub-Saharan Africa. Water Policy 9(4):373-391.

Harvey PA (2008). Poverty Reduction Strategies: opportunities and threats for sustainable rural water services in sub-Saharan Africa. Progress Dev. Stud. 8(1):115-128.

Howard G, Charles K, Pond K, Brookshaw A, Hossain R, Bartram J (2010). Securing 2020 vision for 2030: climate change and ensuring resilience in water and sanitation services. J. Water Clim. Chang. 1(1):2-16.

Jones S (2011). Participation as citizenship or payment? A case study of rural drinking water governance in Mali, Water Altern. 4(1):54-71.

Mebrahtu M (2012). Assessment of the CMP approach in developing rural water supply schemes, Benishangul-Gumuz Region, Master's thesis, Addis Ababa Uniersity. Accessed at: www.cmpethiopia.org/page/454 (20 November 2015).

Mellor JE, Watkins, DW, Mihelcic, JR (2012). Rural water usage in East Africa: Does collection effort really impact basic access? Waterlines 31(3):215-225.

North DC (1990). Institutions, institutional change and economic performance. Cambridge University Press.

OWNP (2014). One WaSH National Program: Program Operation Manual (POM) for the Consolidated WaSh account, Ethiopian Ministry of Water and Eneryg, Addis Ababa, Ethiopia, accessed at: www.cmpethiopia.org/content/download/1285/5790/file/CMP (10 March 2016).

Rautanen S, van Koppen B, Wagle N (2014). Community-driven multiple use water services: Lessons learned by the Rural Village Water Resources Management Project in Nepal]. Water Altern. 7(1):160-177.

Sharma N (2012). CMP in implementing rural Water supply in Amhara region, Master's thesis, Tampere University of Technology, Tampere, Finland, accessed at: www.cmpethiopia.org/page/454 (20 November 2015).

Taylor B (2009). Addressing the Sustainability Crisis – Lessons from research on managing rural water project, Dar es Salaam, Tanzania.

Teddlie C, Yu F (2007). Mixed methods sampling a typology with examples. J. Mixed Methods Res. 1(1):77-100.

Tesfaye Y (2012). A comparative study on woreda managed and CMP rural water supply projects, Master's thesis, Indira Gandhi Open University, Addis Ababa, Ethiopia, Accessed at: www.cmpethiopia.org/page/454. (20 November 2015).

UAP (2008). The Ignition of mass mobilization on universal access plan for water and sanitation program, Ethiopian Ministry of Water and Eneryg, Addis Ababa, Ethiopia, accessed at: ww.cmpethiopia.org/media/universal_access_plan_mass_mobilizatio n_strategy (15 July 2015).

UAP (2011). Revised rural water supply – UAP, Ethiopian Ministry of Water and Eneryg, Addis Ababa, Ethiopia, accessed at: www.cmpethiopia.org/media/rural_water_supply_universal_access_p lan_uap_i (13 September 2015).

UN (2000). Charting the progress of populations, United Nations Population Devision, New York, United Nations, accessed at: www.un.org/esa/population/pubsarchive/chart/2.pdf (16 October 2015).

UN (2003). Indicators for Monitoring the Millennium Development Goals, United Nations Development Group, New York, United Nations, accessed at: http://mdgs.un.org/unsd/mdg/Resources/Attach/Indicators/Handbook English.pdf (12 April 2016).

WHO and UNICEF (2000). Global Water Supply and Sanitation Assessment 2000 Report, World Health Organisation and UNICEF, Geneva/New York, Switzerland/USA.

WHO and UNICEF (2014). Progress on drinking-water and sanitation – 2014 Update, World Health Organisation and UNICEF, Geneva, Switzerland.

WIF (2013). Federal democratic republic of Ethiopia the WaSH Implementation Framework, Addis Ababa, Ethiopia accessed at: http://www.cmpethiopia.org/media/signed_wash_implementation_fra mework_scanned (January, 2016)

World Population Review (2016). Ethiopia population 2016, accessed at: http://worldpopulationreview.com/countries/ethiopia-population/ (12 April 2016).

Full Length Research Paper

Preliminary investigation of transfer of metals from soil to vegetables: Case study of *Spinacia oleracea* L.

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The objective of the study was to measure concentrations of Cu, Ni and Zn in *Spinacia oleracea* cultivated at a site near the copper and nickel mine in Selebi Phikwe. The mean concentrations (in dry matter-basis) of Cu, Zn and Ni in the whole plant system were 7.30 ± 2.51, 6.02 ± 2.16 and 0.03 ± 0.02, mg/kg, respectively. Enrichment factors (EF) of Cu, Ni and Zn were far below the EF value of 1.5 suggesting that the soils at the study site were either good in retention of metals and/or there was minimal translocation of metals in the plants. The authors recommend a multiple exposure effect of heavy metal monitoring to be conducted regularly at the study site.

Key words: Dietary toxicity, estimated dietary intake, *Spinacia oleracea*, target hazard quotient.

INTRODUCTION

Deteriorating environmental conditions resulting from urban industrial activities such as mining and agricultural practices such as application of phosphate fertilisers and sewage sludge are the main man made sources of metals in agricultural soils (Nriagu, 1990; Alloway and Jackson, 1991). Soil-to-plant transfer of heavy metals is the major pathway of human exposure to soil contamination (Cui et al., 2004). For example, studies in Japan (Ryan et al., 1982) and China (Cai et al., 1990; Jin et al., 2002) have reported that lifetime exposure to low level soil contamination with cadmium (Cd), caused renal dysfunction in residents living near the contaminated sites of the respective study areas.

Vegetables are rich sources of vitamins, minerals, fibres and also have antioxidative effects (Jena et al., 2012).

Thus, heavy metal contamination of vegetables cannot be underestimated as these foodstuffs are important components of the human diet. Heavy metal concentrations in edible parts of plants is directly associated with their concentrations in soils, but their levels differ significantly with plant species, and sometimes with the genotypes within the same plant species (Kabata-Pendias and Pendias, 1984). Furthermore, plants display a wide range of adaptations to soils with contrasting metal contents. Heavy metal uptake and translocation are key aspects of plants' ability to accumulate and cope with high concentrations of heavy metals.

Studies by Akan et al. (2013) from four agricultural soils in Nigeria showed higher concentrations of lead (Pb), iron (Fe), copper (Cu), zinc (Zn), cadmium (Cd), nickel (Ni),

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manganese (Mn) and chromium (Cr) in the leaves of spinach, lettuce, cabbage and onions than their roots and stems. Ingestion of vegetables containing heavy metals is one of the main ways in which these elements enter the human body, besides water, dust and several other pathways. Once entered, the metals are deposited in the bone and fat tissues and can cause a range of diseases.

On sensory evaluation basis, dark, green, big leafy vegetables appear safe and of good quality to most consumers, but this alone cannot guarantee that the vegetables are safe for consumption. The importance of vegetables health-wise has led to an increasing demand for vegetables. As such, many people in semi-urban areas of Botswana including the study area in Selebi Phikwe are involved in urban agriculture. Selebi-Phikwe is a copper and nickel mining town of Botswana. Mining and smelting activities have been practiced for more than three decades and are at present associated with environmental problems that include soil, water and air pollution (Schwartz and Kgomanyane, 2008; Ekosse, 2005, 2011; Likuku et al., 2013).

In Botswana, literature is scares regarding transfer of metals and their potential effects to the consumers. Because peri-urban agriculture is practiced in Selebi Phikwe to meet the vegetable demands of the local population, environmental surveys including possible heavy metal contamination is of increasing concern about the safety of crops grown around that area since soil to plant transfer of heavy metals is one of the key components of human exposure to metals through the food chain (Li et al., 2006). The present study was conducted with the aim to (1) quantify the content of Cr, Cd, Cu, Ni and Zn in *Spinacia oleracea* L. (spinach) grown around the copper nickel mining and smelter sites of Selebi Phikwe in Botswana, (2) to evaluate the biological concentration factors, translocation factors and biological accumulation coefficients so as to investigate the degree of pollution and daily intake amount of metals through consumption of the vegetable and finally (3) assess potential health risk to local population via oral exposure routes.

MATERIALS AND METHODS

Sample collection and preparation

The study was conducted at horticultural farms near the Selebi Phikwe copper and nickel mine and smelter area (21.98°S; 27.84°N). The farms were approximately 15 km from the mines. At these farms, *S. oleracea* L. and soils were collected from different sites of the farms. As a reference uncontaminated area, the same sampling procedures were conducted in a farm approximately 60 km away from the mines in the same district where soils are similar to those of the contaminated areas, but without a comparable source of metal contamination. Both farms were drip irrigated. A map showing the position of the experimental area is presented in Figure 1.

Plant and soil sampling

Three planted plots of *S. oleracea* L. were systematically selected to cover the whole farm at the Selebi Phikwe copper and nickel mine and smelter experimental site. From each plot, three recently matured edible parts of spinach were uprooted. Soils from the sampled plots were also sampled at root level, approximately 0–30 cm, using stainless steel hand corers.

For the purpose of experimental control, the same vegetable type was also collected in triplicates from a farm approximately 60 km away to mimic pristine sites. Soil samples were also collected as before. Thus, a total of 18 vegetable and 18 soil samples were collected from both farms. All the samples were brought in polythene bags to the Botswana College of Agriculture laboratories for analysis.

Sample preparation

In the laboratory, plant samples were double rinsed with deionised water to remove adhered soil and dust particles before being sliced into small pieces. The spinach was sectioned into three different compartments: the edible part (the leaves), the stem and the roots. Both plant and soil samples were then oven dried at 50°C until weight constancy, homogenised using a pestle and mortar and then passed through a 2 mm stainless sieve and stored at room temperature for further analysis.

For heavy metal extraction, approximately 0.5 g of dried ground samples were digested with 6 ml of 65% nitric acid (HNO_3) and 2 ml of 30% hydrogen peroxide (H_2O_2) (with 3 ml of 65% HNO_3 and 9 ml of 37% H_2O_2 for soils) in Ethos EZ Microwave Digestion System from Milestone following the condition described: Maximum Power–15000 W; Ramp time– 110 min; hold time– 110 min; temperature–200°C.

After hold time, the vessels were allowed to cool for about 30 min. The suspension was filtered (Whatman filter Merck, 0.45 µm) and the filtrate was diluted by deionized water to a final volume of to 100 ml with deionised water and stored in a refrigerator (<4°C) until analysis (Allen et al., 1986).

Metal analysis

Levels of Cu, Ni and Zn in the solutions were measured using Perkin-Elmer Spectrophotometer Model 460 flame atomic absorption spectroscopy (FAAS) at the Department of Waste Management and Pollution Control, in Gaborone, Botswana. The AAS was optimised and a calibration curve was produced using standards prepared from pipettes of 5 ml each of the 1000 mg/L stock solutions of Cu, Mn, Cd, Co, Al, Pb, Zn, Ni, Mg; 10 ml Fe stock solutions and 20 ml Cr stock, five micrograms per millilitre (5 µg/mL) for Cu, Mn, Cd, Co, Al, Pb, Zn, Ni, Mg; 10 µg/mL for Fe; and 20 µg/ml for Cr. Calibration curves were then prepared using the stock solutions. The instrumental parameters were set depending on the type of analysis done. Samples were aspirated in triplicates.

Data analysis

Biological concentration factor (BCF) was calculated as metal concentration ratio of plant roots to soil given in Equation 1 (Yoon et al., 2006). Translocation factor (TF) was described as ratio of heavy metals in plant shoot to that in plant root given in Equation 2 (Cui et al., 2007; Li et al., 2007). Biological accumulation coefficient (BAC) was calculated as ratio of heavy metal in shoots to that in soil given in Equation 3 (Li et al., 2007; Cui et al., 2007):

Figure 1. Map of Botswana showing Selebi Phikwe (the star with coordinates indicated). The maps are not drawn to scale.

$$BCF = \left(\frac{[Metals]_{root}}{[Metals]_{soil}} \right)_{Dry\ Weight}$$

…………………………………….....   (1)

$$TF = \left(\frac{[Metals]_{shoot}}{[Metals]_{root}} \right)_{Dry\ Weight}$$

…………………………………….....   (2)

$$BAC = \left(\frac{[Metals]_{shoot}}{[Metals]_{soil}} \right)_{Dry\ Weight}$$

…………………………………….....   (3)

Statistical analysis

Basic statistical analysis of maximum, minimum mean and standard deviation values were performed to compare levels of heavy metals in different components of *S. oleracea* at experimental (E) sites as well as at the control (*C*) site.

Normalisation procedure

To analyze anthropogenic enrichment, enrichment factor, *EF* was used to geochemically normalise the dataset and ascertain experimental control or background relationships between pristine site and the site of concern. The enrichment factor was calculated using the formula originally introduced by Buat-Menard and Chesselet (1979) as shown in Equation 4:

$$EF = \left(\frac{\left(C_{plant}/C_{soil} \right)_{Experimental\ site}}{\left(C_{plant}/C_{soil} \right)_{Control\ site}} \right)_{Dry\ Weight}$$

…………………………………….....   (4)

Where C_{plant} is the edible plant material content and C_{soil} is the total material content in soil where the plant was grown at both the wastewater and groundwater irrigated sites, all expressed in dry

weight. It is worth noting that the ratios $C_{\text{plant}}/C_{\text{soil}}$ symbolise translocation of metals in plants.

Enrichment factor categories proposed by Sutherland (2000) was then used as follows: $EF < 2$ = deficiently to minimal enrichment, $2 \leq EF < 5$ = moderate enrichment, $5 \leq EF < 20$ = significant enrichment, $20 \leq EF < 40$ = very high enrichment and $EF \geq 40$ = extremely high enrichment. For this work, metal enrichment will be considered when $EF \geq 1.5$, symbolising minimal enrichment and above.

Statistical analysis

The risk to human beings resulting from consumption of spinach grown from the area was calculated by employing the estimated dietary intake (*EDI*, in mg/kg-per person per day) and target hazard quotient (*THQ*) described by Zheng et al. (2007) and USEPA (1989) as shown in Equation 5:

$$EDI = \frac{C_{\text{plant}}(\text{mg/kg}) \times \text{Intake}(\text{kg/person/day}) \times EFr \times ED}{BM(\text{kg}) \times AT}$$

.... (5)

In Equation 5, C_{plant} is the median concentration of heavy metal in spinach, intake is the ingestion rate, *EFr* is the exposure frequency given as 350 days/year (Wang et al., 2012), *ED* is the exposure duration. In this work, it was proposed that *ED* will be 30 years for adults (Grzetic and Ghariani, 2008), and *AT* is the average time for non-carcinogens of 365 days/year (USEPA, 2005). The average adult daily vegetable intake rate of 0.345 kg/person/day and body mass of 55.9 kg was used as reported in the literature (Ge, 1992; Wang et al., 2005). The conversion factor 0.085 was used to convert fresh green vegetable weight to dry weight, as described by Rattan et al. (2005). This gives the total dose entering the human body through oral ingestion of contaminated vegetables.

Target hazard quotient, *THQ* was determined from the ratio of the *EDI* to oral reference dose *RfD*o values obtained from Integrated Risk Information Systems (IRIS, 2003) and the Department of Environment, Food and Rural Affairs (DEFRA, 1999) given in Equation 6:

$$THQ = \frac{EDI}{RfD_o\,(\text{mg/kg per person per day})}$$

.... (6)

In order to assess the overall potential for non-carcinogenic effects, the total chronic hazard index, *THI* which is the summation of all the individual target hazard quotients is represented as in Equation 7:

$$THI = \sum_{i=1}^{n} THQ$$

.... (7)

If either value of *THQ* and *THI* are above 1, a high risk of non-carcinogenic effects is implied, since the accepted standard is 1.0 at which there will be no significant health hazard (Grzetic and Ghariani, 2008; Lai et al., 2010). The probability of experiencing long-term health hazard effects increases with the increasing *THI* value (Wang et al., 2012) and according to Lemly (1996); *THI* = 1.1–10 refers to moderate hazard while *THI* >10 refers to high hazard.

RESULTS AND DISCUSSION

Concentration of metals

Mean concentrations of Cu, Zn and Ni in whole plan system (leaf + stem + root) at the experimental site were 7.30 ± 2.51, 6.02 ± 2.16 and 0.03 ± 0.02 mg/kg, respectively. Control site mean concentrations of Cu and Zn were 4.01 ± 3.26 and 4.11 ± 1.94 mg/kg, respectively, whereas Ni concentrations at the control site were below detection. Experimental site mean concentrations of Cu and Zn in soils were significantly high; $p = 0.014$ and $p = 0.033$, respectively, as compared to those measured at the control site. Similarly, the mean concentrations of Cu (24.37 ± 0.04 mg/kg) and Zn (12.97 ± 0.21 mg/kg) at the experimental site were significantly higher than those at the control sites: Cu (3.23 ± 0.27 mg/kg) and Zn (7.08 ± 1.17 mg/kg) at $p = 0.0005$. On the leaf-stem-root compartmental basis, the mean concentrations of Cu, Zn, Ni, Cd, Cr and Pb in *S. oleracea* and in soils from experimental and control sites are given in Table 1.

The maximum permissible concentration of Cu in plants recommended by the World Health Organisation (WHO) is 73 mg/kg (Chiroma et al., 2012). From the results obtained in this study, Cu was found to be lower in the edible part of spinach (leaf) than the permissible limit by approximately 6%. The mean copper content in the cultivated soils from this experiment was found to be 23.90 ± 3.31 mg/kg. This value is within the normal Cu content of 5–50 mg/kg (Mico, 2006) and far below the maximum permissible values of 100 mg/kg for Cu in horticultural soils (Kabata-Pendias, 2001). Copper is an essential micronutrient involved in a number of biological processes needed to sustain life. However, it can be toxic when present in excess (de Romañ et al., 2011).

In the case of Zn, the amount measured in the edible part of spinach was found to be 6.02 ± 2.16 and 12.97 ± 0.21 mg/kg in the respective cultivated soil. These values are below the WHO's recommended limit of 50 mg/kg for zinc in plants and the 300 mg/kg recommended limit values reported in Kabata-Pendias and Pendias (2001). Zinc is one of the most important trace elements that play a vital role in the physiological and metabolic processes of many organisms. Traces of Ni at << 0.1 mg/kg were recorded in the plant system, but not in soils. The rest of the measured elements: Pb, Cr and Cd were below the instrument detection limits of 0.0045, 0.0054 and 0.014 mg/kg, respectively.

Transfer of metal from soil to plant is the major pathway of exposure to humans through the food chain. This was measured though enrichment from soils to the plant system using Equation 4, based on values obtained from Equations 1 to 3. As shown in Tables 2 and 3, it is evident from the results obtained and presented in Table 1 that enrichment of metals was below unity. As stated earlier, metal enrichment will be considered only when

Table 1. Statistics of metal concentrations (in mg/kg-dry matter) showing the minimum (Min), maximum (Max), mean values and their corresponding standard deviations (SDEV).

	Cu		Zn		Ni		Cd		Cr		Pb	
	E	*C*	*E*	*C*	*E*	*C*	*E*	*C*	*E*	*C*	*E*	*C*
(N = 9)				Leaf component at experimental (*E*) control (*C*) sites								
Min.	1.87	1.82	4.52	4.37	0.00	ND	ND	ND	ND	ND	ND	ND
Max.	6.53	8.10	7.22	6.96	0.02	ND	ND	ND	ND	ND	ND	ND
Mean	**4.73**	**4.72**	**5.59**	**6.02**	**0.01**	–	–	–	–	–	–	–
SDEV	2.05	2.59	1.17	1.17	0.01	–	–	–	–	–	–	–
(N = 9)				Stem component at experimental (*E*) control (*C*) site								
Min.	7.11	0.58	4.28	1.29	0.01	ND	ND	ND	ND	ND	ND	ND
Max.	9.67	10.40	5.90	3.96	0.02	ND	ND	ND	ND	ND	ND	ND
Mean	**8.20**	**4.85**	**5.21**	**2.49**	**0.02**	–	–	–	–	–	–	–
SDEV	1.08	4.11	0.68	1.11	0.00	–	–	–	–	–	–	–
(N = 9)				Root component at experimental (*E*) control (*C*) site								
Min.	7.66	1.17	4.82	2.33	0.04	ND	ND	ND	ND	ND	ND	ND
Max.	10.40	3.74	11.30	4.73	0.04	ND	ND	ND	ND	ND	ND	ND
Mean	**8.98**	**2.45**	**7.27**	**3.81**	**0.04**	–	–	–	–	–	–	–
SDEV	1.12	1.05	2.87	1.06	0.00	–	–	–	–	–	–	–
(N = 9)				Soil component at experimental (*E*) control (*C*) site								
Min.	23.90	2.93	12.20	6.08	0.05	ND	ND	ND	ND	ND	ND	ND
Max.	24.60	3.46	13.20	8.40	0.06	ND	ND	ND	ND	ND	ND	ND
Mean	**24.37**	**3.23**	**12.97**	**7.08**	**0.05**	–	–	–	–	–	–	–
SDEV	0.33	0.22	0.17	0.97	0.00	–	–	–	–	–	–	–

ND: Not detected.

Table 2. Biological concentration factors, transfer factors and bioaccumulation factors of metal concentrations between soils and the vegetable plant at the experimental site.

	Cu	Zn	Ni
BCF	0.37	0.53	0.75
TF	0.56	0.77	0.25
BAC	0.75	0.43	0.19

BCF = Biological concentration factor; TF = translocation factor; BAC = biological accumulation coefficient.

Table 3. Normalised enrichment factors, *EF* of Cu and Zn in the leaf, stem and roots of *Spinacia oleracea*.

	Leaf	Stem	Root
Cu	0.133	0.224	0.486
Zn	0.510	1.141	1.041

EF values are greater than 1.5. Lower values of heavy metal enrichment factors obtained in this study suggest good retention of metals in soils and/or less translocation in plants.

Potential health risk

Health risks to residents in the study area through consumption of *S. oleracea* were assessed by target hazard quotient *THQ* obtained by estimating the dietary intake (*EDI*) expressed using Equation 5. Table 4 summarises the exposure assessment for adults in the study area.

The applied non-carcinogenic oral reference dose RfD_o values obtained from Integrated Risk Information Systems (IRIS, 2003) for Cu and Zn were respectively 0.04 and 0.3 mg/kg/d. The *EDI* values for Cu and Zn were 0.10 and 0.08 mg/kg BM/d, respectively. The *EDI* values for Cu in *S. oleracea* is approximately 2.5 times higher than the RfD_o value suggesting that people consuming the spinach cultivated from the study site may

Table 4. Estimated daily intake, *EDI* in mg/kg BM/d, and target hazard quotient, *THQ* for adults through consumption of *Spinacia oleracea* from the experimental site.

	EDI	THQ	
Cu	0.10	2.44	ΣTHQ = THI
Zn	0.08	0.27	
Total	0.18	2.71	2.89

experience adverse effects due to the presence of Cu in the vegetable, whereas Zn was about 0.22 mg/kg BM/d below its *RfD*$_o$ value.

The total *THQ* (the health risk index, *THI*) for both Cu and Zn was 2.89. According to Lemly (1996), *THI* = 1.1–10 refers to moderate hazard. It was difficult to reconcile these values with others studies from Botswana since literature on heavy metal exposure and assessment on their effects to human health was unavailable. However, as compared to other countries, the value obtained in this study was relatively high; for example, multiple-exposure of *THQ* values for Cu and Zn from independent studies at a mining area in China were found to be 2.1 (Zhuang et al., 2014).

There is increasing evidence worldwide that pollution due to heavy metal contaminants from mining area cause death, for example, in Zambia alone, tens of thousands of the residents of Kwabe suffered from lead poising by the lead-zinc mining and smelting (Branan, 2008). In japan, release of the metal into the river water that was used for irrigation at the Kamioka mine was responsible for the itai-itai disease that was caused by Cd poising to the local people (Abrahams, 2002). Thus, monitoring of heavy metal concentration and exposure to humans and understanding the human exposure pathways would be of help in the possible need for intervention, and possible medical surveillance. It is recommended that monitoring of these metals must be done regularly at these sites, not only for spinach but all the commonly edible plants vegetables and other foodstuff including ingestion through drinking water, so as to provide a better picture of the levels of the *THI* for multiple exposure pathways.

Conclusions

Concentrations of Cd, Cr, Cu, Ni, Pb and Zn were measured in soils and in *S. oleracea* cultivated at a site near the copper and nickel mine in Selebi Phikwe. The mean concentrations of Cu, Zn and Ni in whole plan system (leaf + stem + root) at the experimental site were 7.30 ± 2.51, 6.02 ± 2.16 and 0.03 ± 0.02 mg/kg, respectively. The mean concentrations of Cu in spinach and in the cultivated soils were below the WHO's

permissible limits. Similarly, the mean concentrations of Zn were also found to be below the recommended limits for both plants and horticultural soils. Enrichment factors of Cu, Ni and Zn were far below the *EF* value of 1.5, suggesting that the soils at the study site are either good in retention of metals and/or there was minimal translocation of metals in the plants.

Conflict of interest

The authors have not declared any conflict of interest.

REFERENCES

Abrahams PW (2002). Soils: their implications to human health. Sci. Total Environ. 291:1-32.
Akan JC, Kolo BG, Yikala BS, Ogugbuaja VO (2013). Determination of some heavy metals in vegetable samples from Biu Local Government Area, Borno State, North Eastern Nigeria. Int. J. Environ. Monit. Anal. 1(2):40-46.
Allen SE, Grimshaw HM, Rowland AP (1986). Chemical Analysis. In: Moore, P.D., Chapman, S. B. (Eds.), Methods in Plant Ecology. Blackwell, Scientific Publication, Oxford, London pp. 285-344.
Alloway BJ, Jackson AP (1991). The behaviour of heavy metals in sewage sludge-amended soils. Sci. Total Environ. 100:151-176.
Branan N (2008). Mining leaves nasty legacy in Zambia. Geotimes website. Available: http://www.geotimes.org/jan08/article.html?id=nn_zambia.html Accessed December, 2015.
Buat-Menard P, Chesselet R (1979). Variable influence of them atmospheric flux on the trace metal chemistry of oceanic suspended matter. Earth Planet Sci. Lett. 42:398-411.
Cai S, Yue L, Hu ZN, Zhong XZ, Ye ZI, Xu HD, Liu YR, Ji RD, Zhang WH, Zhang FY (1990). Cadmium exposure and human health effects among residents in an irrigation area with ore dressing waste water. Sci. Total Environ. 90:67-73.
Chiroma TM, Ebewele TO, Hymore FK (2012). Levels of Heavy Metals (Cu, Zn, Pb, Fe and Cr) in Bushgreen and Roselle Irrigated with Treated and Untreated Urban Sewage Water. Int. Res. J. Environ. Sci. 1(4):50-55.
Cui S, Zhou Q, Chao L (2007). Potential hyper-accumulation of Pb, Zn, Cu and Cd in endurant plants distributed in an old smelter, northeast China. Environ. Geol. 51:1043-1048.
Cui Y, Zhu Y, Zhai R, Chen D, Huang Y, Qiu Y, Liang J (2004). Transfer of metals from soil to vegetables in an area near a smelter in Nanning, China. Environ. Int. 30:785-791.
De Romañ DL, Olivares M, Uauy R, Araya M (2011). Risks and benefits of copper in light of new insights of copper homeostasis. J. Trace Elem. Med. Biol. 25:3-13.
DEFRA (Department of Environment, Food and Rural Affairs) (1999). Total Diet Study-Aluminium, Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Selenium, Tin and Zinc. London: The Stationery Office.
Ekosse G (2005). General health status of residents of the Selebi Phikwe Ni-Cu mine area, Botswana. Int. J. Environ. Health Res. 15(5):373-381.
Ekosse G (2011). Health status within the precincts of a nickel-copper

mining and smelting environment. Afr. Health Sci. 11(1):90-96.

Ge KY (1992). The status of nutrient and meal of Chinese in the 1990s. Beijing People's Hygiene Press pp. 415-434.

Grzetic I, Ghariani RHA (2008). Potential health risk assessment for soil heavy metal contamination in the central zone of Belgrade (Serbia). J. Serbian Chem. Soc. 73(8-9):923-934.

IRIS, Integrated Risk Information System database (2003). US Environmental Protection Agency.

Jena V, Dixit S, Gupta S (2012). Risk assessment of heavy metal toxicity through edible vegetables from industrial area of Chhattisgarh. Int. J. Res. Environ. Sci. Technol. 2:124-127.

Jin T, Nordberg M, Frech W, Dumont X, Bernard A, Ye TT, Kong Q, Wang Z, Li P, Lundström NG, Li Y, Nordberg GF (2002). Cadmium biomonitoring and renal dysfunction among a population environmentally exposed to cadmium from smelting in China (ChinaCad). Biomed. 15:397-410.

Kabata-Pendias A (2001). Trace Elements in Soils and Plants, CRC Press, Boca Raton, Fla, USA.

Kabata-Pendias A, Pendias H (1984). Trace Elements in Soils and Plants CRC, Press Boca Raton, FL pp. 315.

Lai HY, Hseu ZY, Chen TC, Chen BC, Guo HY, Chen ZS (2010). Health risk-based assessment and management of heavy metals-contaminated soil sites in Taiwan. Int. J. Res. Public Health 7(10):3595-3614.

Lemly AD (1996). Evaluation of the hazard quotient method for risk assessment of selenium. Ecotox. Environ. Saf. 35:156-162.

Li MS, Luo YP, Su ZY (2007). Heavy metal concentrations in soils and plant accumulation in a restored manganese mine land in Guangxi, South China. Environ. Pollut. 147:168-1175.

Li Y, Wang Y, Gou X, Su Y, Wang G (2006). Risk assessment of heavy metals in soils and vegetables around non-ferrous metals mining sites, Baiyin, China. J. Environ. Sci. 18(6):1124-1134.

Likuku AS, Mmolawa KB, Gaboutloeloe GK (2013). Assessment of heavy metal enrichment and degree of contamination around the copper-nickel mine in the Selebi Phikwe region, eastern Botswana. Environ. Ecol. Res. 1(2):32-40.

Micó C, Peris M, Sánchez J, Recatalá L (2006). Heavy metal content of agricultural soils in a Mediterranean semiarid area: the Segura River Valley (Alicante, Spain). Span. J. Agric. Res. 4(4):363-372.

Nriagu JO (1990). Global metal pollution. Poisoning the biosphere? Environ. 32:28-33.

Rattan RK, Datta SP, Chhonkar PK, Suribabu K, Singh AK (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. Agric. Ecosyst. Environ. 109:310-322.

Ryan JA, Pahren HR, Lucas JB (1982). Controlling cadmium in the human food chain: a review and rationale based on health effects. Environ. Res. 28:251-302.

Schwartz MO, Kgomanyane J (2008). Modelling natural attenuation of heavy-metal groundwater contamination in the Selebi-Phikwe mining area, Botswana. Environ. Geol. 54(4):819-830.

Sutherland RA, Tolosa CA, Tack FMG, Verloo MG (2000). Characterization of selected element concentration and enrichment ratios in background and anthropogenically impacted roadside areas. Arch. Environ. Contam. Toxicol. 38:428-438.

USEPA (1989). Risk assessment guidance for superfund Human Health Evaluation Manual (Part A) Interim Final Vol. I United States Environmental Protection Agency Washington DC.

USEPA (2005). Toxicological review of zinc and compounds. Washington, DC. EPA/635/R-05/002,CAS NO.7440-66-6. http://www.epa.gov/iris/background.htm. Accessed: January 26, 2016.

Wang X, Sato T, Xing B, Tao S (2005). Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. Sci. Total Environ. 350:28-37.

Wang X, Wang F, Chen B, Sun F, He W, Wen D, Liu X, Wang Q (2012). Comparing the health risk of toxic metals through vegetable consumption between industrial polluted and non-polluted fields in Shaoguan, South China. Int. J. Food, Agric. Environ. 10(2):943-948.

Yoon J, Cao X, Zhou Q, Ma LQ (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Sci. Total Environ. 368:456-1464.

Zheng N, Wang Q, Zhang X, Zheng D, Zhang Z, Zhang S (2007). Population health risk due to dietary intake of heavy metals in the industrial area of Huludao city, China. Sci. Total Environ. 387(1-3):96-104.

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