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Table of Contents: Volume 12 Number 10 October 2018

ARTICLES

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Full Length Research Paper

Performance enhancement of Nalgonda technique and pilot testing electrolytic defluoridation system for removing fluoride from drinking water in East Africa

Teshome L. Yami*, Jim F. Chamberlain, Feleke Z. Beshah and David A. Sabatini

School of Civil Engineering and Environmental Science, University of Oklahoma, Norman, USA.

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High fluoride concentrations in groundwater pose a health risk to people living in the Rift valley of Ethiopia and beyond. The Nalgonda and electrolytic defluoridation (EDF) fluoride treatment systems were developed and adapted in India for fluoride removal. A recent study evaluated twenty Nalgonda techniques that were implemented in the Rift valley of Ethiopia. A number of these systems were found to be non-functional or had never been utilized. The purpose of this study is to evaluate the performance of the Nalgonda technique and seek ways to enhance the fluoride uptake capacities. Further, pilot testing of the EDF system was conducted in the Rift Valley of Ethiopia to evaluate its effectiveness at fluoride removal using natural groundwater in this setting. This study has shown that the performance of the Nalgonda system was significantly enhanced by adding aluminum hydro(oxide) (AO) and cow bone char powder into the existing Nalgonda systems; the initial fluoride concentration of 9.3 mg/L was lowered to 2.5 mg/L on average. In addition to the increased effectiveness at fluoride removal, the addition of AO and cow bone char powder produced significantly less sludge compared to the existing Nalgonda system. The EDF system proved to be effective at removing the excess fluoride concentration in drinking water in the Rift Valley of Ethiopia; the initial fluoride concentration of 7.9 mg/L was lowered to 2.8 mg/L meeting the USEPA standard fluoride level of 4 mg/L. The pilot study showed Aluminum leaching into the treated water. Thus, further optimization of the electrode size, electrolysis time, and voltage/current used during the electrolysis process is needed to meet the WHO target treatment goal of 1.5 mg/L fluoride level and eliminate aluminum leaching as well.

Key words: Electrolytic defluoridation, fluoride, Nalgonda, pilot-testing, sustainability.

INTRODUCTION

More than 748 million people lack access to improved drinking -water supplies globally; it is mainly the low-income and marginalized segment of the population that still lack access to an improved drinking water sources (WHO 2014). Reasons given for the slow expansion of water supply services to the poor include funding constraints, a community's inadequate operation and maintenance skills (Calow et al., 2013). Furthermore, the

*Corresponding author. E-mail: Teshome.L.Yami-1@ou.edu. Tel: (405) 325-5911. Fax: (405) 325-4217.

sustainability of safe water supply schemes is constrained by social, technical, financial, institutional and environmental issues (Brikké and Bredero, 2003). For example, some of the common problems faced by safe water supply systems in Ethiopia include the availability of spare parts, chemicals, capacity for scheme operation and management, tariff collection, and water quality issues (Israel and Habtamu, 2007). The non-functionality rates of the developed safe water supply systems in Ethiopia are also high (up to 33%) due to technical, financial and social problems (Abebe and Deneke, 2008).

Groundwater constitutes 30.1% of total global freshwater (Gleick, 1996) as the single largest available supply of drinking water, especially in rural settings (WHO, 2004). However, groundwater can contain geogenic (dissolution of fluoride and arsenic-containing minerals) and/or anthropogenic sources (e.g., application of pesticides), such as fluoride and arsenic which are known to affect human health (Apambire et al., 1997; Roy and Dass, 2013). A volcano's plume is often the principal source of high concentrations of fluoride in groundwater and the environment (Notcutt and Davies, 1989). For example, drinking water fluoride concentrations in the Ethiopian Rift Valley range from 1-33 mg/L with an average value of 5 mg/L (Haimanot et al., 1987).

Various defluoridation technologies, such as the Nalgonda, bone char and activated alumina have been implemented in Ethiopia (Osterwalder et al., 2014; Frank et al., 2011). Most of these defluoridation systems failed to meet the intended purpose of the provision of fluoride-safe drinking water to the communities. For example, defluoridation systems in Wonji-Shoa irrigation scheme used activated alumina which was expensive and had logistical constraints of operation and maintenances (Teklehaimanot et al., 2006). Supply of equipment and chemicals for fluoride removal is lacking and there is no consistent monitoring mechanism put in place to ensure the quality of treated water. There is a limited engagement of private sectors in the defluoridation processes. As a result, the fluoride removal technologies utilized thus far have not proven sustainable for providing access to safe water supply services in the Rift Valley of Ethiopia.

High fluoride levels in drinking water cause damage to human dental and skeletal systems as well as the structure and functions of the non-skeletal systems, such as brain, liver, kidney, and spinal cord (Guan et al., 1998; Wang et al., 2004). Additionally, excess fluoride concentration in drinking water causes various histological structure changes of the kidney, including extensive induction of cell apoptosis and thereby resulting in impairment of renal function and metabolism (Zhan et al., 2006). The kidney is sensitive to fluoride intoxication; where 50-80% of fluoride adsorbed is eliminated (Guan et al., 2000). Liver, as an active site of metabolism, is also susceptible to fluoride toxicity (Shivashankara et al., 2000; Wang et al., 2000). Fluoride level in drinking water exceeding 2.0 mg/L can cause damage to liver and kidney functions in children (Xiong et al., 2007).

Beyond dental, skeletal and other impacts on the structural functions of human organs, fluorosis has significant socio-economic impacts stemming from the fact that persons who develop skeletal fluorosis suffer considerable hardship and have reduced productivity (Apambire et al. 1997; Frank et al. 2011). It has been estimated that more than 200 million people from more than 25 nations around the world consume water with fluoride concentrations above the World Health Organization (WHO) recommended threshold of 1.5 mg/L (Amini et al., 2008) and are thus at risk of fluorosis. It is therefore critical to either treat fluoride impacted groundwater or find alternative water sources for communities living in fluoride affected areas of the world in order to mitigate the suffering of those people impacted by fluoride-induced health concerns.

Various fluoride removal technologies, such as Nalgonda, electrolytic defluoridation, reverse osmosis, Donnan dialysis, ion-exchange, adsorption and contact precipitation, have been implemented in the field (Ayoob et al., 2008; Brunson and Sabatini, 2009). Adsorption is currently considered as the method of choice for fluoride removal from drinking water because of its high efficiency, potential use of locally available materials, low operation and maintenance cost, high-quality water, and potential for regeneration and reuse (Choy et al., 2004; Jagtap et al., 2012). For example, bone char, activated alumina, red mud, quartz, fly ash, hydroxyapatite, zeolites and modified zeolites, ion exchange resins, layered double hydroxides and chemically activated cow bone (CAB) are among the adsorbents studied for fluoride removal from drinking water (Mohapatra et al., 2009; Du et al., 2014).

However, fluoride removal technologies implemented in the field often fail to be sustainable due to poor community management capacity as well as lack of supply chain for chemicals and equipment (Brunson and Sabatini, 2009). For example, out of more than 20 Nalgonda-based defluoridation systems implemented in the Rift Valley of Ethiopia over the past decade, some were never fully used after installation and more than half of those that were implemented were found to be no longer functional (Ostwerwalder et al., 2014; Datturia et al., 2015). Of those still functioning and recently tested, treated water fluoride concentration levels were found to be significantly higher than the WHO guideline value of 1.5 mg/L (University of Oklahoma's Water Center survey data, July 2014). Therefore, since excess fluoride concentrations in drinking water cause dental and skeletal fluorosis along with other severe socio-economic problems (Dissanayaka 1991), addressing the technical efficiency, sustainability and scalability challenges is of paramount importance. Yami et al. (2017) suggested that

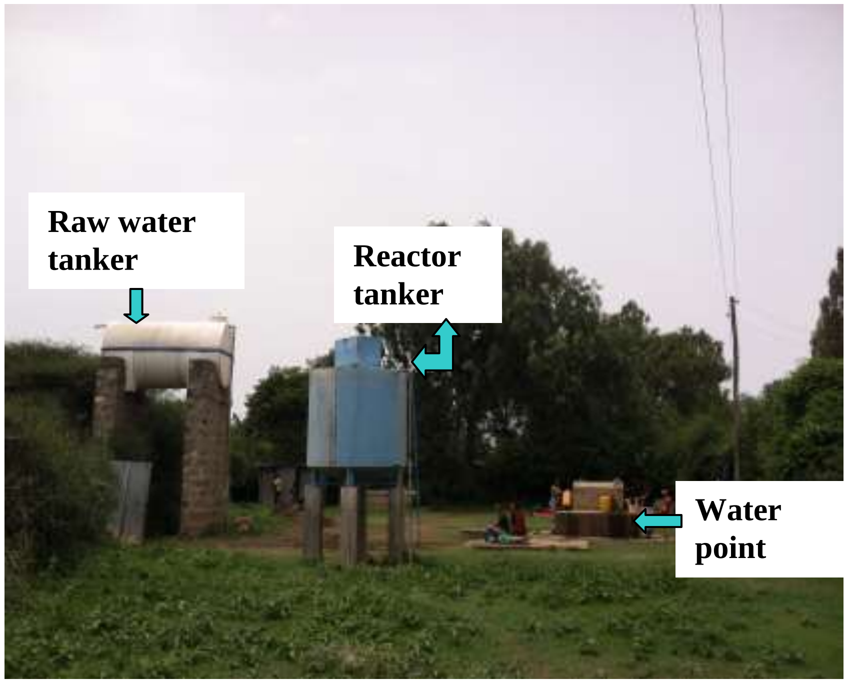

Figure 1. Layout of the small community scale Nalgonda technique, Dodo Wadera defluoridation site in the Rift Valley of Ethiopia (photo by Teshome L. Yami)

sustainability of fluoride treatment systems can be ensured using business model logic in achieving financial and operational sustainability of the systems.

REVIEW OF EXISTING TECHNOLOGIES IMPLEMENTED IN THE RIFT VALLEY OF ETHIOPIA

Nalgonda

The Nalgonda technique was developed and adapted in India by the National Environmental Engineering Research Institute (NEERI). It utilizes aluminum sulfate to enhance coagulation-flocculation-sedimentation, the dosage of which is designed to ensure fluoride removal from the water. The use of alum and lime has been extensively studied for defluoridation of drinking water, and it is popularly known as the Nalgonda technique (Nawlakhe et al., 1975). The layout of the Nalgonda system is shown in Figure 1. In Ethiopia, under the fluorosis mitigation project promoted by UNICEF and the Federal Water, Irrigation and Electricity Ministry, the Nalgonda technique has been pilot tested in several rural communities. Furthermore, Catholic Relief Service (CRS) in collaboration with Meki- Catholic Secretariat office implemented this technique in the Ethiopian Rift Valley communities since 2005 (Datturia et al., 2015).

However, the Nalgonda system has been shown to require a high dose of alum, generates inadequate removal efficiency and has problems associated with large sludge disposal (Shrivastava and Vani, 2009). There were studies conducted to increase the fluoride removal capacity of the Nalgonda systems. For example, Zewge (2016) added aluminum hydro(oxide) (AO) to the Nalgonda system to enhance the fluoride removal capacity. A common concern amongst researchers is that the Nalgonda technique requires a great deal of monitoring and that the daily operators require appropriate training and reliable operation (Ayoob et al., 2008). The experience in WaSH sector demonstrates that community water supply systems fail because the hardware (infrastructure) has been installed but the means to sustain the intervention beyond construction (software) is lacking. The software component requires integration of the social, institutional, technical, economical, operation and management, and environmental aspects. Thus, the hardware and software component of the fluoride treatment systems need to go hand in hand to ensure sustainability. A study conducted on the Nalgonda technique revealed that maintenance costs are high, the process is not automatic, and users do not like the treated water taste (Maheshwari, 2006). Therefore, to enhance the sustainability of the Nalgonda systems requires establishing a strong monitoring system, improving the fluoride removal capacity, and building the management capacity of the community is of paramount importance. The fluoride removal mechanism of the Nalgonda system has been explained as a co-

Figure 2. Electro-defluoridation system installed at Berta-Sembi communities in the Rift Valley of Ethiopia (Photo by Teshome L. Yami).

precipitation where the main constituent (fluoride) is removed as flocs via settling due to combination of sorption and ion exchange with the hydroxide groups produced.

Electro-defluoridation (EDF)

EDF was also developed by NEERI, India, to treat excess fluoride concentration in drinking water. EDF involves the use of aluminum electrodes that release Al^{3+} ions by an anodic reaction and hydrogen gas released at the cathode, and the ions then react with fluoride ions that are found in excess near the anode. Figure 2 shows the arrangement of the aluminum electrodes in the reactor tanker. The aluminum cations are transformed into polymeric species and form $Al(OH)_{3(S)}$. The reactive intermediate hydroxyl species formed during the reaction further interact to form a hydroxide of disordered structure which intensifies the fluoride removal (Andey et al., 2013). Compared with traditional chemical coagulation, EDF process requires less space and does not require chemical storage, dilution and pH adjustment. In addition, the EDF system does not require substantial investment and has lower volume of sludge generation compared to the Nalgonda (Mollah et al., 2001; Essadki et al., 2009). It has proven to be effective drinking water supply for small or medium sized community in India (Andey et al., 2013).

Fluoride removal mechanism EDF

The EDF system's fluoride removal mechanism is through adsorption and co-precipitation with the aluminum-based colloidal precipitates generated by the electrodes (Zhu et al., 2007). The electromechanical reactions promoted by the electrodes (anode and cathode) and the adsorption/co-precipitation reactions are shown in Equations 1 to 4.

Anode: $Al(s) \rightarrow Al^{3+} + 3e^-$ (1)

Cathode: $2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-$ (2)

Adsorption on $Al(OH)_3$ particles: $Al_n(OH)_{3n}$ + m.F- $\rightarrow$ $Al_nF_m(OH)_{3n\text{-}m}$+ $m(OH)^-$ (3)

Co-precipitation: n.Al + 3n-m$(OH)^-$ + m.F^- (4)

Goal of the study

To date, several fluoride adsorbents have been developed and implemented in the field to remove excess fluoride concentrations from drinking water. However, field level observation shows inefficiency and ineffectiveness of these technologies. The overall goal of this work is therefore to evaluate the performance of the Nalgonda technique implemented in the Rift Valley of

Table 1. Quantities of chemicals required for Nalgonda system and dimensions of EDF system.

Fluoride treatment technology		Quantity of media required per treatment batch (kg)[a]		
		Alum	**Lime**	**BC or AO**
Nalgonda	Nalgonda alone	5.85	2.93	
	Nalgonda + cow bone char (BC)	4.5	1.6	0.3
	Nalgonda + AO	4.5	0.75	0.25
EDF	Dimensions (cm)[b]	Length (cm)	Width (cm)	Depth/ Thickness (cm)
	Reactor tanker	105	100	110
	Aluminum electrode	90	80	0.2

Note: [a]The media quantity was determined based on the quantity required to lower initial fluoride concentration of 10mg/L to 1.5 mg/L. [b] This dimension is for one of the four EDF compartments. The depth includes a free board of 20 cm and 10cm slope for sludge removal. Runs 1 and 2 indicate that the EDF system was run twice (for two days consecutively).

Ethiopia. Further, it evaluates the feasibility of the EDF system for fluoride removal from drinking water using natural groundwater in the Rift Valley of Ethiopia.

Research questions

The research questions evaluated in this work are:

(1) Can the addition of bone char powder (waste material from bone char production) and aluminum hydro (oxide) (AO) to the Nalgonda system enhance its fluoride removal capacity?
(2) Does the electrolytic defluoridation (EDF) system developed in India produce similar fluoride removal efficiency in natural groundwater in the Ethiopian Rift Valley?
(3) Is the water treated using EDF system suitable for public consumption?

MATERIALS AND METHODS

Nalgonda

In Dodo Wadera village, a Nalgonda-based water treatment system in the Rift Valley of Ethiopia was selected in collaboration with the National Fluorosis Mitigation Project office of the Ethiopian Ministry of Water, Irrigation and Electricity as a site to evaluate the potential for enhancing the fluoride removal capacity of the Nalgonda system. The community level defluoridation system consists of raw water tanker, reactor tanker with a mixer shaft, treated water tanker, sludge storage tank, water distribution point and the powerhouse. The capacity of the reactor tanker (one batch) is 5000 Liters. The Nalgonda system uses aluminum sulfate (alum) and calcium oxide (lime) chemicals added to the reactor tanker and mixed rapidly with high fluoride concentration water. The motor agitated mixing and reactions of chemicals are conducted for 20 min and the treated water is stored in treated water storage tanker.

The aluminum and lime used in the Nalgonda system were purchased from Melkassa Aluminum Sulfate Production Company in Ethiopia. Based on the working manual of the Fluorosis Mitigation Project Office of the Ethiopian Ministry of Water, Irrigation and Electricity, the amount of alum and lime used to treat 5000 liters of water per batch was 5.85 and 2.93 kg, respectively (Table 1 and SI-1). The quantity of lime added was assumed to be 50% of the alum needed for the treatment which agrees with the quantity of lime recommended as 20 to 50% of the alum dosage by Dahi et al. (1996). The quantity of alum and lime recommended in this study was targeted to achieve the WHO guideline value of 1.5 mg/L. Dahi et al. (1996) indicated that an alum dosage of 12.8 and 6.4 g lime (50% of alum quantity) reduced the fluoride concentration to 2.1 ± 0.7 mg/L based on the findings from studies conducted in 76 families. Lime is added to alum to maintain neutral pH since the hydrolysis of aluminum hydroxide releases H^+ ions and to facilitate formation of dense floc for rapid settling (Shrivastava and Rani, 2009). Both alum and lime were dissolved in separate buckets and poured into the Nalgonda system as slurry and stirred for 20 min until it reaches equilibration within 2 h.

In this study, efforts were made to improve the performance of the existing Nalgonda system considering the modality of operation by the local community, that is, the quantity of alum and lime added and the duration of mixing. The second option was using a hybrid system (the existing Nalgonda system and adding aluminum hydro(oxide) (AO)) prepared by the National Fluorosis Mitigation Project Office, Ministry of Water, Irrigation and Electricity, Ethiopia. The third option was using the existing Nalgonda system and adding cow bone char powder which is a byproduct of bone char produced by Oromo Self-Help Organization (OSHO), Ethiopia.

AO was prepared by adding 100g $Al_2(SO_4)_3.14\ H_2O$ in 500 mL of Deionized water (DI) and NaOH solution that gives 2.7 OH:Al ratio due to its highest performance and surface properties (Mulugeta et al., 2014). The resulting pH 2.7 was raised to neutral pH using 2 M NaOH. In this study, 4.5 kg alum, 0.75 kg lime and 250 g AO (Table 1) were mixed in a bucket and poured into the Nalgonda system as slurry and stirred for 15 min until it reaches equilibration within 2 h. Thermally activated cow bone (bone char) was prepared by heating cow bone in a furnace at 500°C to remove volatile and organic matters. Bone chars have been widely used as an adsorbent for removal of excess fluoride concentrations. The fluoride removal mechanisms of bone chars are direct adsorption of fluoride on bone char surfaces and ion exchange mechanisms where fluoride ions exchange with hydroxyl ion (Equation 5) (Kawasaki et al., 2009). Bone char powder used in this study was obtained from OSHO bone charring site located in Modjo town in the Ethiopian Rift Valley. The quantity of alum, lime and cow bone char powder added to the Nalgonda system was 4.5 and 1.6 kg and 300 g, respectively (Table 1).

$$Ca_{10}(PO_4)_6(OH)_2 + 2F^- \longrightarrow Ca_{10}(PO_4)_6\,F_2 + 2OH^- \quad (5)$$

Electrolytic defluoridation (EDF)

The feasibility study of EDF system for removal of fluoride from drinking water under the context of groundwater quality in the Rift Valley of Ethiopia was conducted in July 2014. An existing incomplete EDF system (finishing work remains on system's construction) at Berta Semi village in the Rift Valley of Ethiopia was used to conduct this study. The EDF system has four tankers to conduct the electrolysis. In this study, the aluminum plates were installed in one of the EDF tanker compartments to run the pilot testing work. The aluminum plates, electrical wires, and other accessories were purchased from Modjo town in the Rift Valley. The dimensions of the EDF system, Aluminum plate and the electrolysis time of the EDF system is summarized in supplemental data (Table 1 and SI-II).

The generator installed to pump raw water from Berta Semi drilled well was used as a power source to run the EDF system. The AC current was converted to DC current to run the electrolysis using BK Precision, Model 1796- high current DC power supply 0-16 V/0-50A with 800-watt output. Water pump (model 6000-125E, 3/4″ Barb, 230V/240V, Laing Thermotech, USA) was used for mixing and recirculation of the treated water.

RESULTS AND DISCUSSION

Nalgonda

The separate addition of cow bone char powder and aluminum hydro(oxide) into the existing Nalgonda system (Aluminum sulfate and lime) significantly enhanced the fluoride removal capacity. The existing Nalgonda system (alum and lime) lowered the initial fluoride concentration of 9.3 to 7.0 mg/L, which is significantly higher than the WHO guideline value of 1.5 mg/L. The treated water fluoride concentration in the reactor tanker increased to 8.0 mg/L after 20 h of treatment due to the higher dosage of lime added above the design requirement for the treatment. This situation raised the pH which resulted in competition between OH^- and F^- and thereby reduced the fluoride removal capacity. Thus, the inappropriate ratio of alum and lime used by the local scheme operator in the Nalgonda reactor raised the pH and reduced the fluoride removal capacity of the system. The design requires the addition of a specific proportion of alum and lime (lime = 50% alum quantity). According to the field level observation of the Nalgonda system operation by local community, steel plates and bowls were used to measure the quantity of alum and lime added to Nalgonda reactor tanker. The OU WaTER Center's study conducted in July 2014 on the operation of Dodo Wadera Nalgonda-based treatment system indicated that 7 kg alum and 5 kg of lime (71% of the alum quantity) was added by the community, which is more than the recommended lime dosage level (50% of alum).

Further, since a separate tanker for treated water was not installed, the treated water stays in the treatment tank and the sludge releases OH^- back to the system and thereby raising the pH which reduced the fluoride removal capacity. It was observed that the Nalgonda system produced large quantity of sludge which required labor to clean it before the next round of water treatment. Up on the addition of AO to the existing Nalgonda system, initial fluoride concentration of 9.3 mg/L was reduced to 2.8 mg/L (Figure 3). The treated water samples were collected at 5 h interval after the addition of AO and analyzed for fluoride and pH. Besides the improved performance of the treatment system, the addition of AO resulted in a lower quantity of sludge produced. Cow bone char powder (BC) added to the Nalgonda system could lower the initial fluoride concentration to 2.1 mg/L (Figure 3). This study demonstrated that both AO and cow bone char powder added to the existing system could be used to enhance the fluoride removal capacity of Nalgonda techniques. The treated water fluoride concentration met the US standard for fluoride of 4.0 mg/L. However, the treated fluoride level is still slightly above the WHO guideline value of 1.5 mg/L thus requiring further optimization of chemicals dosage (alum, lime and AO) and pH to meet the standard. Further, these two media (AO and cow bone char powder) produced significantly lower quantities of sludge which was one of the common problems of the existing Nalgonda systems.

The combination of the alum/AO and cow bone char powder has a beneficial effect on the properties of the treated water by reducing the quantities of alum and lime needed to treat the water. Upon the addition of AO/cow bone char powder into the Nalgonda Technique, less sludge was produced, and the treated water quality met the WHO guideline values compared to the Nalgonda Technique alone. The addition of these media into the Nalgonda Technique enhances the formation of aluminum hydroxide flocs which is responsible for the co-precipitation of the fluoride ions. Further, the combined AO/cow bone char powder and alum/lime is low-cost and the treated water is affordable to the rural communities.

Electrolytic defluoridation (EDF)

The pilot electrolytic defluoridation system installed at Berta Semi community in the Rift Valley of Ethiopia significantly reduced the fluoride concentration from 7.9 to 2.8 mg/L (Figure 4). The initial pH of raw water (8.02) was reduced to an average of 7 during the electrolysis process. The calculated electrolysis time was 3 h (SI-II) although it was increased to 4 h to further lower the fluoride concentration. The EDF system was run in two batches and the result of the fluoride removal versus the electrolysis time was consistent, that is, it did not show a statistically significant difference. During operation of the EDF system, it was observed that bubbles (hydrogen gas) formed at the electrode probably due to the highly acidic surface nature. Optimization of the operational voltage and current may help overcome the problem associated with the bubble formation. To further reduce the fluoride concentration in the treated water to the WHO guideline value (WHO, 2004) of 1.5 mg/L, it is also

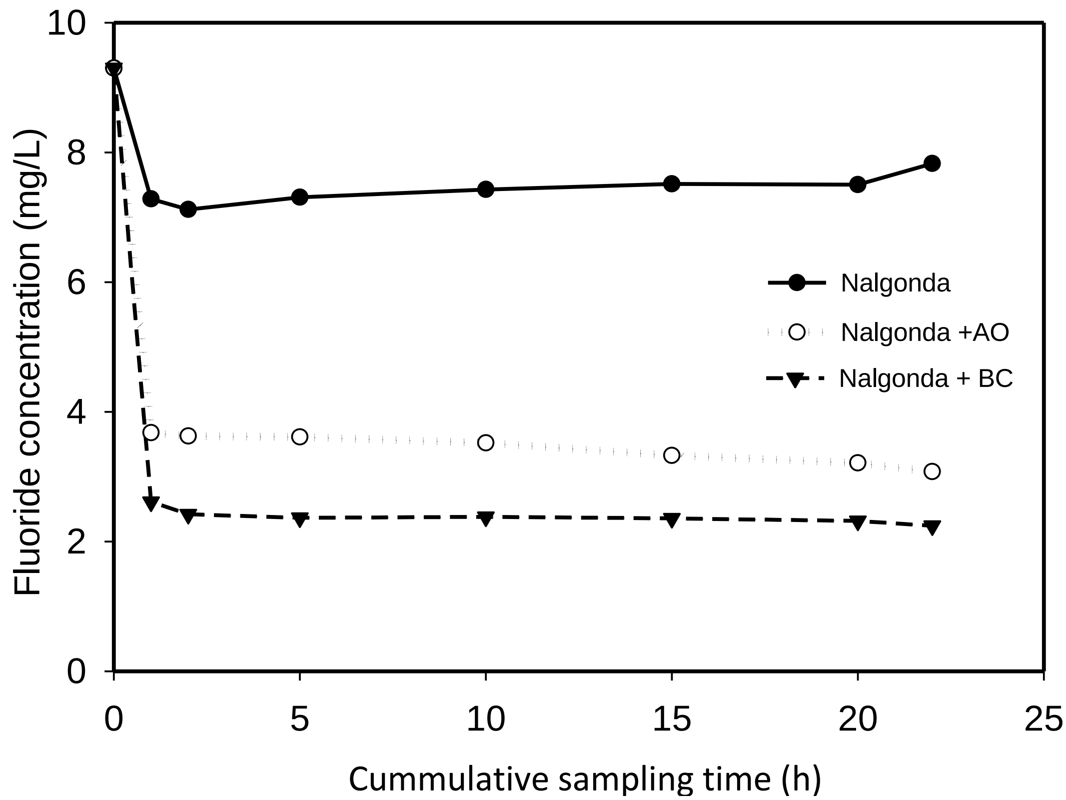

Figure 3. Treated water fluoride level for samples collected at five-hour interval from the Nalgonda system.

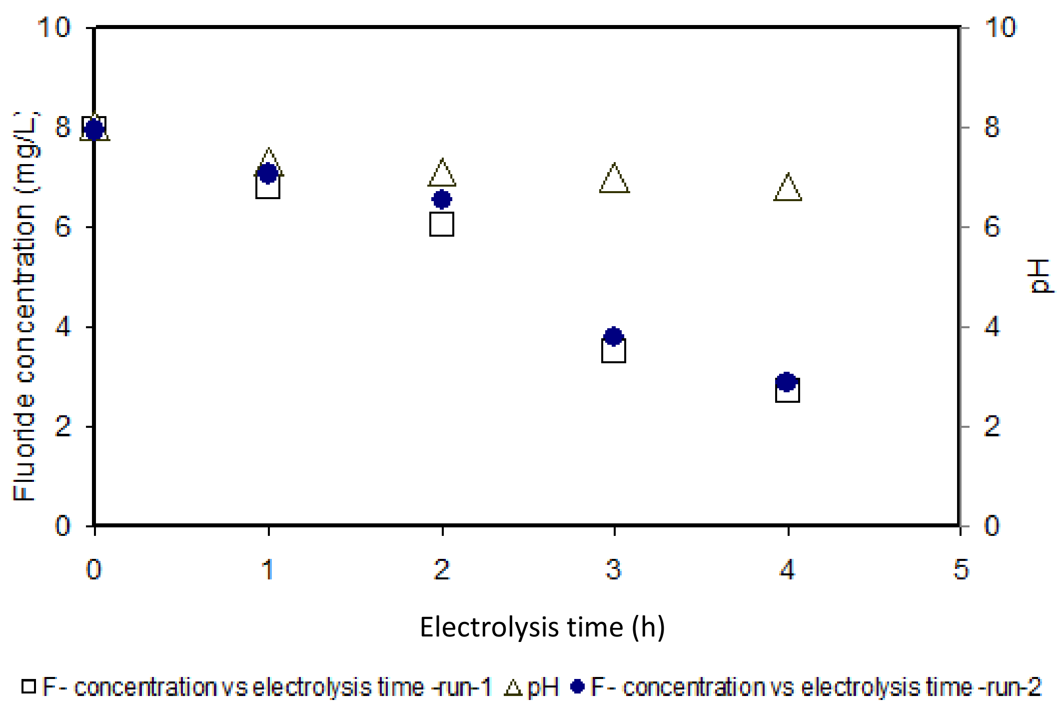

Figure 4. Fluoride level of treated water over four hours of electrolysis time from the pilot tested EDF system in the Rift Valley of Ethiopia (Summer 2015).

Table 2. Treated water quality parameters for Berta Semi EDF site.

Water Quality Parameters	Unit	Pilot project site	
		Berta semi (EDF site)	Standards
pH	Dimensionless	7.0	6.5 – 8.5[1]
Fluoride	mg/L	2.8	2[1]
Arsenic, Total	mg/L	0.00414	0.01 MCL[1]
Sulfate	mg/L	1.73	250[1]
Aluminum, Total	mg/L	32.1	0.05-0.2[1]
Calcium	mg/L	9.95	50[2]
Magnesium, Total	mg/L	2.05	50[2]
Total Hardness Ca/Mg Eq. $CaCO_3$	mg/L	33.3	75[2]

Note: [1]WHO (2008), [2]Canadian Health act safe drinking water regulation BC Reg 230/92, and 390, Sch 120, 2001 .

necessary to further optimize the size of the aluminum plate and the electrolysis time. It is also of paramount importance to understand what is happening at the surface of the electrode as well. For example, scaling formation at the surface of the electrode reduces the performance of the system and it is difficult to regenerate the plate after scaling formation.

The aluminum concentration of the treated water using the EDF system was 32.1 mg/L (Table 2) which is higher than the WHO guideline value of 0.2 mg/L (WHO 2008). To lower the treated water aluminum concentration, configuration of the electrode during installation of the EDF system needs due consideration to avoid alkaline or acidic formation which reduces the performance of the system and posing treated water quality problem due to leaching of the A^{+3}. The fluoride concentration of the treated water of 2.8 mg/L was slightly higher than 1.5 mg/L of WHO guideline value. Therefore, optimization of the number and size of the aluminum electrodes used in the EDF system, duration of electrolysis time, and the electric current/voltage may help lower the treated water fluoride concentration to achieve the treatment goal of 1.5 mg/L. Other water quality parameters such as arsenic, sulfate, calcium, magnesium and total hardness are lower than the WHO guideline values (Table 2). Nonetheless, this first ever implementation of EDF in Ethiopia shows the great promise of this approach to addressing fluoride impacted groundwater in Ethiopia.

To ensure the sustainability of both the Nalgonda and EDF based- fluoride treatment systems, business model logic plays significant roles in achieving financial and operational sustainability of the systems (Yami et al., 2017). Engagement of the private sector/ local service providers can also significantly contribute towards scaling up of defluoridation technologies by actively engaging in production and installation of treatment systems, and supply of equipment and chemicals. The private sector/ service providers can produce adsorbents, treat fluoride impacted water, and distribute treated water and undertake operation and management works. Therefore, using business model logic can help solve the prevailing shortage of raw materials, chemicals and equipment and ensure sustainability of the defluoridation systems.

CONCLUSION AND RECOMMENDATIONS

This study demonstrated that the poor performance of Nalgonda-based water treatment system implemented in the Rift Valley of Ethiopia was due to the community's lack of necessary skill to manage and operate the system. The user community added an inappropriate ratio of alum and lime which raised the pH and thereby affected the fluoride removal capacity. Further, lack of supply chain for chemicals and equipments affected the sustainability of the Nalgonda systems. Upon addition of AO and cow bone char powder, the final fluoride concentration of the treated water was 2.8 mg/L and 2.1 mg/L, respectively compared to 7 mg/L for the Nalgonda system alone. This study has thus shown that the performance of the Nalgonda system can be significantly enhanced by adding AO and cow bone char powder into the existing Nalgonda techniques. Besides increased capacity, the addition of AO and cow bone char powder of the Nalgonda techniques reduced the amount of sludge produced and the labor cost required to clean the reaction tanker.

The raw water fluoride concentration of 7.9 mg/L considered in the pilot testing of the EDF system was reduced to 2.8 mg/L at an electrolysis time of 4 h. Thus, the EDF system was proven to be effective at removing the excess fluoride concentration in drinking water in the Rift Valley of Ethiopia. Significant reduction of the initial fluoride level was achieved meeting the US standard but further optimization of the size of the aluminum plate, electrolysis time and voltage is needed to further reduce the fluoride concentration of the treated water to the reach the WHO treatment goal of 1.5 mg/L and thereby eliminate the leaching of aluminum ion. Furthermore, to ensure the continuity of operation of the EDF system, installation of solar power source is of paramount importance to fill the gaps in electric power supply. Monitoring water quality also needs attention to reduce the impact of chemicals leaching into treated water. Thus, the pilot testing of the EDF system using natural water in the Rift Valley has shown good potential to provide access to safe water supply to communities and thereby reduce the negative health impact of excess fluoride concentration in the Rift Valley of Ethiopia and beyond. To ensure sustainability of fluoride treatment systems, giving equal attention to the hardware and software component of the treatment system is important.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Supplemental Data

SI-1- Design of Nalgonda Technique (Dodo Wadera site in the Rift Valley of Ethiopia**)**

Raw water fluoride concentration (C_0) = 9.3 mg/L
Treated water fluoride concentration = 1.5 mg/L (WHO 1984).
Present project users = 3000 persons
Growth rate (r) = 3%
Project life (n) = 10 years

Projected population (P) = Po $(1+ r)^n$ (1)

P = 3000 $(1+3\%)^{10}$ = 4000 persons (2)

Quantity of treated water consumption per day =
water consumed per person per day X number of people (3)
= 4 L/P/D X 4000 persons = 16,000 L/day (4)

Two reactors of each with 5000 Liters capacity are needed to treat the 16,000 Liters of water to meet the daily demand. Each reactor produces two batches of treated water daily i.e., one reactor produces 10,000 L/day.

Quantity of chemicals required

Quantity of fluoride removed per batch = $(C_0 - C_f)$ X V (5)

Where, C_0 = initial fluoride concentration (mg/L)
C_i = treated water fluoride concentration (mg/L)
V = volume of treated water per batch (4000 L)
= (9.3– 1.5 mg/L) × 5000 L
= 39.0 g F^- per batch (6)
The quantity of fluoride removed to treat the daily water demand of 16,000 L:
= 4 batches per day × 39.0 g F^- per batch
= 156 g F^-**/** day (7)

According to Ethiopian Ministry of Water and Energy, fluoride treatment design manual, 150 g alum ($Al_2(SO_4)_3$) required to remove 1 g fluoride. The amount of lime required is 50% of the alum quantity.

Quantity of alum required per batch of treated water is,

= 39 g F^- × 150 g/ 1 g F^- (8)
= 5.85 kg alum (9)

Quantity of lime per batch = 50% × 5.85 kg = 2.93 kg (10)
Quantity of alum required per day (to treat 16,000 L) = 4 batches × 5.85 kg alum/batch
= 23.4 kg/day (11)
Quantity of lime per day = 4 batches × 2.93 kg lime/batch = 11.72 kg lime/day (12)

SI-II Design of Electrolytic Defluoridation System (EDF)

Raw water fluoride concentration (C_0) = 7.93 mg/L
Treated water fluoride concentration = 1.5 mg/L (WHO 1984).
Present project users = 3000 persons
Growth rate (r) = 3%
Project life (n) = 10 years
Projected population (P) = Po $(1+ r)^n$ (1)

$P = 3000\ (1+3\%)^{10} = 4000$ persons (2)

Quantity of treated water consumption per day =

water consumed per person per day × number of people (3)

= 4 L/P/D X 4000 persons = 16,000 L/day (4)

Four tankers of each with 1000 Lcapacity are needed to treat the 16,000 Liters of water in four batches to meet the daily demand.

The dimension of the defluoridation tank is 100 cm(wide), 105 cm (length) and 110 cm (depth). The net height of the tanker after provision of slope for sludge removal (10cm) and free board (20 cm) is 80cm. The dimension of one compartment (tanker) of the EDF system is shown in Figure S2-1 below.

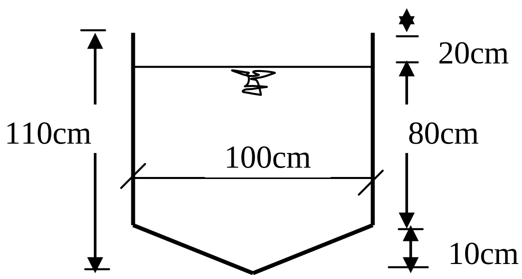

Figure S2-1. Dimension of one compartment (tanker) of the EDF system. The bottom wedge is for sludge removal.

Volume of the tanker is calculated below:

Volume of the rectangular section of the tanker:

$=1.0\ m \times 0.9\ m \times 1.05\ m = 0.945\ m^3$ (5)

Volume of the triangular section = $(0.5 \times 1.0\ m \times 0.1\ m) \times 1.05\ m = 0.0525\ m^3$ (6)

The total of volume of one compartment of the EDF system is 1.0 m^3 (1000 L).

Dimensions of aluminum plate (electrode) fitting to the tanker:

= 90 cm (length) × 80 cm (high) × 2 mm (thick)

Number of aluminum plate used in each tanker = 3, where the first and the third plates are used as cathodes and the central plate is anode. The distance between the electrodes is 1cm.

Weight of Aluminum plate = $\rho_{aluminum}$ X V (7)

Where, ρ is density of aluminum (kg/m^3), and V is the volume aluminum plate (m^3)

= 2700 kg/m^3 × (0.9 m× 0.80 m × 0.002 m)

= 3.9 kg (8)

Using Faraday's law, the weight of aluminum dissolved (m) can be calculated as:

$m = KIt$ (9)

$m = (C_o - C_i) \times V \times$ (Al/F ratio) (10)

m = (7.93-1.5 mg/L) × 1000 L ×4 = 25.72 mg per tank (11)

In Equation 9, K is a constant determined using,

$K = M/ZF$ (12)

where, M is atomic weight of aluminum, Z is valency of aluminum and F is Faraday's constant = 96500.

$$K = \left(\frac{27}{3X96500}\right) = 9.326X10^{-5} \quad (13)$$

Therefore, from m = KIt,

$$It = m/k = 25.72/(9.326X10^{-5}) = 275{,}788 \quad (14)$$

Considering current, I = 25 Amp,
Electrolysis time,

$$t = 275{,}788/25 = 11{,}315\ s = 184\ min = 3\ h \quad (15)$$

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Use of integrated pollution indices in assessing heavy metals pollution in soils of three auto mechanic villages in Abuja

Nwoko Christopher Ikpe[1], Enenebeaku Conrad Kenechukwu[1] and Ekeocha Christopher Ikechukwu[2*]

[1]Department of Chemistry, Federal University of Technology P. M. B. 1526, Owerri, Imo State, Nigeria.
[2]Mathematics Programme (Applied), National Mathematical Centre, Sheda Kwali, P. M. B. 118, Gwagwalada, Abuja, Nigeria.

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This research work targeted at the use of integrated pollution indices models of Pollution Index (PI), Average of Pollution Index (PI_{Avg}), Pollution Load Index (PLI) and Nemerow Pollution Index ($NIPI_{Nemerow}$) in assessing heavy metals pollution in soils of three auto mechanic villages of Abuja. Soil samples were randomly collected with a stainless hand auger to a depth range of 0 to 15 cm and were analyzed with atomic absorption spectrophotometer of model Unicam 969 Solar to determine the heavy metal contents in them. Mean concentration (mg/kg) of heavy metals from the results were observed to follow a decreasing order; Apo: Cu (7668) > Zn (5360) > Cr (1174) > Fe (467) > Pb (333) > Ni (196) > Cd (10.5); Kugbo: Zn(1587) > Cu (1042) > Cr (783) > Ni (234) > Fe (217) > Pb (170) > Cd (9.47) and Zuba: Zn(1190) > Cr (767) > Cu (512) > Fe (279) > Pb (250) > Ni (127) > Cd (10.4). Strong positive correlations exist between heavy metals which indicate same source of contamination, mutual dependence and identical behaviors. Results of integrated pollution indices showed that investigated soils have been polluted to various degrees ranging from low to high level pollution. This indicates deterioration of sites quality.

Key words: Auto mechanics villages, atomic absorption spectrophotometer, heavy metals, integrated pollution indices, soil, statistical analysis.

INTRODUCTION

One of the major fallout of industrialization and urban development is the release and accumulation of heavy metal containing wastes and other environmental pollutants in the environment (Du et al., 2013). Pollution of natural environment by heavy metals over the years has been a global problem due to their indestructive nature, potential toxicity, wide spread sources, non-biodegradable nature, and bioaccumulation properties (Kacholi and Sahu 2018; Ihejirika et al., 2016; Zhu et al., 2012). Pollution sources of heavy metals in environment

*Corresponding author. E-mail: x2xtopher@yahoo.com; nwokochristopher@yahoo.com.

are mainly from anthropogenic sources which include; traffic emission (Wei et al., 2010), industrial emission (Jiang et al., 2017; Ekeocha et al., 2017; da Silva et al., 2016; Du et al., 2015; Jiang et al., 2014), and agricultural processes (Arao et al., 2010). Heavy metals can exert their toxicity via dermal, skin contacts (exposure/ absorption), inhalation and ingestion which all have adverse effect on health of humans and organisms (De Miguel et al., 2007). Bioaccumulation of heavy metals in human tissue can lead to some health problems like: cellular and tissue damage, infertility, neurotoxic effects in children, circulatory and nerve tissues damage, breakage of metabolism route, heart and liver disease, kidney damage, chronic renal, cancer, lung infection, cardiovascular diseases, respiratory system disorders, skin and tooth decay among others (Jarup et al., 2013; Damek-Proprawa et al., 2003). Hence there is need to assess the contamination level and environmental effects of selected heavy metals in major auto mechanic villages of Abuja, bearing in mind the inflow of vehicles to these auto mechanic sites on daily basis for various vehicle maintenance.

With the development of ecological and exploration geochemistry survey, a great deal of data related to heavy metal concentration in soils and water sediments have been measured which can be used to assess the quality of ecological geochemistry environment. Many calculation methods have been presented to assess the environmental quality, such as pollution index (Gong et al., 2008) and Principle correlation (Cheng et al., 2007). Pollution index is a powerful tool for processing, analyzing and conveying raw environmental information to decision makers, managers, technicians and the public (Caeiro et al., 2005). This research was carried out in Abuja, North Central part of Nigeria in order to evaluate the contamination level(s) of various heavy metals in soils in selected auto mechanic villages in the area. Nevertheless, the research was not conducted as a regulatory sampling or as a result of an outbreak of any disease. The sole objective was to assess the levels of heavy metals in soils and to evaluate the degree of contamination of soils by heavy metals using various integrated pollution indices models.

MATERIALS AND METHODS

Study sites, sample collection and analysis

The study was conducted in three major auto mechanic villages in Abuja namely; Apo, Kugbo and Zuba (Figure 1). The area is located in the North-Central part of Nigeria with geographical coordinates of latitude 9°40' N and 9°29' E. The city also shares a land border with six other states namely: Benue, Kaduna, Kogi, Nassarawa, Niger and Plateau States. Soil samples were randomly selected with a stainless hand dug auger to a depth range of 0 - 15 cm with five of the soil samples drawn from each of the mechanic villages (Apo, Kugbo and Zuba). A control sample was also collected from a distance of 100 km were neither industrial nor commercial activities takes place. Sampled soils were homogenized, air dried; crushed and sieved in a mechanical sieve of mesh size 338 μm with make Endecott's Limited London, England, serial number 489494. Heavy metals concentrations in each sample were determined using atomic absorption spectrophotometer (Unicam 969 Solar) immediately after digestion of soil samples (George et al., 2013; Kouadia et al., 1987). The sampling and analyses were all done in the month of November, 2014.

Statistical analysis

Descriptive statistics were conducted to determine the average, range, mean and standard deviations of investigated heavy metals in soil samples. Person's correlations matrix was also performed to evaluate sources of heavy metals in soils of studied sites, the dynamic of the contamination and potential relationship among measured variables. Statistical analysis was done using IBM SPSS 16.0 software.

Integrated pollution indices assessment

Integrated indices are indicators used to calculate more than one metal contamination which are based on single indices and each kind of integrated index might be composed by the above single indices separately (Gong et al., 2008). Four integrated pollution indices: Pollution Index (PI), Average of Pollution Index (PI_{Avg}), Pollution Load Index (PLI) and Nemerow Pollution Index ($NIPI_{Nemerow}$) were used.

Pollution index

Pollution index is defined as the ratio of the metal concentration in the city to the background concentration of that metal (Wei et al., 2009).

$$PI = \frac{C_i}{C_{ri}} \quad (1)$$

Where C_i is the mean concentration of each of the investigated metal in soil or sediment drawn from at least five sampling sites and C_{ri} is the background value of the metal. In order to unify the assessment results, reference values as provided by DPR (2002) were used as background values (Cr = 100, Fe = 5000, Ni = 35, Cu = 36, Zn =140, Cd = 0.8 and Pb = 85). The following terminology was used for the pollution index model: PI < 1, non pollution; 1 ≤ PI < 2, low level pollution; 2 ≤ PI < 3, moderate level of pollution; 3 ≤ PI < 5, strong level of pollution; PI ≥ 5, very strong level of pollution (Yang et al., 2011).

An average of pollution

An average of pollution index (PI_{Avg}) model is an aspect integrated indices used to calculate more than one metal contamination and it's mathematical written as:

$$PI_{Avg} = \frac{1}{m}\sum_{i=1}^{m} P_i \quad (2)$$

Where P_i is the single pollution index of heavy metal i and m is the count of the heavy metal specie. Values of $PI_{Avg} < 1$ indicates high

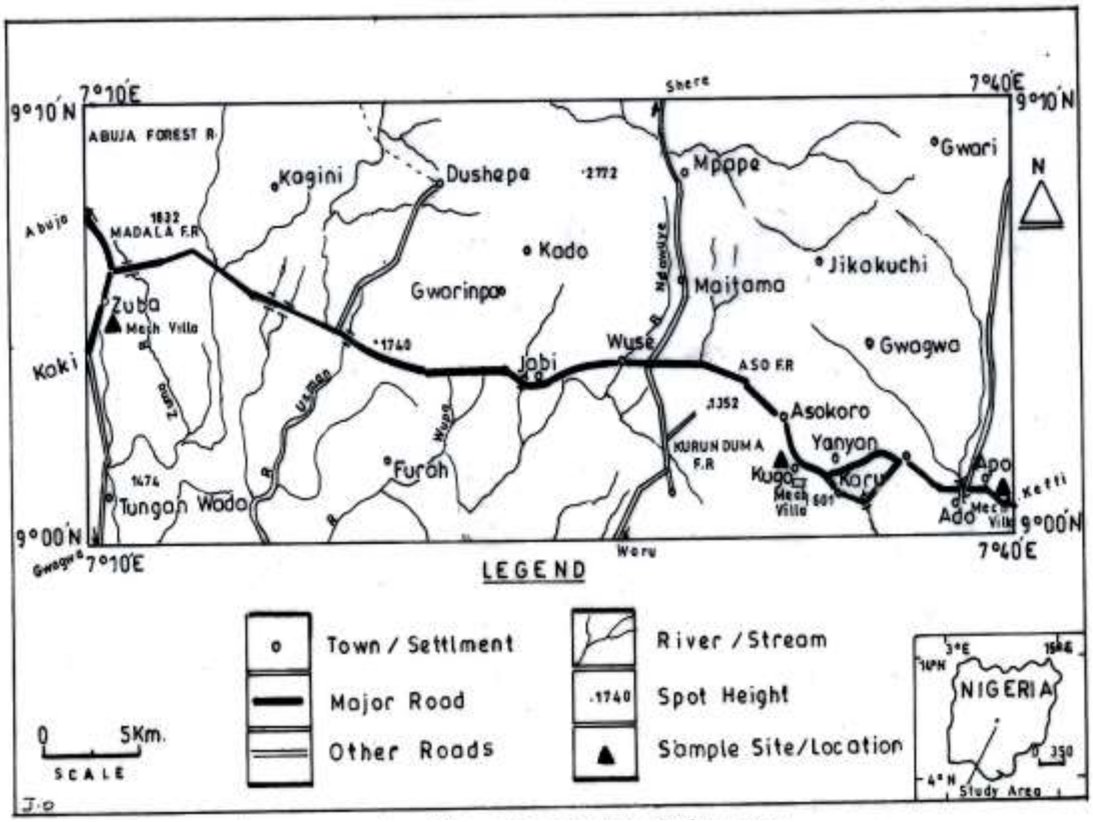

Figure 1. Geographical location of investigated Auto Mechanic Sites in Abuja.

quality soil and $PI_{Avg} > 1$ indicates low quality soil. This type of pollution index was used to assess the quality of abandoned-mined-tailings environment (Bhattacharya et al., 2006).

Pollution load index

Pollution load index is an example of root of the product of pollution index indices which is based on contamination factor of each metal in soil. This aspect of integrated pollution indices have been used to quantify pollution load of heavy metals in both soils and sediments. The model also provides an easy and comprehensive means of assessing the quality of an investigated site (Waheshi et al., 2017; Goher et al., 2014).

$$\text{PLI can be defined as; } PLI = (PI_1 \times PI_2 \times PI_3 \times \text{------} PI_n)^{\frac{1}{n}} \quad (3)$$

Where PI is pollution load index of individual metal described earlier and n is the number of investigated metals. The following terminology was used for the pollution load index: PLI < 1, perfection; PLI = 1, only baseline levels of pollutants present; and PLI > 1, deterioration of site quality (Tomlinson et al., 1980).

Nemerow pollution index

The formula of Nemerow pollution index contains the biggest monomial pollution index in the evaluation of parameter which illustrates the effect of the pollutant the highest pollution index on the environmental quality. In recent times, some researchers have applied Nemerow pollution index model in assessing the quality of soil in an environment (Jiang et al., 2014; Cheng et al., 2007).

$$NIPI_{Nemerow} = \frac{\sqrt{\left(\frac{1}{m}\sum_{i=1}^{m} P_i\right)^2 + \left(P_{imax}\right)^2}}{2} \quad (4)$$

Where, P_i is the single pollution index of heavy metal i; P_{imax} is the maximum value of the single pollution indices of the investigated heavy metal(s) and m is the count of the heavy metal species. The quality of soil were classified into five categories from Nemerow pollution index: $NIPI_{Nemerow} < 0.7$, unpolluted, $0.7 \le NIPI_{Nemerow} < 1.0$, little pollution; $1.0 \le NIPI_{Nemerow} < 2.0$, slight pollution; $2.0 \le NIPI_{Nemerow} < 3.0$, moderate pollution; $NIPI_{Nemerow} \ge 3.0$, serious pollution (Cheng et al., 2007). Sum of pollution index can be mathematically defined as:

$$PI_{sum} = \sum_{i=1}^{m} P_i \quad (5)$$

Where P_i is the single pollution index of heavy metal i and m is the count of the heavy metal species. The sum of pollution index was widely used in soil and sediment quality assessment by heavy metal such as the degree of contamination and potential ecological risk index (Maanan et al., 2014; Håkanson et. al., 1980).

Table 1. Heavy metal concentration in soils (mg/kg) in investigated sites compared with permissible limits of some international regulatory bodies

Samples	Cr	Fe	Ni	Cu	Zn	Cd	Pb
A_{p-1}	1117	561	238	1677	8200	12.5	96.4
A_{p-2}	1173	426	212	22000	5288	11.5	357
A_{p-3}	1916	423	402	12830	8421	10.6	967
A_{P-4}	814	411	48.6	219	847	8.90	194
A_{p-5}	848	512	80.5	1616	4045	8.90	51.7
Average	1174	467	196	7668	5360	10.5	333
Mean ±SD	1174±444	467±66.4	196±141	7668±9488	5360±3144	10.5±159	333±373
Range	814-1916	411-561	48.6-402	219-22000	847-8421	8.94-12.5	51.7-967
K_{u-1}	911	203	195	3144	2869	1.20	89.6
K_{u-2}	288	320	370	407	719	10.2	201
K_{u-3}	726	259	110	340	2016	15.2	316
K_{u-4}	915	145	178	1017	1441	1.50	15.7
K_{u-5}	1074	157	318	306	890	19.2	225
Average	783	217	234	1043	1587	9.47	170
Mean ±SD	783±303	217±73.3	234±107	1043±1210	1587±879	9.47±8.07	170±118
Range	288-1074	145-320	110-370	340-3144	719 - 2869	1.20-19.2	15.7- 316
Z_{u-1}	830	302	187	686	410	10.2	199
Z_{u-2}	764	331	148	351	976	12.5	58.3
Z_{u-3}	1120	195	127	956	1010	9.50	249
Z_{u-4}	630	306	126	352	1710	8.80	443
Z_{u-5}	491	260	48.0	217	1845	11.1	298
Average	767	279	127	512	1190	10.4	250
Mean ±SD	767±236	279±53.4	127±50.7	512±302	1190±589	10.4±1.41	250±140
Range	491-1120	195-331	48.0-187	217-956	410-1845	8.84-12.5	58.3-443
C_T	1108	2.45	108	37.3	73.4	na	102
B_T	100	5000	35.0	36.0	140	0.80	85.0
I_V	380	nl	210	190	720	17.0	530
UK [a]	130	n.a	130	n.a	n.a	10	450
Poland [c]	100	n.a	100	100	300	3.0	100
Japan [d]	n.a	n.a	100	125	250	n.a	400
Canada [e]	250	n.a	100	150	500	3.0	200
Germany [f]	200	n.a	100	50	2	300	500

Ap, Apo auto mechanic village; Ku, Kugbo auto mechanic village; Zu, Zuba auto mechanic village; C_T, control sample; na, not available; B_T, background values of DPR (2002); I_V, intervention value of DPR (2002). n.a, not available; n.l, no limit, [a]Kamunda et al. (2016);; [c]Mtunzi et al. (2015); [d]Fagbote et al. (2010); [e]Canadian Ministry of the Environment (2009); [f]Lacatusu (2000).

RESULTS AND DISCUSSION

Results of concentrations of heavy metal (mg/kg) in soil from investigated sites are presented in Table 1. The results revealed that in Apo auto mechanic village, values of investigated heavy metals fluctuated as follows; Cr (814 to 1916) mg/kg; Fe (411 to 561) mg/kg; Ni (48.6 to 402) mg/kg; Cu (219 – 22000) mg/kg; Zn (847 to 8421) mg/kg; Cd (8.90 to 12.50) mg/kg; and Pb (51.7 – 967) mg/kg. A trend of decrease in mean values of heavy metal concentration in Apo can be deduced as Cu > Zn > Cr > Fe > Pb > Ni > Cd. Values of heavy metals in Kugbo auto mechanic village also fluctuated as follows; Cr (288 to 1074) mg/kg, Fe (145 to 320) mg/kg, Ni (110 to 316) mg/kg, Cu (306 to 3144) mg/kg, Zn (719 to 2869) mg/kg, Cd (1.20 to 19.2) mg/kg and Pb (15.7 to 316) mg/kg.

Values of heavy metal in Zuba also fluctuated between (491 to 1120), (195 to 331), (48 to 187), (217 to 956), (410 to 1845), (8.80 to 12.5), and (58 to 443) mg/kg in Cr, Fe, Ni, Cu, Zn, Cd and Pb respectively. Comparatively

Table 2. Pearson's correlation coefficient matrix for heavy metals in investigated auto mechanic villages.

Apo	Cr	Fe	Ni	Cu	Zn	Cd	Pb
Cr	1						
Fe	-0.275	1					
Ni	0.962**	-0.073	1				
Cu	0.523	-0.490	0.530	1			
Zn	0.745	0.394	0.883*	0.330	1		
Cd	0.374	0.379	0.603	0.405	0.762	1	
Pb	0.943	-0.565	0.827	0.549	0.483	0.121	1
Kugbo							
Cr	1						
Fe	-0.928*	1					
Ni	-0.370	0.267	1				
Cu	0.277	-0.221	-0.274	1			
Zn	0.326	-0.144	-0.724	0.814	1		
Cd	0.003	0.179	0.283	-0.739	-0.508	1	
Pb	-0.268	0.530	0.050	-0.575	-0.201	0.865	1
Zuba							
Cr	1						
Fe	-0.532	1					
Ni	0.535	0.365	1				
Cu	0.949*	-0.626	0.498	1			
Zn	-0.654	-0.098	-0.867	-0.643	1		
Cd	-0.228	0.402	-0.074	-0.415	-0.149	1	
Pb	-0.321	-2.226	-0.389	-0.138	0.643	-0.840	1

Significant /r/*($p < 0.05$); ** ($p < 0.01$)* ($n = 5$).

mean values of heavy metals in all the sites were observed to have exceeded those from control, DPR background value and those of some international regulatory bodies (Table 1). They also exceeded those reported by some researchers (Mugoša et al., 2016; Kamunda et al., 2016). This indicates that the studied sites have been contaminated by heavy metals generated from various auto mechanic repairs carried out the studied sites.

In other to determine the relationships that exist among the investigated heavy metals, Person's correlation analyses were conducted and the results are shown in Table 2. The results showed that in Apo site, strong positive correlation exist between Cr and the following metals; Ni, Pb, Zn (0.962**, 0.943*, 0.745) respectively. Ni also had good positive correlation with Zn, Pb, Cd and Cu (0.883*, 0.827, 0.603 and 0.530), Zn/Cd (0.762) and Cu/Pb (0.549). The results obtained also showed that the investigated heavy metals have mutual dependence, identical behaviour and same origin. Negative correlation also exist between Fe/Pb (-0.565*), Fe/Cu (-0.490) and Fe/Cr (-0.275) indicating different source(s). Strong positive and negative correlation exists between the following metals in Kugbo site; Cd/Pb (0.865), Cu/Zn (0.814), Fe/Pb (0.530), Cr/Fe (-0.928*), Cu/Cd (-0.739), Ni/Zn (-0.724), Cu/Pb (-0.575) and Zn/Cd (-0.508). In Zuba auto mechanic village, strong negative correlation also exist between Zn/Ni (-0.867), Cd/Pb (-0.823), Zn/Cr (-0.645), Zn/Cu (-0.643) and Fe/Cu (-0.626) with few strong positive correlation among Cr/Cu (0.947*) and Zn/Pb (0.643).

Results of the pollution index (PI) shown in Table 3 reveal that in Apo auto mechanic village, 71.24% of investigated heavy metals: Cu, Zn, Cd, Cr and Ni were in the class of very strong level of pollution. Pb and Fe were also in the class of strong level and non-pollution. In Kugbo auto mechanic village, 71.24% of the heavy metals were in the class of very strong level of pollution leaving 14.28% of it to moderate and non-pollution respectively. 57.14% of the heavy metals in Zuba auto mechanic village were also in the class of very strong level of pollution with 21.43% of the metals in the class of serious and non-pollution. High (PI_{Avg}) values (Table 3) recorded in the three sites depicts that soil in these sites

Table 3. Values and categories of Pollution Index (PI), Average of Pollution Index (PI_{Avg}), Pollution Load Index (PLI) and Nemerow Pollution Index ($NIPI_{Nemerow}$).

Sites		Cr	Fe	Ni	Cu	Zn	Cd	Pb	PI_{Avg}	PLI	$NIPI_{Nemerow}$
Apo	C_i	1173	467	196	7668	5360	11.1	333			
	C_{ri}	100	5000	35	36	140	0.80	85			
	PI	11.7	0.093	5.60	213	38.3	13.9	3.92	40.9	8.26	153.4
	category	v_{sp}	n_p	v_{sp}	v_{sp}	v_{sp}	v_{sp}	s_p	lq	dsq	sp
Kugbo	C_i	783	216	234	1043	1587	9.40	169			
	C_{ri}	100	5000	35	36	140	0.80	85			
	PI	7.83	0.043	6.70	29.0	11.3	11.8	1.99	9.81	1.83	21.65
	category	v_{sp}	n_p	v_{sp}	v_{sp}	v_{sp}	v_{sp}	m_p	lq	dsq	sp
Zuba	C_i	767	278	127	512	1190	10.4	250			
	C_{ri}	100	5000	35	36	140	0.80	85			
	PI	7.67	0.056	3.63	14.2	8.5	13.0	2.94	7.14	3.59	11.24
	category	v_{sp}	n_p	s_p	v_{sp}	v_{sp}	v_{sp}	m_p	lq	dsq	sp

C_i, mean concentration of heavy metals from at least five points; C_{ri}, background value; PI; pollution index; n_p, non pollution; l_p, low level pollution, m_p, moderate level of pollution; s_p, strong level of pollution; v_{sp}, very strong level of pollution; PI_{Avg}, average of pollution index; lq, low quality of soil; hq, high quality of soil; PLI, pollution load index; p, perfection; bp, baseline pollutants; dsq, deterioration of site quality; $NIPI_{Nemerow}$, Nemerow pollution index; s_p, slightly polluted; mp, moderately polluted; sp, seriously polluted.

have low quality due to contamination by heavy metals. Results of pollution load index also revealed that Apo, Kugbo and Zuba sites had PLI values of 8.26, 3.99 and 3.59 which are all greater than 1 which indicate deterioration of site quality due to pollution. These values were also higher than those reported by Goher et al. (2014).

Conclusion

Different pollution indices models employed in the calculation of heavy metal pollution in soil samples from three auto mechanic villages of Abuja showed that mean content of these heavy metals (mg/kg) follow a decreasing order of: Apo site: Cu > Zn > Cr > Fe > Pb > Ni > Cd; Kugbo site: Zn > Cu > Cr > Ni > Fe > Pb > Cd and Zuba site: Zn > Cr > Cu > Fe > Pb > Ni > Cd. These values also exceeded those from control, background values of national and some international regulatory bodies. Results of correlation analysis indicated that some of the investigated heavy metals in all the sites are mutually dependence with identical behaviour and same origin.

Integrated pollution indices assessment conducted reveal that soils in the investigated sites have been polluted to various degrees by heavy metals. These heavy metals could also be traceable to anthropogenic sources probably from various auto repairs done in the area which poses serious ecological risk to human, organisms and environment at large.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Phytoplankton species diversity and biomass and its impact on the sustainable management of Lake Bosomtwe in the Ashanti Region of Ghana

ADDICO Gloria[1], AMU-MENSAH Frederick K.[1*], AKRONG Mark O.[2], AMU-MENSAH Marian A.[3] and DARKO Humphrey[3]

Council for Scientific and Industrial Research, Water Research Institute, Accra, Ghana.

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Lake Bosomtwe is a closed, stratified, natural freshwater body located in the Ashanti Region of Ghana. Recently residents along the Lake shore complain of foul smells emanating from the Lake and also there have been occasional fish deaths there. This led to the study of the composition of phytoplankton community dominating the lake. Sampling was done during the rainy and dry seasons. Samples were collected from twelve towns along the lakeshore. Phytoplankton samples were collected using clean 100-ml bottles and fixed with Lugol's solution. In the laboratory, phytoplankton was identified using a Carl Zeiss inverted microscope. The results obtained during the dry season (August) showed the dominance of blue-green algae in all the twelve stations, comprising more than 90% of the biomass as was also found in the rainy season. This implied that the presence of the blue-green algae in Lake Bosomtwe was not seasonal but all year round, and is also nutrient-dependent as shown by the chemical data collected during the studies. However, the green algae population reduced from 6.2 to 3.7%, in August while the diatoms increased from 0.9 to 3.5%. Notable among the blue-green algae were *Cylindrospermopsis*, *Planktothrix* and *Spirulina* for both the dry and rainy seasons. A positive correlation was obtained between temperature, phytoplankton and dissolved oxygen. This was expected as the blue-green algae which form over 90% of the phytoplankton counts are favoured by elevated water temperatures, a phenomenon which is notable of tropical Lakes. A mean temperature of 27°C was recorded in Lake Bosomtwe. High mean temperature (27°C) and high nutrient of the lake, coupled with its stagnant nature had led to its eutrophic state and the proliferation of blue-green algae. Some blue-green algae contain toxins that are toxic to both man and animals. These could be the cause of the occasional fish deaths and foul smells emanating from the Lake.

Key words: Lake Bosomtwe, fish deaths, phytoplankton, sustainability, blue-green algae, eutrophic state, Ghana.

INTRODUCTION

The importance of phytoplankton in nature, especially in aquatic ecosystem dynamics is beyond question.

*Corresponding author. E-mail: fkamu.mensah@csir-wter.com Tel: +233–24-474-8197.

Planktons' primary production provides the base upon which the aquatic food webs are founded. This results in the natural fish populations being exploited by man (Reynolds, 1993). Phytoplankton also generates about 75% of atmospheric oxygen supply through the process of photosynthesis (Selorm, 2014). This is possible due to the large surface area of water bodies that house the organisms, as well as the relatively larger specific surface area of the plankton. Photosynthesis is also responsible for the transformation of carbon dioxide from the atmosphere into food and energy. Worldwide, this "biological carbon pump" transfers about 10 Gigatonnes of carbon from the atmosphere each year into food chains (Birdsey et al., 2009). Cyanobacteria have the ability to fix atmospheric nitrogen within their cells. In some cases nitrogen fixation by cyanobacteria contributes as much as 50% of the annual nitrogen input into lakes (McCarthy, 1980). Phytoplanktonic organisms are sensitive indicators, as their structure and metabolism changes quickly in response to environmental changes (Reynolds et al., 1987) and are therefore used as a basis for preparing and monitoring the strategies for management of lakes. Growth rate of phytoplankton is subject to cyclic changes; fluctuation and succession play a vital role in all aquatic ecosystems (Arhonditsis et al., 2004). However, unnatural or excessive growth of algae especially the cyanobacteria (Harmful blooms) may interfere with the enjoyment of aquatic resources and may even be harmful (Odum, 1971 Oberemm, 2001). The pressure from human activities along Lake Bosomtwe has led to decreasing water quality as evident by the response of respondents in a survey (Amu-Mensah et al., 2014). These people testify that certain species of fishes which they used to catch during their fishing activities were no longer there, as well as the occasional death of fishes, skin irritation and foul odour emanating from the water. It is for these reasons reported by Amu-Mensah et al. (2014), that the study of the phytoplankton interplay in Lake Bosomtwe was initiated.

Study area

Lake Bosomtwe is located in the Ashanti Region of Ghana within latitudes 6° 28' 15.11"N and 6° 32' 28.53"N and longitudes 1° 24' 24.06"W and 1° 26' 46.30"W (Figure 1). It lies within the semi-deciduous forested zone of West Africa (Hall and Swaine, 1981). It is the only natural closed lake in Ghana and Africa, and the third largest closed lake in the world. The lake is enclosed within two administrative districts namely, Bosomtwe District and the newly created Bosome-Freho District. The catchment is semi-forested and semi-cultivated. The steep-sided catchment has no outflows. Over 80% of its water input is from direct rainfall and loses most of it through evaporation (Amu-Mensah et al., 2014, 2017).

For the most part of the year, Lake Bosomtwe is stratified (Puchniak et al., 2009).

The main livelihood activities of the people are fishing and agriculture. Recently, tourism has developed in Abono, Ankaase and Abrodwom with its negative effects on the Lake's environment. Rainfall is high ranging from 1,419.8 to 1,454.3 mm indicating significant humid periods within each year. Temperatures are moderate to high for the most part of the year ranging from 20°C in August to 32°C in March. This allows for high yields of agricultural cash crops such as cocoa, plantain, cassava, cocoyam, maize and vegetables including pepper, tomatoes, okra and garden eggs.

METHODOLOGY

The catchment of Lake Bosomtwe was divided into four zones, namely North, South, East and West to reflect the human and economic activities within the watershed. Some of these activities were tourism, agriculture, irrigation, fishing, hunting, animal watering, recreation, building and water cooling for small breweries. Sampling was done between April and August 2015, which represents the end of the dry season and the start of the raining season. A total of twelve phytoplankton samples were collected each during the raining and dry seasons. These were from Pipie, Nkawie and Amakom from the East, Esaase, Adwafo and Apewu in the West, Duase, Dompa, Agyamanmu and Ankaase in the South and Obo Nsebi and Abono in the North. Samples were collected using the Van Dorn water sampler. This is an integrated water sampler. Samples were fixed in Lugol's solution immediately after collection and transported to the laboratory of the CSIR-Water Research Institute for identification and counts. Activities around the surroundings of the sampling locations were noted.

In the laboratory, water samples were well shaken and aliquots of 25 ml were transferred into counting chambers for microscopic study. Identification and enumeration of algae were done using a Carl Zeiss inverted microscope with a counting chamber as described by Lund et al. (1958). Sedimentation was carried out in counting chambers with a settling time of four hours for every 1 cm of the water column of the sample (Wetzel and Likens, 1991). All colonies and filaments were counted as individuals, and the average number of cells was determined for 20 individuals and cell concentration calculated at 20% error. In order not to contaminate the samples, counting chambers were cleaned with detergent after each sample analysis and the cover slides were also changed. Identification was carried out using a combination of identification books (Cronberg and Annadotter, 2006).

RESULTS AND DISCUSSION

A total of 16 taxa were identified in the Bosomtwe Lake (Table 1). This was made up of five taxa of green algae, eight of blue-green algae and three of Diatoms. The blue-green algae dominated all the twelve stations sampled (Figure 2).

The dominance of blue-green algae is typical of most stratified lakes such as Lake Bosomtwe which is noted to have high water retention time, high surface irradiance and high surface temperature (Puchniak et al., 2009). Nutrients, especially nitrate and phosphorous mostly locked up in the bottom during stratification would not be available to other phytoplankton forms such as green algae. This gives the blue-green algae an advantage to

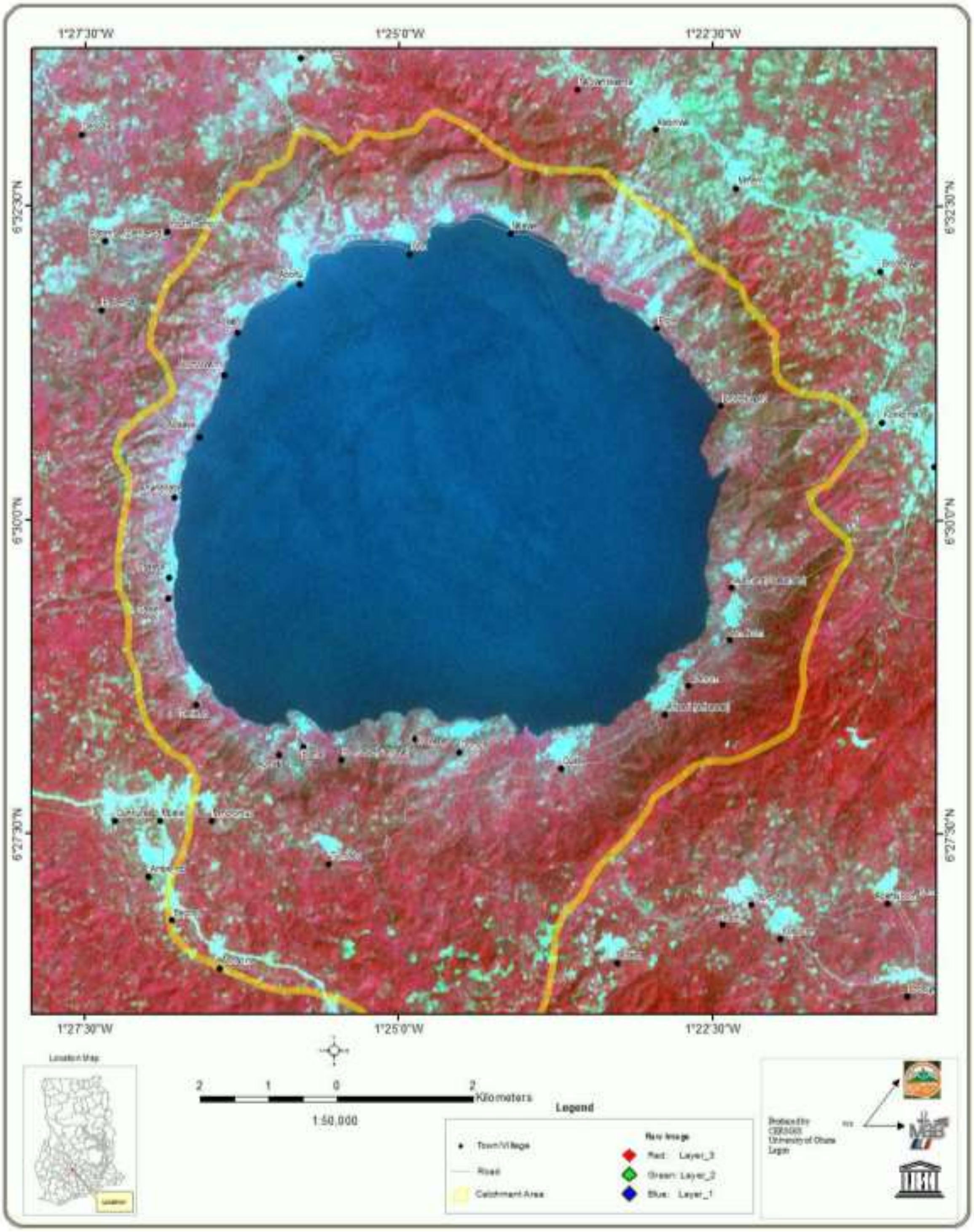

Figure 1. Raw satellite image of Catchment of Lake Bosomtwe showing watershed boundary. Source, MAB Ghana (2012).

grow and proliferate to such nuisance levels. Blue-green algae have been described as strategist (Cronberg and Annadotter, 2006). Cronberg and Annadotter (2006) gave eight reasons for blue-green algal dominance. These were total nitrogen to total phosphorous ratio, low light hypothesis, elevated water temperatures, zooplankton grazing hypothesis, trace metal hypothesis, storage strategy hypothesis and inorganic hypothesis. Lake

Table 1. Phytoplankton species distribution within the twelve stations sampled in Lake Bosomtwe in the Ashanti Region.

Species	Sampling Station (Counts/ml)											
	Esaase	Pipie	Duase	Nkawie	Obo Nsebi	Dompa	Amakom	Adwafo	Abono	Agyamanmem	Ankaase	Apewu
Green Algae												
Ankistrodesmus	79	63	93	77	106	57	46	61	93	102	69	0
Scenedesmus	66	92	4	54	69	84	84	12	28	84	67	61
Staurastrum	39	27	23	18	21	17	0	0	0	16	0	23
Ulothrix	0	28	48	64	34	24	0	0	0	28	0	0
Blue-green Algae												
Dolichospermum	0	129	56	0	0	0	75	58	0	29	0	0
Aphanocapsa	0	131	21	46	24	12	13	0	0	21	8	0
Cylindrospermopsis	48	632	398	252	481	310	96	48	28	34	32	21
Merismopedia	54	16	8	26	17	14	0	14	0	20	0	16
Oscillatoria	15	6	9	12	7	8	9	0	13	3	0	0
Planktothrix	1493	1548	1603	1583	1308	1408	1207	1314	1105	1403	1523	928
Spirulina	1320	1191	1302	1386	1423	1538	501	667	432	531	613	1223
Pseudanabaena	71	56	93	83	59	74	0	46	93	44	102	22
Diatoms												
Navicula	0	36	14	31	3	24	0	0	12	16	4	56
Pleurosigma	0	0	0	2	0	3	0	0	5	0	0	0
Synedra	13	27	8	11	18	22	0	0	0	25	3	0

Bosomtwe which is a tropical lake with high water temperatures (average of 26°C) throughout the year will benefit the blue-green algae to out - compete the other forms of phytoplankton. Blue-green algae, which have the ability to alter their position in the water column can migrate vertically down the stratified layer to assimilate stored phosphorous and nitrogen in the water for growth; this is what the green algae and diatoms are not able to do thereby out-competing them. Kromkamp (1987) reported that unlike green algae, blue-green algae has the capacity to store large amounts of nitrogen in the cytoplasmic inclusion phycocyanin and cyanophycin functioning as reserve products.

These together with other factors such as the buoyancy strategy which allow them to accumulate on the water surface and intercept necessary sunlight needed for photosynthesis, and their ability to fix their own nitrogen, have given them the unique advantage to over populate the other phytoplankton forms (Cronberg and Annadotter, 2006) (Figure 2).

Horne and Commins (1987) concluded that to induce nitrogenous activity in the blue-green algae total inorganic nitrogen must be lower than 0.050 – 0.100 µg/l. Amu-Mensah et al. (2014) reported mean values for total nitrogen as 0.272, 0.245 and 0.202 mg/l for Abono, Nana Abrewa (Apewu) and Atafram streams respectively during the study (Table 2). These three rivers are the tributaries of Lake Bosomtwe which influence the chemistry of the lake. These values are all higher than the needed total nitrogen stress to induce nitrogenase activity in the lake as reported by Horne and Commins (1987). This may imply that there is enough natural nitrogen supply in the Bosomtwe Lake to support the growth and proliferation of the blue-green algal dominance as shown in Figure 3.

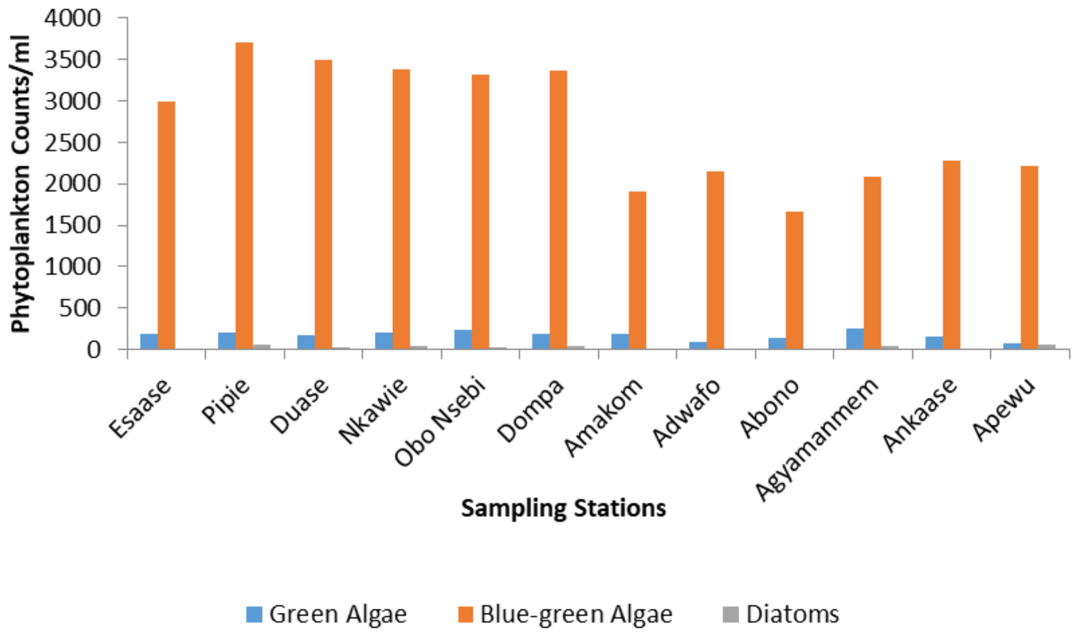

Figure 2. Composition of the various phytoplankton taxa identified in Lake Bosomtwe.

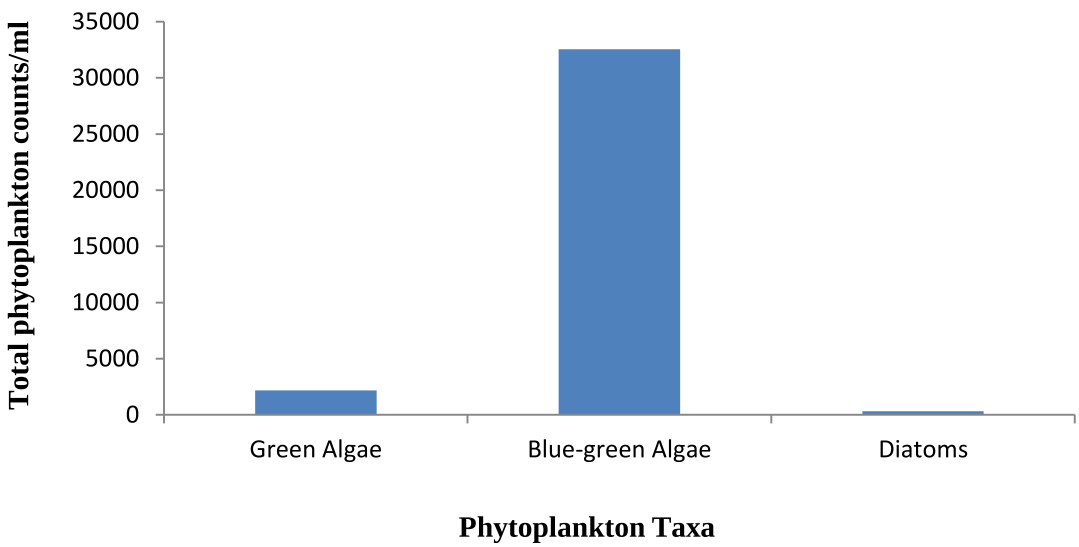

Figure 3. Dominance of blue-green algae in Lake Bosomtwe.

These unnatural nitrogen supply sources come from domestic, sewage and agricultural wastes discharged into the Lake. Calculating the nitrogen/phosphorous ratio which is a good indicator for explaining the dominance of blue-green algae dominance, as reported by Smith (1983), a low N/P ratio of 0.316, 0.308 and 0.474 was obtained for Abono, Nana Abrewa (Apewu) and Atafram streams respectively. This indicates that phosphorous which is usually the limiting factor to blue-green algae was abundant to support their growth (Chapman, 1996).

Karikari and Bosque-Hamilton (2004) reported that Lake Bosomtwe has high nutrient concentration especially nitrate-nitrogen and phosphate to support phytoplankton growth. Amu-Mensah et al. (2014) also reported very high phosphorous concentrations in the lake's water, which is above the Water Resources Commission recommended guideline of 0.1 mg/L (WRC 2003e). The high concentration of phosphorus in the lake may be due to inputs from human activities such as domestic waste-water, fertilizer leachates, and livestock

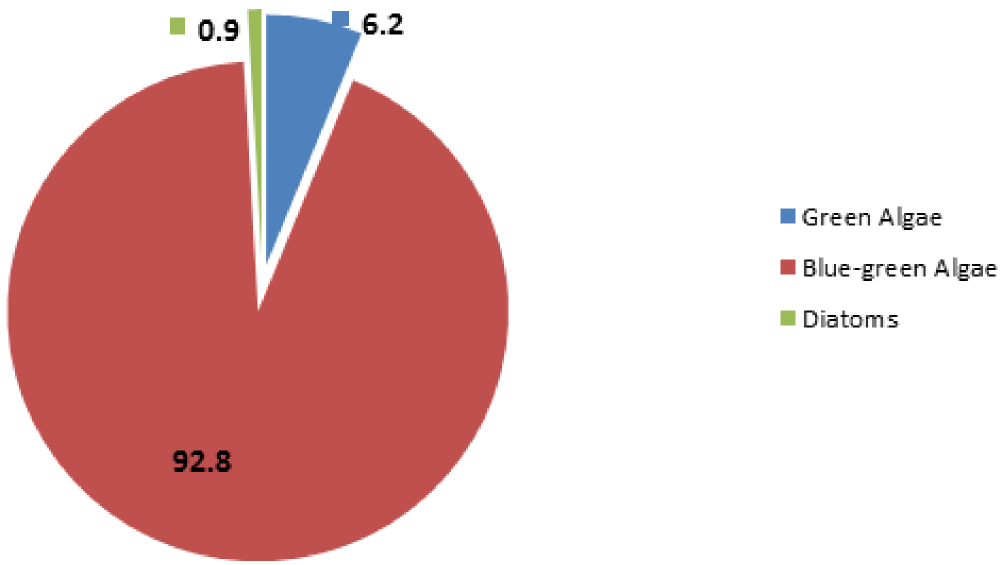

Figure 4. Phytoplankton density (%) of the three major genera recorded in Lake Bosomtwe.

Table 2. Physico-chemical data used to calculate N/P ratio.

Location	pH	Turbidity	Colour	Conductivity	TSS	TDS	NO_2-N	NO_3-N	PO_4-P	Fe	Mn	Na
Abono (Lake)	8.72	10	12.5	1161	4	639	0.132	0.104	0.748	0.052	0.007	325
Apewu	8.76	19.4	37.5	1210	2	666	0.08	0.076	0.506	<0.010	<0.005	242
Atafram	7.77	4.5	1	415	1	252	0.05	0.132	0.311	0.04	0.02	23.1

droppings from the surrounding communities (Prakash et al., 2005).

The major human activities within the catchment of Lake Bosomtwe are farming, fishing and animal rearing for domestic consumption. Recently tourism activities have increased within the catchment with some hotel facilities equipped with rudimentary sanitary facilities. Puchniak et al. (2009) also reported the dominance of blue-green algae in Lake Bosomtwe for all seasons. The blue-green dominance in Lake Bosomtwe was over 90% of the phytoplankton biomass (Figure 4). Three species of the blue green algae contributed to their high biomass.

Planktothrix is a highly toxic alga and is noted to produce a neurotoxin, a secondary amine alkaloid with toxic effect on the nervous system, and hepatotoxins, a major cyanotoxin causing illness and occasional death in both man and animal (Sivonen et al., 1990). It is possible that their high numbers recorded at all the twelve stations sampled (Table 1) may be responsible for the death of fishes in the lake and poisoning of animals along the banks of the lake as several variants of microcystins have been measured in other lakes in Ghana (Addico et al., 2006, 2009, 2017) . Fish deaths can occur directly as a result of intoxication by cyanotoxin during oral intake of contaminated water or by absorption through surface tissues (Tencalla et al., 1994). Indirectly, fish kills can occur through the process of asphyxiation when dissolved oxygen is depleted by the sudden lysis and decomposition of algal blooms during the early hours of the day (Pillay, 1992). The low density of green algae (6.2%) and diatoms (0.9%) may also be due to overgrazing by zooplankton and herbivorous fishes as blue-green algae are not palatable to them and are also not easily digested. The lake is used as a source of drinking water and other domestic activities such as cooking, washing and bathing. The high blue-green algae in the Lake can affect human health through these uses and has the potential to increase downtime, reduce productivity and the economy of the area if not controlled.

Conclusion

It is evident by the phytoplankton data supported by the chemistry of the water that Lake Bosomtwe is organically polluted by waste materials generated from within the catchment, domestic, sewage and agricultural sources. This has been compounded by the lentic (static) nature of the aquatic system. This has had direct influence on the chemistry and the type and biomass of phytoplankton in the lake and its resources.

RECOMMENDATION

There were no data collected on spatial and temporal water temperature and dissolved oxygen during this study. This would have given a better insight into the most probable if not actual cause of the occasional fish mortality in the lake. It is recommended that future studies should include these two important parameters.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effects of Changes in Use of Indigenous Knowledge Systems on Land Cover in Teso Busia County, Kenya

Ayaa Dominics Dan[1*] and Kipterer John Kapoi[2]

[1]Department of Development Studies, Daystar University, P. O. Box 44400-00100, Nairobi, Kenya.
[2]World Health Organization, Regional Office for Africa, Cité du Djoué, P.O Box 06 Brazzaville, Republic of Congo.

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This paper introduces indigenous land knowledge conservation systems as a significant resource which would contribute to the increased efficiency and effectiveness in the management of land and land based resources among rural communities. Despite their critical role in the conservation of the land based resources, these knowledge systems and technologies are being marginalized or even forgotten among rural communities. This paper discusses Teso community indigenous land conservation systems and the effects of their level of application/adoption on land use/land cover status trends from the time of Kenya's pre-independence to the 2000s era. Data was collected using a variety of social science research methods such as structured questionnaires, in-depth face-to-face interviews, focussed group discussions, content analysis of literature and environmental check lists. The status of the bio-physical environment was tracked using GIS techniques. The common Teso community indigenous land conservation systems included mixed farming, traditional terracing, use of grass-strips, agro-forestry and fallowing. Results showed that adherence to the key Teso community indigenous land management systems have been on the decline since the 1960s. This has negatively impacted on the state of the biophysical environment by increasing land area under rain-fed agriculture by 11.2% and a decline in land under seasonal swamps by 21% between 1973 and 2010. Land size under wetlands dropped by about 33% between 1973 and 2000. These changes were indicative of the negative impact of the decline in level of application of indigenous land conservation systems in the protection and conservation of these resources.. In view of the above, it is recommended that rekindling, recording and preservation of indigenous land-based best practices among local communities such as the Teso for sustainable land management must be integrated into conventional environmental management plans.

Key words: Indigenous knowledge systems, land cover, land use, conservation, Teso, Kenya.

INTRODUCTION

Since time immemorial, Indigenous Knowledge Systems (IKSs) have been used in Africa and in many other parts of the world for a number of purposes as determined by the needs of the society concerned. They include knowledge forms that have remained despite the effects of colonialism, western imperialism and ignorance

*Corresponding author. E-mail: ayaadominics@gmail.com, jkipterer@who.int/karantili@gmail.com

(Cobb, 2011).

Chikaire et al. (2012) referred to these knowledge systems as, “a body of knowledge, or bodies of knowledge of the indigenous people of particular geographical areas that have survived on for a very long period of time”.

Such knowledge is also referred to as the local knowledge that is unique to a culture or society. This knowledge is passed from generation to generation, usually by word of mouth and cultural rituals, and has been the basis for agriculture, food preparation, health care, education, natural resource conservation and for a wide range of other activities that sustain societies in many parts of the world.

A study by Tanga (2013) however reveals that in the recent decades an increasing number of case studies from across the planet have provided evidence of rapid TEK degradation. In view of this, Maffi and Woodley (2010) have argued that due to the critical role that TEK plays in shaping natural resource management strategies, its rapid degradation can have substantial implications on the quality of land based resources.

Indigenous Land Conservation Systems (ILCs) in the context of this paper refers to all traditional cultivation practices which were used to conserve soil, enhance vegetation cover protectwater resources and increase soil fertility for increased crop production.

This study sought to establish the Teso community indigenous land conservation systems and ascertain the effects of the trend in the level of use of these knowledge systems on the status on the biophysical enevironment in the study area.

Lireature review

Combert et al. (2016) note that historically, land based resources among people in most parts of the world formed the basis on which socio-economic, political, cultural and religion were founded and organized. This attachment led to the perception of sacredness of land and land based resources . In view of this Awuah-Nyamakye (2014) points out that the sacred nature of land in turn called for responsible exploitation of its resource which necessitated various ethnic groups to devise different methods and practices for its conservation. Such measures were accordingly tested over time and eventually constituted part of indigenous technical environmental knowledge systems for natural resources conservation.

Hilhorst et al. (2015) submit that these knowledge systems are better understood as practical, personal and contextual units which cannot be detached from an individual, their community, or the environment (both physical and spiritual).

Zeimbicki et al. (2013) noted that most of the indigenous land management systems began with the onset of the activities of land clearing and cultivation. According to the authors above, simple tools were used which in most cases consisted of tools that were not capable of cutting big trees or clearing large trucks of land easily and such were less destructive. Such tools included curved iron blades with long handles used to clear shrubs and grass and the planting hoes that were not capable of opening up large trucks of land or deep layers.

The use of these tools meant that large trees and forests were left largely untouched and erosion was controlled due to minimum tillage, where only the top soil was disturbed. The most common practice involved first slashing land and thereafter burning the resultant debris. This method despite leading to the deterioration of soil nutrients and living organisms, helped to control disease vectors for both human and livestock thereby enabling farmers to cut down on the cost using expensive pesticides.

A study by UNEP (2008) focusing on indigenous knowledge pertaining to disaster management in Kenya, Tanzania, Swaziland and South Africa, similarly reveals that communities in these countries practiced slash-and-burn, shifting cultivation and intercropping, as well as a number of other technologies and practices to optimise food production under varying environmental conditions. Roy et al. (2012) concur that the practice of shifting cultivation (which is an agricultural system in which plots of land are cultivated temporarily, then abandoned and allowed to revert to their natural vegetation while the cultivator moves on to another plot) has been common among rural communities in different parts of the world. Van Vliet et at. (2012) noted that the period of cultivation is usually terminated when the soil shows signs of exhaustion or, more commonly, when the field is overrun by weeds.

Besides, the length of time that a field is cultivated is usually shorter than the period over which the land is allowed to regenerate by lying fallow. Inter-cropping and mixed farming were reported to have also been commonly adopted by indigenous communities in many parts of the world. Intercropping is the cultivation of two or more crops simultaneously on the same field. It also means the growing of two or more crops on the same field with the planting of the second crop after the first one has completed its development.

Within such a system, leguminous plants that included alfalfa, peas, beans and peanuts were intercropped with non-leguminous plants including maize and cassava. The practice consisted of planting leguminous plants that compete only slightly with non-legumes crops for nutrient and which in some cases even supplied nitrogen to adjacent plants via leakage and root decomposition (fine roots grow and die rapidly within the season, even in healthy plants) as noted by Sileshi et al. (2011).

These leguminous plants within the intercropped system did not only act as cover crops but also do have modules that house Bradyhizobium bacteria that act as nitrogen fixers to the soil.

Mixed farming on the other hand is a system of farming in which a farmer conducts different types of agricultural practices together on a single farm in view of maintaining soil fertility, increasing his income through different sources as well as increasing food production. An example of mixed farming includes keeping of poultry, dairy, animals for meat, bee keeping, goat and sheep rearing, piggery and agro forestry (Bell et al., 2014).

The resultant crop production and animal rearing in this mixed system of indigenous agricultural practices enabled communities to take advantage of the ability of the cropping systems to reuse their own nutrients and the tendency of certain crops to enrich the soil with organic matter.

The above finding agrees with the observation by Lemaire et al. (2014) who note that mixed farming maintains soil biodiversity, minimizes soil erosion, helps to conserve water, and maintain the vegetation cover that provided a suitable habitat for birds, animals and insects. Besides, this system also makes the best use of crop residues and animal waste. When crop residues are not used as feed, stalks may be incorporated directly into the soil where they act as mulches and upon decomposing enriched the soil with organic matter.

Neufeldt et al. (2012) noted that another common indigenous land management practice was the tropical agro-forestry system which involved the planting of coffee under shade trees common in countries such as Uganda and Ethiopia (Inga SSP; Erytrina SSP). In such systems there was evident ample compensation of nitrogen loss at harvest with a subsidy from the shade trees litter thereby maintaining the soil nutrients (Leakey, 2010).

Mahapatra (2011) provides an example of another traditional land management system referred to as the tropical corn/bean/squash polyculture system. This system suffered less frequent attacks by caterpillars, leafhoppers, thrips and other pests, due to its capability to hinder a great numbers of parasitic wasps and by providing alternative hosts for predators and parasites.

Eskandari and Kazeni (2011) present another land management practice, known as the traditional intercropping system, common among indigenous communities especially in developing countries. This practice was capable of preventing competition from weeds due to the large crop leaf area of their complex canopies that prevented direct sunlight from reaching sunlight receptive weed species. Certain associated crops also inhibited weed germination or growth by releasing toxic substances into the environment becoming a more preferred option to the use of dangerous and expensive chemicals (Leakey, 2010)

Bell et al. (2014) observed that the traditional practice of integrating animals such as cattle, goats, sheep, swine and poultry into farming that was common among rural communities in different parts of the world, besides providing sufficient food for the communities, contributed greatly to soil fertility as animals recycled the plant content and transform it into manure that enriched soil fertility.

Based on the above literature, indigenous farming systems and technologies had certain elements of land conservation that enhanced the control of soil degradation.

However in spite of the importance of TEK in on the conservation of land, findings of a global survey by Rufei and Gavin (2016) on a classification of threats to TEK that was undertaken in 48 countries and regions between 2010-2012 found out that the degradation of TEK was widespread. The outcome from the literature sources reviewed and questionnaires indicated that TEK degradation was by far the most trend- (89%) in literature; (87%) of the questinnaires respondents (Ruifei and Gavin, 2016). Tang (2013) attributes the evident degradation government policy and legislation, contact with other cultural groups, colonization, marginalization by dominant groups, economic development pressures among other reasons.

In view of the above, this study sought to establish the Teso community indigenous land conservation systems with the view to assessing the effects of changes in the use of these knowledge systems on the land use/land cover and soil fertility within the study area in Busia County, Kenya.

METHODOLOGY

Area of study

This study sought to establish the effects of the trend in used of TEKs on the land cover in Teso, in Busia County, Kenya. It focused on the geographic area covered by two administrative divisions; Ang'urai and Chakol Divisions of Teso district in Busia County. Teso community is relatively small in size and has been dominated by the large Luhya ethic groups leading to the former's cultural beliefs and practices being marginalized and eventually getting extinct (Ayaa and Waswa, 2016)

The two Divisions were purposely selected since they marked the two extreme ends of the district-that is to say Angurai to the North and Chakol to the south and also due to the fact that the two have evidenced adverse natural resource degradation (Republic of Kenya, 2014 to 2018).

Besides, the two are home to the Teso community cultural centers and educational institutins where various cultural events and education are carried out especially by the elderly members of the community (Republic of Kenya, 2013 to 2017).

The District borders Bungoma District to the North and East, Busia District to the south and the Republic of Uganda to the West. It lies between latitude O° 20 North and O° 32 North and longitudes 34° 01 and 34° 07 East. Teso District is divided into four administrative divisions; Amagoro, Angurai, Chakol and Amukura. It covers a total land area of 558.5 km^2 (Figure 1).

Data collection proceedure

Both quantitative and qualitative approaches of data collection and analysis were used. The quantitative approach was employed to

Figure 1. Teso district location by grids (Source: Kenya Survey Maps).

quantify social phenomena, by collecting, analyzing and interpreting numerical data. This approach was also useful in quantifying and mapping the status of some selected elements of the biophysical environment during pre-and post- independent Kenya.

The qualitative approach was useful in addressing issues related to the Teso community ILCs and the effects that changes in the use of these systems have had on the bio-physical environmental status from the time of Kenya's independence up to the 2000s.

The study sample was drawn from selected members of the Teso community, government officials from the ministries of environment and natural resource management as well as representatives from Non-governmental and Private sector organizations in the district using different sampling techniques using fischer's formula.

Due to the study focus on ILCs, the researcher, despite being conscious of the role of the youth in environmental conservation, targeted only those respondents from the community who were household heads, due to their wealth of knowledge in norms and cultural issues as related to environmental conservation.

A special category of respondents consisting of the elderly (Sages) aged 70 years and above who were also included in the study sample helped the researcher track the trends in the use of indigenous land conservation systems and land use-land cover status in Teso District during the pre-independence and post-independence of Kenya. Both male and female respondents were included in the study sample.

In view of the above, a total sample size of 384 respondents was drawn for the study. From the above sample, 289 consisted of house hold heads who were randomly selected from the two administrative Divisions of Teso district. Of the remaining, 80 respondents consisted of the Teso community elders (Sages) while the 15 respondents were selected from government, Non-governmental and private sector organization within the District who were purposively selected.

The 249 household heads formed the first category of respondents who responded to questionnaires administered by researcher assisited by research assistants while the remaining 40 household heads formed a second category of respondents that were involved in the focus group discussions (four focus group discussions of between 6-10 people each-two from each of the two divisions).

Of the remaining, 50 respondents consisted of the Teso community elders (sages) 25 drawn from each of the two divisions through snow-ball technique and they formed part of the key informants in the study. Besides, another group of 30 elders from the two divisions were purposively selected and were involved in a follow up discussion on indigenous Teso community norms and environmental management systems.

The remaining 15 respondents who were also categorized as key informants were purposively selected from the top government district representatives of relevant departments as well as Non-governmental and private sector organizations whose operations have a bearing on environment and natural resource management.

Data collection methods

Several methods of collecting data were used:

Interviews and focus group discussion

Changes in the use of the Teso community indigenous land conservation systems through time were investigated by the use of in-depth interviews targeting the Sages from the two administrative divisions of the Teso District. From the study's key respondents, the researcher was able to gain historical and current information related to the community's indigenous land conservation systems and their status trends from pre-independence to the 2000s era. This information assisted in supplementing and validating information obtained through the questionnaire surveys conducted with the household heads in the two Divisions.

Similarly, from the interviews conducted with the heads of different government departments and representatives from NGOs and private sector organizations in Teso, the researcher was able to attain a clearer understanding of how ILCs are perceived and treated by different government representatives.

Questionnaires

To assess the effects of the changes in use of the indigenous land conservation systems on the land use/land cover, through time, structured questionnaires interviews were administered by the research assistants targeting individual household heads. Questionnaires containing both closed and open-ended questions enabled the researcher to gain useful and up to date information regarding the status trends in the use of the Teso community indigenous land conservation systems from pre-independence to the 2000s era. This research tool also made it possible to establish the Teso community community indigenous land management systems and analyse the perceived effects of changes in these systems on the land use/land cover through time.

Participatory observation and focus group discussions

The focus group discussions that were carried out with the household heads and the follow-up discussion with the Teso sages generated detailed past and current information regarding trends in use of ILCs and effect of this trend on the status of the bio-physical environment. Varying views, opinions, perceptions, attitudes, beliefs and experiences, on Teso community indigenous land conservation systems and their usefulness in the conservation of land based resources were generated. Trough observation, the researcher was able to deduce the clearance of bushes and trees for charcoal burning purposes, silting up of river banks, eroded riverbanks and hilly slopes, among other forms of land damage.

Geographic Information System (GIS) Tool

To ascertain changes in the land use/land cover status trends, the GIS software was used. Analysis of GIS data involved acquisition of satellite images for Teso District for the years 1973, 1986, 2000 and 2010 (for which satellite images for District were available/ found) and processing them using GIS standard procedure. Geographic information system and Remote sensing/mapping techniques were used to track and obtain accurate, current and detailed information on how the status of the bio-physical environment has changed over- time in Teso District.

The tools used were Erad 9.1 Arc View GIs 3.2 and Arc Map software

The final output was maps and a table of quantities of changes in the amount of land under rain-fed agriculture, seasonal swamps, wetland vegetation, shrub land and settlement.

Secondary data

Additional data was obtained from secondary sources such as: textbooks, newspapers, journals and electronic sources including the internet.

Data analysis methods

All questionnaire-based data was cleaned, coded and entered into statistical package for social sciences (SPSS) for analysis.

PRA and FGD data were transcribed and typed into Microsoft Word. Themes and sub-themes were created based on the study objectives of establishing the trend in the use of Teso community indigenous land management systems and analyzing the effects of changes in indigenous land conservation systems on the land cover. Coding, cutting and pasting of relevant information into the sub-themes was done. This information was later described to provide meaning in line with the objectives addressed by the study.

RESULTS

The study found out that the use of the five main indigenous land conservation systems which included: mixed farming, agro-forestry, traditional terracing, use of grass-strips and fallowing have been on the decline since the 1960s.

The results showed that, prior to 1963 the time Kenya gained internal self-rule, up to 94% of the respondents upheld the use of traditional mixed farming, 88% agro-forestry, 81% traditional terracing, 84% use of grass strips and 80% observed traditional fallowing/shifting cultivation as a strategy for maintaining the vegetation cover within the study area. However, from the 1960s to the 2000s era, use of mixed farming had declined by 20%, agro-foresty by 46%, traditional terracing by 65%, use of grass-strips 75% and following by 96% as indicated in Figure 2 and Table 1.

DISCUSSION

Mixed farming and environmental conservation

Prio to Kenya's independence when members of the Teso community greately adhered to certain common forms of indigenous beliefs and practices in general and especially those related to land conservation, any form of activities carried out on land such as farming or settlement were controlled or guided by these traditional beliefs or practices.

The common beliefs and practices that were articulated by the houasehold heads who participated in questionnaire interviews and especially the elders who

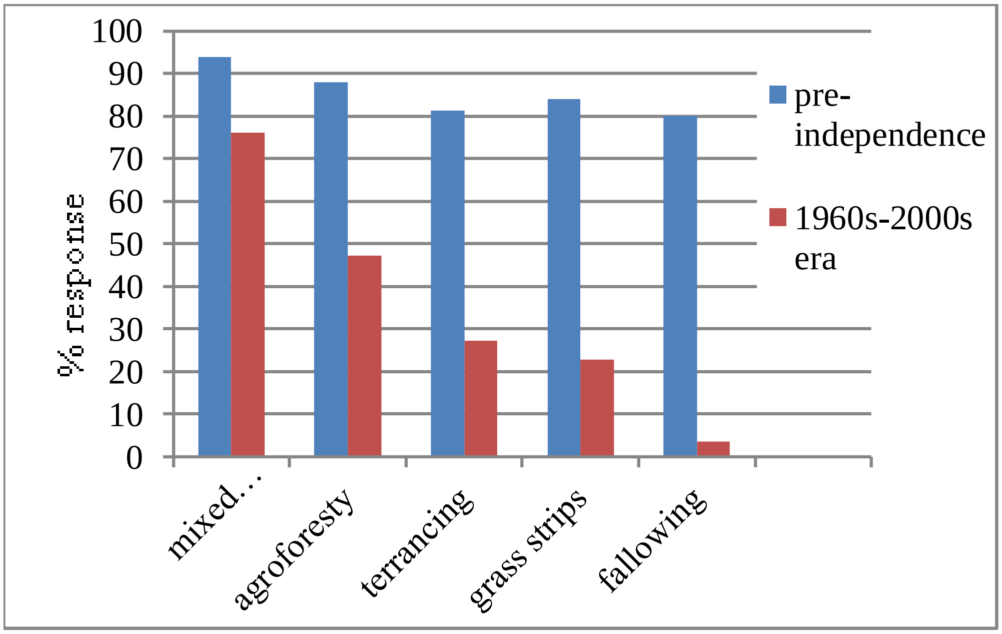

Figure 2. Changes in indigenous land management systems.
Source: GIS Data.

Table 1. Trends in the use of indigenous land conservation systems.

ILCs	Pre-independence (%)	1963-2013(%)	Trend (%)
Mixed farming	94	75	-20.2
Agro-forestry	88	48	-45.5
Traditional terracing	81	28	-65.4
Use of grass strips	84	21	-75
Fallowing	80	3	-96.2

participated in the key informant interviews included use of totems, protection of saced places, prohibitios as well as age and gender restraints.

The results from the key interviews with the Teso community elders showed that mixed farming was one of the most common forms of agriculture practiced by the majority of the Teso community members prior to Kenya's independence in 1963. Mixed cropping, or intercropping of crops such as maize with beans, maize with pumpkins, and maize with potatoes was a common practice throughout the district and had several important land conservation properties.

Most of the household heads who participated in the study revealed that in addition, different varieties of indigenous trees/shrubs were planted in gardens to provide shade, as wind breaks and also to demarcate farmlands and homes. Some of these trees/shrubs had medicinal properties or had cultural importance and were thus protected from any harm. This enabled the existence of large tracks of land under vegetation such as shrubs to increase since the practice of mixed farming was highly upheld by the members of the Teso community.

Interviews with the household heads also revealed that members of the Teso community relied on the indigenous knowledge of the three Ws and one H of indigenous food crop production- that is to say what crop(s) should be planted, when (during which season should it be planted), where (in which ecological location should it be planted depending on the soils and moiture requirements) and how (varying traditional methods of planting for example sowing vegetative cuttings). This practice can be compared to the Satoyama traditional system practised in Japan where different agricultural activities were only undertaken in locations deemed suited to as determined by their nutrient, water and soil requirements.

In this case, the village elders took an active role in giving advice and directing the community on what food crops to plant, when to plant them where to plant them and how to plant them depending on the agro-ecological conditions. This enabled the community members to only plant food crops that were seen as most suited and could sustainably utilize the available soil and water requirements in given ecological zones.

The results showed that indigenous mixed farming technique had the advantage of enabling a more efficient use of the land using a different crop species combination with different requirements. The crops in such a system tended to provide a complete vegetation canopy of varying heights, thus dissipating heavy rainfall impact, protecting the soil from erosion, as well as controlling weed germination and growth.

This finding concurs with earlier observation by Lemaire et al. (2014) who noted that the synergies between cropping and livestock husbandry in mixed farming offers various environmental conservation opportunities including increasing efficiency of resource use and protecting soil from elements of erosion. According to the above, such a system reduces natural resource depletion and environmental fluxes to the atmosphere and hydrosphere, offering more diversified landscapes that favour biodiversity and increase system flexibility to cope with socio-economic and climate variability.

Agro-forestry and the conservation of soil and water bodies

Among the ancient Teso Community members, there was a belief that God penetrated all his creatures with his (sic) presence and as such any of these creatures had to be handled in a sensitive manner with empathy and reverence. In this regard every community member had the natural responsibility to be a steward of the "mother nature" to tend to its trees, valleys, ponds, swamps, rivers and habitation.

Among members of the Teso community traditional agro-forestry has been in use since time immemorial. It involves planting various indigenous trees, grasses and crops on the farm lands and around homesteads, as well as keeping different types of animals and domesticated bird varieties. Certain tree species were planted around seasonal swamps, natural springs or ponds that were considered as dwelling places for ancestors or evil spirits or cultural sites for ceremonies.

This greatly helped in maintaining the area of land under wetlands and forests/shrubland since there was minimal disturbance from external causes. The most preferred indigenous tree varieties included medicinal trees such as *Tamarindus indica apeduru,* whose various parts were believed to treat different human and livestock ailments.

This form of farming practice provided multiple benefits of high productivity and income generation while at the same time maintaining the vegetation cover and soil health. Tree leaves, bark, roots and grasses provided herbal medicine to human beings and domesticated animals.

Trees were also seen as symbols of God's presence among people. The leaves of the trees, grasses and shrubs as well as crop residues were used for mulching, fodder for livestock and for thatching of traditional Teso houses. The mulching material from agro-forestry practices was regarded important since it helped protect soil from being eroded by heavy rain and drying out from hot sun and winds that could easely be deposited in water bodies such as swamps. The mulch protected the fertile top soil from being swept away by the agents of soil erosion such as wind and water that runs off the surface thereby facilitating the growth of natural vegetation.

Mulching material, besides retaining moisture by reducing evaporation, was also used to suppress weeds by smothering their growth, thereby reducing the work-load of the farmer.

This observation conforms to the earlier findings by Neufeldt et al., (2012) who note that the trees in an agroforestry system provide important ecosystem services including; soil, spring and watershed protection, animal and plant diversity conservation and carbon sequestration as well as storage which are all key in conserving the environment.

Importantly, the study found out that the diversity from trees and other vegetation in traditional agro-forestry besides improving the land vegetative cover also provided other benefits such as: reduction in pest problems, microsite modification to allow plants with varying climatic requirements to be grown in a small area and the production of multiple products including firewood, bio-fuel, timber, food, fodder, building materials, materials for tools, medicine, for subsistence and sale.

This finding concurs with an earlier observation by Frison et al. (2011) who noted that besides being key in solving the problem of food security by encouraging cultivation of a wide range of edible plants and vegetables and shrubs for fodder, the system also enables diversification of household income through the sale of wood products.

Trees in agro-forestry practice also serve as: windbreaks, as ground water management systems, by draining water logged areas, as shade provision for people and domesticated animals and importantly provided habitat for a wide range of fauna. The systems therefore ensured the various elements of the biophysical environment including the vegetation, swamps, natural springs and rivers were left undisturbed for long periods of time.

This confirms the work by Garibaldi et al. (2013) who pointed out that a diversity of trees in farm land support populations of different bird, animal and insect species by providing an alternative habitat thereby enabling conservation.

Also, the vegetative filter strips established in the form of agroforestry or contour grass buffer strips have the potential to improve water quality, wildlife abundance, biodiversity and aesthetic value. Filter strips of permanent vegetation that reduce the runoff and trap sediments can be used to reduce non-point source (NPS) pollution. Besides, a reduction in runoff helped protect stream, rivers and ponds from silting thereby enabling maintaince of the size of land under these elements. This finding corresponds with the views by Maliki et al. (2012) who hold that the vegetation in an agroforestry practice serves two major purposes: the fine root system holds soil in place thereby reducing soil erosion and secondly, plant stems decrease the flow velocity thus enhancing sedimentation which in turn can enhance the growth of natural vegetation.

Traditional terracing and the conservation of soil and wetlands

The indigenous Teso farmers were known for making traditional ditches locally known as *iperejene* to allow excess water to infiltrate easily and drain out of the cultivated land to the side of an artificial natural water way. A ditch was sometimes dug on the upper side of the cultivated land to act as a cut-off drain to protect the field from run-off coming from higher ground. In this way traditional ditches helped drain excess water from the fields protecting the soil from being eroded and surface runoff generated within the cultivated land area.

This finding confirms the work by Agnoletti et al. (2011) which illustrates the crucial role terracing has played in the conservation of soil, especially in highland areas in many parts of the world. The work demonstrates how small-scale agriculturalist inhabiting much of the highlands in developing countries have continued to embrace the traditional practice of constructing cut-off drains in order to divert the run-off from the upper parts of the hill and mountains before it reaches the farm land. These cut off drains were also often adopted in low laying floodplains in order to protect crops from inundation.

Besides protecting soil from the run-off, these farmers also constructed cut-off drains to prevent loss of seeds and fertilizer which can easily be washed away by excessive run off coming from uplands. The said cut- off drains according to the study findings were directed away from water bodies such as traditional wells, natural springs or ponds due to the belief that such water bodies were abodes of the gods and could be used for worship, consultation and appeasement of the gods.

The study found that the indigenous Teso farmers also adopted traditional ridges which were associated with the growing of crops such as: beans, groundnuts, sweet potatoes and cassava, locally known as *emaragwe*, *emaido, achokaa* and *emwogo* that helped increase vegetative cover and protect soil from both rain and wind erosion.

Related to ridging was contour farming which was mostly observed by those communities living at the slopes of Amukura, Ikieng, Chelelemuk and Kolanya hills. Because of the evident soil and gulley erosion in these areas, the inhabitants constructed water channels along hill contours to divert water to the sides of the slopes. Some specific plants with soil retaining root systems such as elephant grass (*Pennisitum purpureum*) and sugar cane (*Saccharum officinarum*), were used to support the channel embankments or dykes so as to prevent them from collapsing.

These greatly helped control soil erosion as well as maintained soil fertility thereby encouraging natural growth of vegetation which attracted a variety of bird species. The above observation concurs with the findings by Mutegi et al. (2008) who have documented the importance of combining Napier grass with leguminous shrubs in contour hedgerows in controlling among small-scale farmers in Central Kenya.

This is comparable to the traditional practice found on the slopes of the Uluguru Mountains in Tanzania whereby traditional terraces are used separately or in combination with other conservation structures including plantation trees such as sisal (*Agave sisalana*), euphorbia (*Euphobia splendens)* and eucalyptus (*Eucalyptus globu*) that were planted along the contour alongside other conservation practices. Kajembe et al. (2010) say that the above practice has been used for several decades as an effective method of controlling gulley erosion as well as for promoting rainfall infiltration among communities inhabiting the mountainous regions of Tanzania.

Grass-strips and conservation of the land

The findings from the study showed that within the traditional Teso community farming systems, the use of grass-strips which entailed leaving pieces of land with traditional vegetation between the main cultivated fields to control soil erosion and conserve biodiversity was common and greatly emphasized prior to Kenya's independence.

The strips locally known as *amang'uria,* consisted of different species of grasses and traditional plants that were planted to separate adjacent farms under different activities.

The trees commonly planted included local tree species such as *Ficus sycomorus*, locally known as *Ebule* which was an indigenous tree species. Grass species such as Spear grass (*Heteropogon contortus*), Napier grass (*Pennisetum purpureum*) and Rhodes grass (*Chloris gayana*) also locally known as *Esere, Eludeka* and *Akalias* were the most preferred.

These plants also served as important sources of medicinal plants and acted as feed for livestock. The above practice also created habitats for different birds, insects and reptiles rodents, etc in-spite of some crop damage caused by these creatures, thereby aiding in the conservation of these elements of the environment. The practice also helped protect the loose soil particles from being blown away by the wind or water runoff. Such a practice helped to ensure that any top soil blown a way by wind or water runoff was trapped by the vegetation thereby reducing the possibility of silting into ponds, dams, rivers and other water bodies.

Donjadee and Tingsanchali (2013) echoed the above observation by noting that indigenous communities in most parts of the world adopted different types of buffers as an effective way of land conservation. They give examples of buffers as grass-strips, hedgerows, grassed water ways, wind breaks (mostly consisting of rows of trees or bushes) and riparian buffer zones of grass or shrubs adjacent to water courses that helped filter pollution.

They also observe that besides reducing the effects of water and wind erosion, buffers significantly reduce the volume of sedimentation in water bodies such as ponds, dams natural springs and rivers and thus enabling maintance of the size of the area of land under wetlands and wetland vegetation.

Buffers also prevent the drift of pesticides from the fields into water bodies, roads or other areas, thereby reducing incidences of pollution. Further, Donjadee and Tingsanchali (2013) confirm the effectiveness of buffers as wind breaks, which they say have been successfully used to halve the wind speed over a distance equal to twenty times the trees' height and incept the drift of aerial pollution and soil particles.

Zhang et al. (2010) further observe that with time, the above traditional buffers evolved into semi-natural habitats that improved the vegetation cover of a given landscape that enabled such area to host a variety of wildlife on farm land and created a network of corridors for the movement of fauna and flora. They noted that buffers provided commodities which included fruits, wood, fodder among other, thereby contributing to a more diverse production on the farm. The traditional practice of protecting soil erosion through planting grass-strips or use of other buffer materials thus enabled many communities in different parts of the world to sustainably manage land.

Fallowing soil fertility and the protection of water resources

The Indigenous Teso farmers practiced fallowing which meant a resting period for agricultural land between two cropping cycles during which soil fertility is restored. The decline in total nitrogen, organic carbon, potassium, Zinc and the acidification of soils was due to continuous cultivation that resulted to soil exhaustion that necessitated fallowing among members of the Teso community. Two main types of fallowing were upheld by members of the Teso community-that is to say natural fallowing in which the soil was left to the natural vegetation and the improved fallow where leguminous trees, shrubs and or cover crops are planted in the fallow.

Accordingly, this practice did not only allow for the natural rejuvenation of land but also greatly helped to control gully erosion by allowing natural vegetation to reclaim the land. The practice helped reduce the amount of silting into nearby water bodies including rivers, streams, dams traditional wells and ponds. In this regard, the practice of traditional fallowing helped to maintain the quality and size of water bodies among traditional Teso community members.

This practice also enabled avoidance of those land areas that were infested with pests and animal diseases or those viewed to be ecologically fragile or sensitive thereby enabling sustainable utilization of land. In addition, it helped restore soil organic matter and rehabilitate the population of soil organisms that was reduced during the cultivation period.

Effects of changes in the use of ILCs and LULC status

As shown in Figure 2 and Table 3 the use of indigenous land conservation systems showed declining trend through time. Nearly all the study participants noted with much concern that currently in most of Teso community, there is very little respect for the traditionally upheld traditional beliefs and practices that guided members previously in different aspects of life. The elders in particular blamed the above on contact with outside cultures through marriages, rapid population growth, modern church and education systems that have demonized the traditional practices. This curcurs with views by Tang (2013) who has noted that today, as a result of rapid population increase, increased adoption of modern agricultural methods of production among other factors have played a role in the noted trend, thereby leading to marginalization of the previously upheld beliefs that helped conserve various elements of the biophysical environment.

A study by Ayaa and Waswa (2016) on the role of indigenous knowledge on the management of the biophysical environment within the same community for instance revealed that the use of commonly held belief and practices such as totems, protection of sacred places, prohibitions and age and gender restraints declined throughout the period of time covered by the study.

Spatial analysis results

As indicated in Table 2 and Figure 3, Spatial analysis results showed that land use in Teso has changed drastically in favour of rain-fed agriculture and settlement in particular. In this regard, the area of land under rain-

Table 2. Land use land cover quantities in hectares (000 HA).

Land use/Year	1973	1986	2000	2010
Rain-fed Agriculture	35,283	36,583	38,794	39,217
Seasonal Swamps	16,645	15,149	13,208	13,194
Settlement	14	64	84	295
Shrub-Land	3,384	3,614	3,467	2,768
Wetland Vegetation	706	619	476	555

Source: GIS data.

Table 3. Effects of changes in ILCs on land use/land cover trends (000 HA).

Spatial Parameters	1973-1986 (%)	1986-2000 (%)	2000-2010 (%)
Rain-fed agriculture	+3.7	+6.04	+1.1
Seasonal swamps	-8.9	-12.8	-0.11
Settlement	+357	+31.25	+251
shrub land	+6.8	-4.06	-20.2
Wetland vegetation	-12.3	-23.1	+16.6

Source : Gis data.

fed agriculture increased by about 3.7% between 1973 and 1986. In the period between 1986 and the year 2000, the land area under rain-fed agriculture further increased by 6% while in the years between 2000 and 2010; it further increased by 1.0%.

Land used for human settlement increased by 357% between 1973 and 1986 and by about 31% between 1986 and 2000. In the years between 2000 and 2010, the area of land under settlement expanded by 251%.

Although the noted growth in settlement and agriculture could be the cause of the significant decline in the area of land covered by seasonal swamps, shrubs and wetland vegetation, marginalization or low level of adherence to commonly upheld indigenous beliefs and practices in general and traditional land conservation systems in particular may have also contributed to a great extent.

The above corresponds with the findings by Ojomo (2011) who argues that among rural communities in Sub-Saharan Africa Teso included before the onslaught globalization, modern Religion, urbanization,formal education and change in economic trends, there existed certain vibrant traditional beliefs systems that controlled human behaviour and activies that ensured minimal disturbance to the elements of the biophysical environment.

Most members of these communities for instance believed in totensm whereby certain living things such as birds, animals, plants or water bodies were regarded with special awe, reverence and respect and thus could not be harmed. Members of such communities could designate certain places as being sacred. This was exemplified by setting aside patches of forest/shrubland, marshes, natural springs and ponds for sustainable resources use and the preservation of biodiversity as noted by- Awuah-Nyamekye (2014).

The intention in the views of Douglas (2015) was to protect watershed, fragile ecosystems as well as plants and animals of conservation importance to the local community. Despite other factors, the declining trend in the use of indigenous knowledge systems in general and land conservation systems in particular could have contributed significantly to change in the land use-land cover within Teso District during the period of time covered by the study.

It could peharps be as the results of the foregoing that the area under seasonal swamps for instance declined by 8.9% between 1973 and 1986 and further by 12.8% between 1986 to the year 2000. Between the year 2000 and 2010, the amount of land under seasonal swamps only declined marginally by 0.11%. This is in spite of the fact that that in general cropping tends to favor the low lying areas and hence the competition and loss of wetlands.

The study also found out that in- spite of the area under shrubs increased by 6.8% between 1973 and 1986, it declined by 4.1% between 1986 and 2000 and further by 20.2% between 2000 and 2010. The study findings also indicates that land area under wetland vegetation declined by 12.3% between 1973 and 1986 and further by 23.1% between 1986 and 2000. In the years 2000 and 2010, the area under wetlands however increased by 16.6% probably as a result of the government afforestation programme.

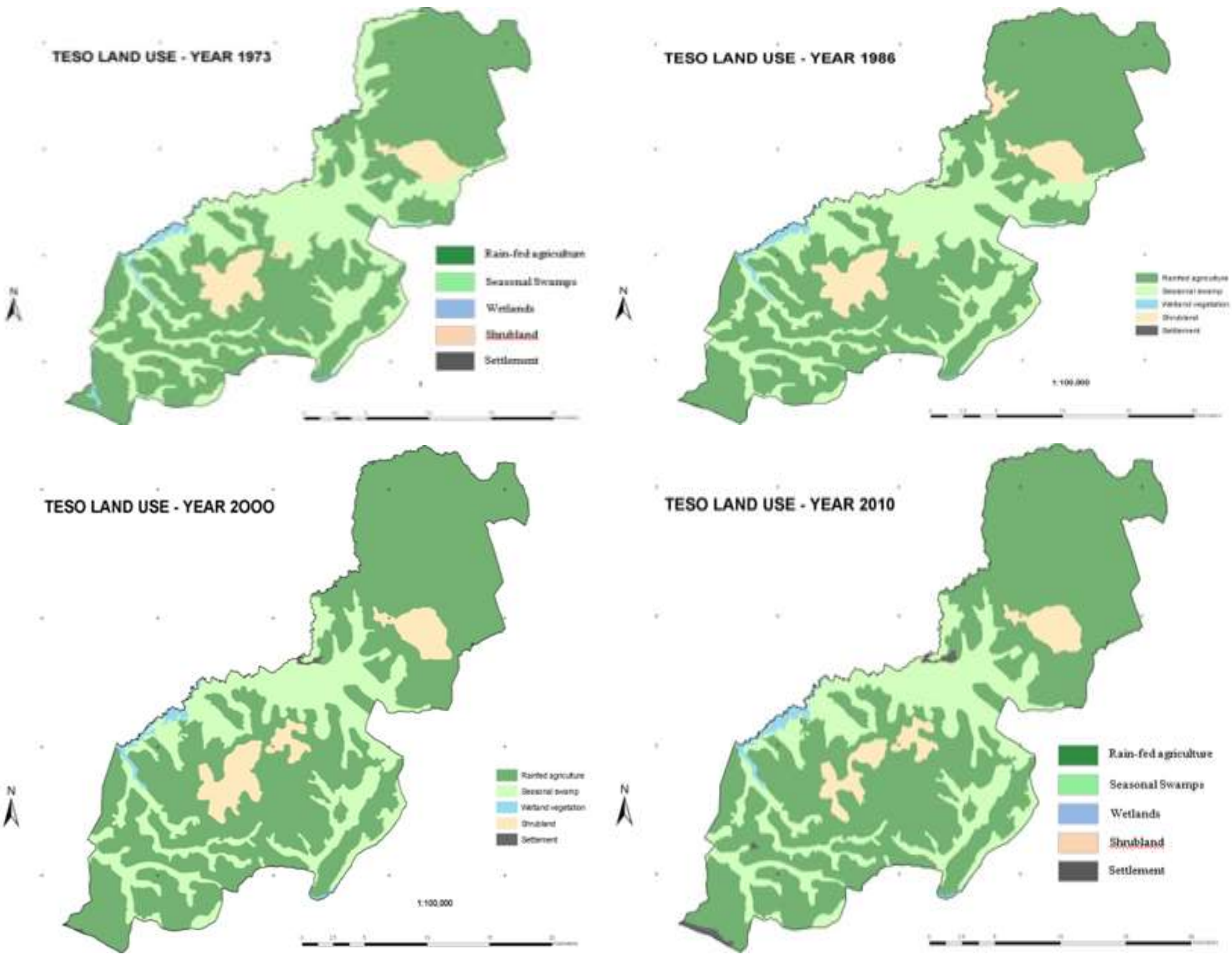

Figure 3. Spatial analysis (LULC) results.
Source: GIS data.

As pointed out earlier, although other factors including expanding population growth and commercialization of agriculture could have caused expansion in amount land under rain-fed agriculture, marginilization of indigenous beliefs systems may have contributed to some extent.

Conclusion

The level of use of tradional ecological knowledge systems is on the decline in parts of the world, Teso community included. Factors responsible for the marginilization of TEK among rural communities such as Teso include increase in population that require more land for farming and settlement, modern agricultural practices, intermarriages, modern religion among others.
The adoption and level of use of tradional ecological land management knowledge systems can contribute to the conservation of certain elements of the biophysical environment including wetland vegetation, shrublands and seasonal swamps. Guided by traditional beliefs such as sacredness, prohibitions and age and gender restraints human activities on land are controlled thereby minimizing disturbance of the said elements of the biophysical environment.

Recommendations

There is need for a long and an ongoing process aimed at assisting local community members to build or improve their collective resources and skills to maintain and /or revitalize their traditional cultural lifestyles.

Efforts should be towards a partnership between relevant governmental agencies, NGOs, private sector organizations, research organizations and other external partners with a target of conserving TEK and traditional culture.

Community-based TEK conservation activities should be undertaken within the existing cultural sites with the partnership with custodians of TEK (elders) with a target of conserving and revitalizing TEK.

Areas for further research

There is need for further study to investigate the strategies for documenting and disseminating indigenous land conservation systems and a framework and the integration of ICT in the documentation and dissemination of indigenous land conservation systems.

There is also need for a study on the process of designing an appropriate frame work for integrating indigenous best practices into the conventional conservation practices in order to achieve sustainable natural resource management.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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