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African Journal of Environmental Science and Technology

ARTICLES

Table of Contents: Volume 9 Number 4, April 2015

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Review

A simple anaerobic system for onsite treatment of domestic wastewater

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The use of anaerobic process for domestic wastewater treatment would achieve lower carbon footprint as it eliminates aeration and generate methane. Among several anaerobic treatment processes, high rate anaerobic digesters receive great attention due to its high loading capacity and chemical oxygen demand removal rate. Up-flow anaerobic sludge blanket reactor (UASB) is getting wide acceptance among several anaerobic processes. However, its application is still limited to industrial wastewater treatment. There are some unresolved problems to be accepted it in developing countries with lower temperature conditions for domestic wastewater treatment. Several studies have been carried out for the performance of UASB reactor but there is still lack of updated information especially on the issue of low temperature domestic wastewater treatment. Considering the gravity of the issue, an attempt have been made to compile updated information so as to help engineers, researchers and practitioners in the selection of reactors and future prospects of research.

Key words: Wastewater, anaerobic, up-flow anaerobic sludge blanket reactor (UASB), carbon footprint.

INTRODUCTION

Domestic wastewater refers to the wastewater from toilet, bathroom and kitchen of household. Anaerobic treatment of organic material proceeds in the absence of oxygen and the presence of anaerobic microorganisms. It is the consequence of a series of metabolic interactions among various groups of microorganisms which ultimately converts waste into a renewable energy, that is, biogas along with other useful byproducts.

Anaerobic wastewater treatment system is considered to be a sustainable and suitable process for on-site (individual or cluster) treatment due to its low or no

energy consumption, low space requirement and relatively simple reactor design (Zeeman et al., 2000). This is partly explained by the elimination of aeration.

The important advantages of anaerobic wastewater treatment are production of methane and bio-fertilizer, reduce carbon dioxide (CO_2) emission and more importantly improve sanitation and public health, while the excess sludge production is low as compared to aerobic processes. Also, the excess sludge is highly stabilized and generally its dewaterability is excellent which eliminates the costs for aeration (Lettinga, 1996;

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Hammes et al., 2000; Luostarinen and Rintala, 2005).

A recent study in Nepal shows that an estimated biogas production potential from urban wastewater is about 22 million m^3/year equivalent to 14.5 MWth, at the sametime, the carbon dioxide (CO_2) emission reduction potential is about 2460 tons per year (Lohani et al., 2013). This may directly relate with financial benefits, however, it also has several economic benefits for instance reduction of indoor air pollution, improvement in public health due to improved sanitation and greenhouse gas reduction. This indicates that anaerobic treatment of wastewater could be a sustainable solution due to its vast economic and environment benefits for developing countries like Nepal. Despite enormous benefits, its use is usually limited to high strength industrial wastewater with soluble substrates (Lew et al., 2011).

Domestic wastewater has generally low concentration of chemical oxygen demand (COD) and relatively high concentration of suspended solids with low specific methane yield that requires initial hydrolysis to convert the suspended solids into soluble substrate. Hydrolysis is often the limiting step, especially at low temperature conditions (Lew et al., 2011). Hence, operation of anaerobic reactors for domestic wastewater with a high content of suspended solids is therefore, only feasible at higher ambient temperature or with external heat supply. Nevertheless, standard septic tanks are useful for removal of inert solids, preliminary hydrolysis of particular organic matter, though optimized fermentation and hydrolysis depends on its design (Richard et al., 2005). Therefore, combination of a septic tank, serving as the primary treatment step, combined with a pulse fed UASB reactor as secondary treatment could be a suitable low cost and effective onsite sanitation option. Pulse feeding UASB was found to be simple and effective (Nadais et al., 2005). In addition, it stimulates the development of granular sludge with both improved settling and degradation properties (Franco et al., 2003; Rocktäschel et al., 2013).

For the purpose of anaerobic treatment of domestic wastewater, various technologies have been developed which are core sustainable wastewater treatment (Mahmoud et al., 2003; Luostarinen et al., 2007). Recent reviews mostly focus on anaerobic digestion (Aiyuk et al., 2004; Gomec, 2010) and enhance the start-up and granulation in UASB reactors (Chong et al., 2012). However, there is still lack of information and documen-tation on the enhancement of treatment efficiency and energy recovery from high rate anaerobic digestion treating domestic wastewater at low temperature climatic condition. Hence, the goal of this study is to compile up to date information of commonly used anaerobic systems with focus on the UASB and septic tank-upflow anaerobic sludge blanket (ST-UASB) reactors, which may serve as background information for perspective research direction.

The information regarding UASB reactor pilot/field opera-tion is given emphasis so that future improvement on reactor process control would be possible.

TECHNOLOGIES FOR ANAEROBIC TREATMENT

Two types of digesters are used in the anaerobic digestion process which are batch and continuous process. In batch process, all the constituent is put in the reactor in the beginning and is removed completely after the reaction is complete, whereas in continuous process fresh influent is fed into the reactor and effluent is regularly drawn out (Ostrem et al., 2004). Most commonly continuous type reactors are used for domestic wastewater treatment.

Septic tank and soak-away system

The most commonly used anaerobic system for pre-treatment of domestic wastewater in on-site application is septic tank. The conventional septic tank is the oldest anaerobic treatment system still widely employed in developing countries and isolated residential locations in developed countries (Coelho et al., 2003). Septic tank has simple design of horizontal flow mode with one-two baffles between the inlet and outlet. But there are certain problems like short circulation in the tank and dissolved oxygen input through inlet (Arceivala and Asolekar, 2007). Moreover, performance of the septic tanks is rather poor due to the horizontal flow mode of the influent sewage despite its lengthy hydraulic retention time (HRT) (Mgana, 2003). About 30-50% COD and about 60% total suspended solids (TSS) removal can be achieved in septic tank treatment system. Thus, septic tank effluent requires further processing in a post-treatment system to meet environmental standards, which would increase the cost and complexity of the system.

Soak-away system is another treatment process in which dispersal of wastewater is done through soil purification process and ground water recharge. As it is basically used for post treatment of septic tank effluent, the performance is dependent on the treatment efficiencies of the septic tank, wastewater distribution and loading to the soil infiltrative surface (Foxon et al., 2004).

Among the anaerobic digesters, high-rate digesters are popularly used in sewage treatment. This is because, unlike the conventional low-rate anaerobic digesters such as anaerobic ponds and septic tanks, high-rate anaerobic reactors are designed to operate at short HRT and long solids retention times (SRT) to incorporate large amounts of high-activity biomass, thus allowing improved sludge stabilization and higher loading capacity (Sperling and et al., 2001). For the treatment process to be considered as high rate, two conditions must be fulfilled which are to retain high concentration of sludge under high loading rate and ensure proper contact between wastewater and

retained sludge (Lettinga et al., 1987). Some of the examples of high rate digesters are anaerobic baffle reactor, upflow anaerobic sludge blanket reactor and expanded granular sludge bed reactor as described below.

Anaerobic baffle reactor

Anaerobic baffle reactor (ABR) is a reactor which uses a series of baffles in which the water is forced to rise upward and simultaneously drop downward which ensures good solid retention and more contact between biomass and organic substrate therefore achieving good organic removal rates (Barber and Stuckey, 1999). This technology has been used in the treatment of a variety of wastewater types; however most studies were focused on high strength wastewater with soluble biodegradable material (Barber and Stuckey, 1999). Studies on domestic wastewater have been limited to laboratory scale using synthetic wastewater, or at full scale with limited investigation of internal reactor dynamics (Singh and Viraraghavan, 1998; Foxon, 2004). The ABR functioned as solids retention device where particulate material retained through settling in the first compartment, forming a gel-like matrix and anaerobic conversion to CH_4 and CO_2 reduced the amount of solid (Foxon, 2004). For the smooth operation of ABR, initial loading rates should be kept low to prevent overload of slow growing micro-organisms along with gas and liquid up-flow velocities to encourage flocculent and granular growth (Barber and Stuckey, 1999). According to Henze and Harremoes (1983) approximately 1.2 kg COD/m^3d is recommended for start-up period. But for the treatment of dilute wastewater, it is recommended to start-up with high biomass concentration (> 3 gVSS/l) so that sufficiently high sludge blanket and improved gas mixing could be obtained in short time (Barber and Stuckey, 1999).

Expanded granular sludge bed (EGSB) reactor

EGSB is the latest amongst high-rate anaerobic treatment systems which has also become increasingly popular, mainly because of very high loading potential (Lettinga, 2001) with high superficial velocity of 5-10 m/h (Lettinga, 1995). The high surface velocities of the liquid in the reactor are achieved through the application of a high effluent recirculation rate, combined with the use of reactors with a large height/diameter ratio of 20 or more (Kato, 1994; Lettinga, 1995). A practical case of high up-flow velocity in EGSB reactor results in a significant reduction in the area required and this is interesting in the case of treatment of soluble effluents from industries.

The EGSB process use granular anaerobic biomass and have the operation principles as UASB, but differ in terms of geometry and process parameters (Zoutberg and Eker, 1997). In the EGSB process, granular biomass is expanded by the high gas and liquid up flow velocities

and hence only granulated sludge is retained at the bottom of the reactor whereas, significant amount of sludge remains in fluidized state at higher levels (Parawira, 2004). Small granule and dispersed biomass are washed out leading to retaining of mainly well structured granular sludge. Advantages like higher OLR up to 40 $kgCOD/m^3$ is achieved depending on the type of wastewater but drawbacks like granule disintegration, washout of hollow granules and occurrence of fluffy granules are prominent in this reactor (Parawira, 2004). However, in one such study, use of tall reactors with effluent recirculation resulted in EGSB reactor with high superficial velocity and granular sludge bed expansion eliminating dead zones and better sludge-wastewater contact (Man et al., 1986). This prevented the accumulation of excess flocculent between sludge and sludge granules (Van der Last and Lettinga, 1992) with efficient removal of soluble pollutants.

Up-flow anaerobic sludge blanket (UASB) reactor

The UASB reactor was developed by Gazte Lettinga in 1972 during a laboratory study on anaerobic treatment of beet sugar wastewater (Lin and Yang, 1991). Among all high-rate anaerobic digesters UASB reactors have been most widely used (Chong et al., 2012). It is a reactor which operates without any power requirement and is like an inverted septic tank which is more efficient than conventional septic tanks for removal of pollutants and production of biogas (Arceivala and Asolekar, 2007). This has rather become successful due to the presence of solid liquid gas (SLG) seperator on the top for the prevention of solid loss and absence of fixed bed which otherwise would have induced clogging (Foresti et al., 2006). The critical elements of UASB reactor are the influent distribution system, gas-solid separator and effluent withdrawal design (Metcalf and Eddy, 2003). Lin and Yang (1991) concluded UASB to be better performing than other advanced anaerobic systems in terms of having high specific activity (rate of reaction), handling high organic rate, retaining high concentration of biomass due to relatively slow upward flow velocity and good COD removal. The key feature of the reactor that makes it popular high rate anaerobic digester (especially in tropical countries) is the availability of granular or flocculent sludge due to its upflow mode of operation, high COD removal efficiency and the ability to apply high volumetric COD loading rate as compared to other anaerobic processes (Crites and Tchobanoglous, 1998). Due to the granulation and blanketing in a UASB reactor, the solid and hydraulic retention time can be independent as a result, the reduction in treatment time from days to hour is possible (Hickey et al., 1991). The UASB reactor eliminates the need of mixing as rising gas bubbles and upflow mode of operation is enough to provide required mixing, this lowers energy demand for the plant operation.
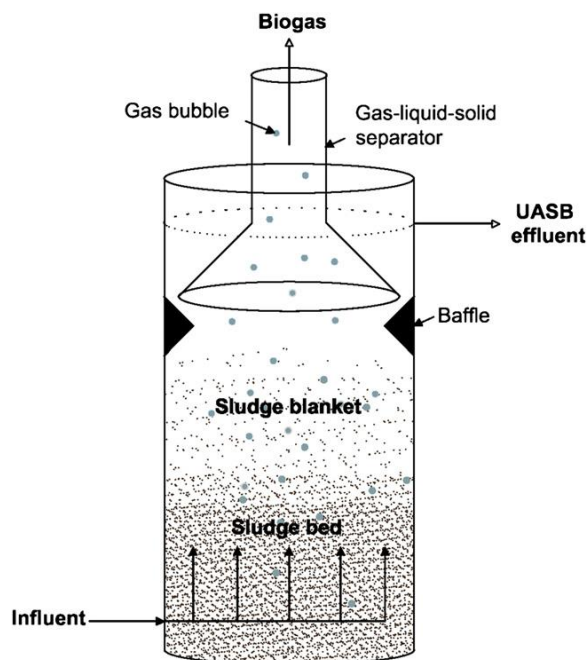
Figure 1. Schematic representation of UASB reactor (Chong et al., 2012).

Working of UASB

A UASB reactor is divided into four components which are sludge bed, sludge blanket, gas-solid separator and settlement compartment as shown in Figure 1. The biomass present at the bottom of the tank is the sludge bed whereas sludge blanket lies above the sludge bed where the suspended particles are found. Gas-solid separator is present at the top for the gas and solids separation and it helps for scum removal as well. The settlement compartment is where settlement of solid into the sludge blanket occurs (Lin and Yang, 1991). The UASB reactor is initially seeded with inoculums such as digested, anaerobic, granular, flocculent and activated sludge. Wastewater is passed from the bottom of the reactor which comes in contact with the inoculums and the biological reaction occurs throughout the sludge bed and sludge blanket (Chong et al., 2012). The baffles prevent wash-out of the viable bacterial matter or floating granular sludge by sliding the settled solids back to the reaction zone. A quiescent zone is created in the settlement zone where heavier sludge settles down and the light and dispersed ones are washed out as effluent. During the upward movement of wastewater, the soluble organic compounds are converted to biogas bubbles consisting of mainly methane and carbon dioxide which are separated by GLS.

Studies show that internal mixing is not sufficient in a pilot-scale UASB reactor treating sewage at temperatures ranging from 4 to 20°C as it may produce dead space in the reactor (Man et al., 1986). Better influent distribution is then required which can be attained by different inlet devices, more inlet feed or high superficial velocities.

Start-up and granulation in UASB

UASB start-up is a time-consuming and delicate process as it begins from the initial feeding to the stage until when stable sludge preferably granular sludge is obtained (Ling and Yang, 1991). This initial start-up is responsible for the overall effectiveness and stability of a UASB reactor which is affected by numerous physical, chemical and biological parameters (Ghangrekar et al., 1996), for instance wastewater constituents, operating conditions, availability and growth of active microbial populations in the inoculum (Chong et al., 2012). Experiences show that the main drawback of UASB reactor is start-up process. It takes long start-up time and is mainly susceptible to temperature and organic loading rates (Lew et al., 2011). The start-up period can take from 2 to several months (Vlyssides et al., 2008) and therefore is a major disadvantage for its applications. An inoculation with seed sludge helps reduce the acclimatization period required before applying the designed organic loading rates. Although a UASB reactor can provide efficient performance without granules, granules formation during start-up would be an advantage for reducing start-up period and has given importance in it (Hulshoff Pol et al., 2004; Liu et al., 2002). Furthermore, the use of septic tank as preliminary treatment step combined with a pulse feed UASB as secondary treatment could shorten the start-up period reducing effect of temperature and granular formation (Richard et al., 2005; Franco et al., 2003; Rocktäschel et al., 2013).

Digested sewage sludge is commonly used as inoculum while other types have also been used (Lin and Yang, 1991). Although, there are many advantages of using UASB, certain processes like interference of particles with flocculation, dead space, bed disruption due to vigorous gas production and speedy inflow rate could hamper the working of UASB (Parawira, 2004).

DOMESTIC WASTEWATER TREATMENT IN UASB REACTOR

The use of UASB reactor for domestic wastewater treatment is usually limited to tropical regions because of low COD concentration and relatively high particulate matter concentration (Lew et al., 2011; Sperling and Oliveira, 2009; Khan et al., 2011?). This needs an initial pre-treatment (hydrolysis) step to convert particulate matter into soluble substrate particularly at low temperature condition which otherwise accumulate in UASB reactor and inhibit anaerobic process. Few studies from various authors on application of UASB reactor for domestic/municipal wastewater treatment are shown in Table 1.

Table 1. Summary of UASB performance results at varied operating conditions.

Temperature (°C)	HRT (h)	OLR (kg COD/m³d)	TSS, removal efficiency (%)	BOD, removal efficiency (%)	COD, removal efficiency (%)	Reference
30	8	1.2	-	-	85	Behling et al. (1997)
20	10-48	-	-	-	60-75	Singh and Viraraghavan (1998)
13-15	10-11	-	75-85	63-73	54-58	Alvarez et al. (2006)
30-35	10	2.7-3.3	-	-	54-72	Mahmoud (2008)
24	48-96	-	56-58	-	81-82	Shayad et al. (2008)
17	48-96	-	51-54	-	74-78	Jamal and Mahmoud (2009)
10-28	6	-	-	-	42-78	Lew et al. (2011)
25-30	9	-	-	77-83	79-81	Rizvi et al. (2014)
8-40	8	0.6- 6.4	65-85	65-85	65-85	Khan et al. (2015)

Behling et al. (1997) examined a pilot scale UASB reactor of 55.5 L capacity for 200 day trial. The equalization tank maintained the OLR 1.21 kgCOD/(m³.d) with 7.2 l/h flow rate and 7.6 h HRT to feed UASB reactor. The digestion temperature was constant at 30°C. The reactor was fed 10% of the reactor volume (5.5 L) with granulated sludge as inoculum. Results show that the gas production increased steadily until it reached a constant value of about 28 l/d (0.34 m³ methane per Kg COD removal) and the concentration of effluent COD gradually decreased from 1206 to 60 mg/l (85% COD removal efficiency) which took 60-70 days of plant operation that is when a digestion process is stabilized.

Singh and Viraraghavan (1998) studied start-up and operation of UASB reactors at 20°C for municipal wastewater treatment. They worked on two laboratory scale UASB reactors of 8 L capacity (1 m height and 10 cm internal diameter). Above 50% (4.5 L) digested sludge was seeded as inoculum in both reactors and was operated in a continuous mode. The HRT of the reactor was reduced from 48 to 10 h in about 280 days of operation. The COD concentration of wastewater was about 350-500 mg/l COD (40-50% insoluble) which in initial month of operation COD removal efficiency was in the range of 30-55%. After steady state, the average COD removal efficiency was in the range of 60-75%. But as the insoluble fraction of COD was high in the influent, it appeared that a significant amount of COD removal was due to entrapment of suspended solids in the sludge bed resulting in a significant increase in volatile suspended solids to suspended solids (VSS/SS) ration from 0.5 to 0.8. The high accumulation of particulate matter in the sludge bed seemed to be fine initially because of the fair removal of pollutants but in the long run it, creates disturbance and inhibition of anaerobic digestion in the reactor resulting in diminishing performance of the reactor.

Alvarez et al. (2006) also studied on start-up alternatives and performance of an UASB pilot plant treating diluted municipal wastewater at low temperature. His reactor was a metallic cylinder of total volume 34.9 m³ (7.1 m height and 2.5 m diameter) and active volume of 25.5 m³. Three different start-up procedures of an UASB digester were carried out in which start-up A was without inoculum, B was done with inoculation of 10 m³ digested sludge while C used sludge developed in 50 days of operation of B type digester as its inoculum. Start-up of digester without inoculums (start-up A) was for about 120 day. However, it reached 75-85% TSS removal, 54-58% total chemical oxygen demand (CODt) removal and 63-73% biological oxygen demand (BOD₅) removal at influent concentrations of 240-340 mgCODt/l at temperatures of 13.5-15°C and hydraulic retention times (HRT) of 10-11 h. While in experiment B, start-up period was 75 days, digester efficiencies were 58, 41 and 54% for TSS, CODt and BOD₅ removal, respectively, working at 169 mg CODt/l input at temperature of 14°C and HRT of 11 h. The sludge bed developed and stabilized quickly while using a hydraulically adapted inoculum in experiment C, but CODt and BOD₅ removals remained as low as 43 and 46%, respectively with volatile fatty acids (VFA) accumulation in the effluent.

Luostarinen et al. (2007) studied three pilot scales UASB–septic tank (modified septic tank) reactor of 1.2, 0.2 and 0.2 m³ capacity used for treating blackwater. The first reactor was inoculated with 100 L granulated methanogenic sludge and operated for 13 years. The flow of the system varied from 1-2 persons for the first year of operation and 3-4 persons in the 13th year. The second reactor was inoculated with 80L sludge obtained from 1.2 m³ UASB system and maintained at 15°C whereas the third reactor was not inoculated and maintained at 20°C. The performance of the 1.2 m³ UASB-septic tank was monitored for 52 weeks during the 1st year and for 13 weeks during the 13th year of operation, while others two 0.2m³ reactor were monitored for 51 (15°C) and 47 weeks (25°C) from the start-up. Comparisons between the gas production in warm and cold season of these reactors showed that higher conversion of COD into methane was in warm season. However, most of the COD washed out as dissolved COD and suspended COD in warm season had been

settled in sludge bed in the cold period. This is because with the increase in temperature, hydrolysis of accumulated solids apparently started and dissolved compounds were formed.

Mahmoud (2008) studied high strength sewage treatment in a UASB reactor and an integrated UASB digester system of working volume of 140 and 106 L, respectively. The one-stage UASB reactor was operated at 10 h HRT at ambient temperature for more than a year in order to assess the system response to the Mediterranean climatic seasonal temperature fluctuation. Afterwards, the one-stage UASB reactor was modified to a UASB-digester system by incorporating a continuous stirred tank reactor (CSTR) digester operated at 35°C with continuous mixing at 60 rpm. Pre-treated influent (screens and grit removal) was pumped into a holding tank (200 L plastic container) for about 5 min. The reactor was operated for about a year in which the first 42 days was considered to be start-up. The sludge bed of the UASB reactor was discharged more than two to three times a week to keep its content below 40 cm and that discharge was immediately fed into the digester with the help of peristaltic pump. At that very moment, the digester effluent was pumped out and re-circulated to the lower part of the UASB reactor at 10 cm from the bottom. The whole system operated for 107 days with 57 days as a startup period. The OLR of one stage UASB reactor was 3.35 and 2.73 kgCOD/(m^3.d) for hot and cold six months respectively, whereas it was 2.84 kgCOD/(m^3.d) for the reactor in the UASB digester system. The achieved COD removal efficiency was 54% during the first warm six months of the year, and achieved only 32% over the following cold six months of the year. The modification of the one-stage UASB reactor to a UASB reactor-digester system had remarkably improved the overall performance as the COD removal efficiency of digester alone was 72%.

Shayad and Mahmoud (2008) studied start-up of an UASB-septic tank for community on-site treatment of strong domestic sewage of COD_t concentration of 1189 mg/L. The two pilot scale UASB-septic tank reactors R1 and R2 with two and four days HRT with 0.8 m^3 working volume were operated in parallel for a period of 6 months (October to March) with sewage temperature of 24°C. Domestic sewage was pretreated with screens and grit removal chamber and collected in holding tank (200 L). The UASB reactor was inoculated with anaerobic sludge from cesspit and operated in parallel at ambient temperature. Steady state was considered after 80 days of operation due to poor results in the first 60-80 days. However, methanogenic activity increased with sludge bed development as methane gas began to produce after 30 days. Increase in biogas production was a result of COD conversion likely due to better mixing conditions created by intense gas production along with the bio-conversion. Methane gas production is strongly influenced by the development of sludge bed and the ambient temperature. This experiment resulted in the average removal efficiencies for COD_t and TSS as 56% (1267-56 mg/l) and 81% (623-116 mg/l) for 2 days and 58% (1267-530 mg/l) and 82% (623-113 mg/l) for 4 days HRT which does not have much differences and makes 2 days HRT more adequate and economical.

Jamal and Mahmoud (2009) researched on community onsite treatment of cold strong sewage (average influent COD_t 905 mg/l) in a UASB-septic tank system (up-flow septic tank). They experimented on two pilot scale UASB septic tank reactors R1 and R2 with 2 and 4 days HRT, respectively, with 0.8 m^3 working volume. They were operated in parallel for a period of cold 6 months (October to March) with sewage temperature of 17.3°C. Domestic sewage was pretreated with screens and grit removal chamber and collected in holding tank (200 L). The tank was inoculated with anaerobic sludge from cesspit and operated in parallel at ambient temperature. During the monitoring period, the removal efficiencies in R1 and R2 for COD_t, and TSS were 51%, 74 and 54%, 78, respectively. The difference in the removal efficiencies of those parameters in R1 and R2 is marginal. The sludge filling period of the reactors is expected to be four to seven years.

Sperling and Oliveira (2009) evaluated the comparative performance of full-scale anaerobic and aerobic waste-water treatment processes in Brazil. Evaluation and comparison of 166 full-scale WWTP (both aerobic and anaerobic) operated in Brazil was done which included septic tank anaerobic filter (ST+AF), UASB, UASB-post treatment, facultative pond (FP), anaerobic pond-FP and activated sludge (AS). The results from the statistical tests confirmed that the best performance was achieved by AS followed by UASB with post treatment. These technologies presented better performance than the other processes with regard to the effluent concentration and removal efficiency of almost all constituents. The UASB reactor showed good BOD and COD removal efficiencies but was poor in TSS, FC and nutrients removal.

Lew et al. (2011) studied about an integrated UASB-sludge digester for raw domestic wastewater treatment in temperate climates to improve the performance of UASB reactor treating raw domestic wastewater under such climatic conditions. An experimental UASB reactor made of plexiglass with working volume of 5.3 L was initially seeded with 2 L granular sludge from a full scale UASB reactor treating food wastewater. Domestic wastewater with COD concentration of 1576 (±376) mg/l was fed at temperatures of 28, 15 and 10°C for 2 months each with 6 h HRT. Gas collector was used to collect and measure the gas produced, sludge degradation as mg COD/l was calculated using the theoretical specific methane production per kg COD (350 L CH4 per kg COD). Results show declining removal efficiencies with decreasing temperatures, that is, COD removal decreased from 78% at 28°C to 42% at 10°C with highest methane production of 6.19 L CH_4/day to nil, respectively. This decline was

attributed to low hydrolytic activity at lower temperatures that reduced suspended matter degradation resulting in solids accumulation at the top of the sludge blanket. Solids removed from the upper part of the UASB sludge were treated in an anaerobic digester. The anaerobic digester of 2 L working volume was designed for that purpose working in 15°C and increasing temperatures. Result shows gas production increase with rise in temperature reaching up to 4.1 L CH_4/day at 30°C which indicates that non-degradable fraction of sludge decreases with increasing temperature. Maximum utilization of COD was also observed at 30°C which accounted to about 60% (17.9 to7.16gCOD/l) COD removal.

Rizvi et al. (2014) studied start-up of laboratory scale UASB reactor treating municipal wastewater and effect of temperature, HRT on its performance. It was found that the start-up period was about 120 days. The COD and BOD removal efficiencies were in the range of 57-62 and 61-66%, respectively at 17°C and 60 days of operation. However, the removal efficiency increased to the range of 79-81 and 77-83%, respectively at 25-30°C, 9 h HRT and 150 days of operation.

Khan et al. (2015) studied performance evaluation of UASB reactor treating domestic wastewater using 60 L pilot scale reactor. The treatment efficiencies were investigated at 8 h HRT and ambient temperature ranged from 8 to 40°C. TSS, COD and BOD removal efficiencies were found to be in between 65 to 85% under different OLR between 0.57 and 6.35 kgCOD/(m^3.d). The removal of organic matter followed a liner correlation with organic loads.

Reviewing these literatures, it can be concluded that start-up process and temperature are major issues in UASB reactor for the efficient performance of the reactor. There are lack of sufficient information and experience that the UASB reactor has successfully been operated for domestic wastewater in low temperature regions. To bridge this gap, the author has applied simple principle of combining septic tank into UASB reactor for reducing/converting high content of organic particulate matters available in domestic wastewater into soluble solution before supplying to UASB reactor.

Moreover, to get benefit from sufficient mixing and stimulate granulation process (usually takes long time at lower temperature environment), pulse feed strategy was applied to overcome effects of lower temperature environment. The preliminary results and experience is discussed below.

Future prospect (ST-UASB combined system for domestic wastewater treatment)

In tropical countries, UASB reactors are widely accepted for domestic wastewater treatment and there are several pilot and full scale plants in operation in Japan, India, Brazil and Columbia. Studies suggest that COD, BOD and TSS removal efficiencies are in the range of 65 - 75% in these countries at HRT of 6 to 18 h (Seghezzo et al., 1998; Lew et al., 2011; Sperling and Oliveira, 2009; Khan et al., 2011?). But especially in developing countries with lower temperature conditions, there are concerns in pre-removal of particulate matters prior to anaerobic treatment in order to obtain good effluents quality and biogas production, which inhibit the widespread use of this technology (Elmitwalli et al., 2002; Chong et al., 2012). One probable easiest way to improve UASB performance in these countries are to combine it with septic tank or settling tank (usual existing systems in developing countries) to ensure preremoval of suspended solids and allow for hydrolysis of particulate organic matter to generate a feed solution that is appropriate for UASB as described in earlier. Though, there is no published information on how to integrate UASB system into existing infrastructure like septic tanks and the performance of such combined system, it could attract researchers especially from developing countries with fluctuating climatic conditions to investigate on it and find a suitable solution in a local context.

The authors have conducted a preliminary study at Kathmandu University, Nepal on septic tank-UASB combined system which shows very encouraging results. A 250 L pilot scale UASB reactor is fed with septic tank effluents and operated at ambient temperature range of 0 to 30°C. The reactor is fed intermittently 12 times per HRT and the performance is recorded for different HRTs from 18 to 4 h during 1.5 years operation. The start-up period is found to be about 2 to 3 weeks even at low temperature. The average COD hydrolysis and methanogenesis percentage are about 18 to 36%, and 23 to 36%, respectively. About 22 to 37% of influent COD are converted into methane, 12 to 19% accumulated in the reactor while 44 to 62% remained in the effluent. The COD removal efficiency of UASB reactor is in the range of 38 to 56%, while the performance of the combination of septic tank and UASB is 55 to 72% at all HRT except for 4 h. At this HRT, all parameters are significantly lower, because the removal efficiency collapsed. This also shows good pollutant removal efficiencies and short start-up period for reactor operating at fluctuating temperature conditions. Though it needs further long term study and as far as possible parallel study at different countries with similar low temperature conditions to establish the similarity of operation, it can be said that the combined system could be a suitable low cost and effective onsite sanitation option especially for developing countries like Nepal.

CONCLUSION

Start-up of UASB reactor was affected by various factors, most importantly temperature and OLR. In general, a long start-up period of about two months was required, which could even be longer at lower temperature. Treatment

efficiency and methane conversion was strongly dependent on temperature, HRT and OLR primarily for the treatment of domestic wastewater. The high organic particulate matter content in domestic wastewater was a major issue for lower temperature conversion and therefore, a septic tank pretreatment with pulse feed UASB (ST-UASB) combined system might be worth attended for prospective research to help solve the concerns. A preliminary study on ST-UASB combined system carried out at Kathmandu University at ambient temperature range of 0 to 30°C. The UASB reactor was fed intermittently 12 times per HRT and the performance was recorded for different HRTs from 18 to 4 h during 1.5 years operation. The start-up period was found to be 2 to 3 weeks even at low temperature conditions and the COD removal efficiency of the combined system was 55 to 72% at all HRT except for 4 h. At this HRT, the removal efficiency collapsed.

Conflict of interests

The authors did not declare any conflict of interest.

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Full Length Research Paper

Effects of different NaCl Concentrations on germination and seedling growth of *Amaranthus hybridus* and *Celosia argentea*

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Salinity refers to the salt content of any given system. By nature, arid soils are naturally saline. Soils could also acquire salinity due to some agricultural practices like irrigation. There is need therefore for search on halophytes that could adapt to such soils and be used to reclaim soils contaminated with salts. Thus, this present study focused on investigating *Amaranthus hybridus* and *Celosia argentea* with respect to their potentials and suitability for use in saline environments. This study was conducted in two phases; germination (laboratory-based) and seedling tests (field-based). Shoot length, root length, root/shoot ratio, total length, fresh weight, dry weight, dry matter content, leaf area index, leaf number as well as relative water content were parameters used for assessing results for the field-based test. Germination results showed that only the control (0 mM) showed 100 % germination in both species. Germination percentages decreased steadily with increasing NaCl concentrations in both species. Growth was steadily stimulated in both species at lower NaCl levels with best growth stimulation at 50 mM NaCl but was adversely affected by higher NaCl concentration levels (75, 100 and 150 mM). Both species showed almost the same phenomenon for fresh weight, dry weight, dry matter, leaf area index, number of leaves as well as relative water concentration. These show that both species would best be cultivated under moderate than low or high saline concentration. The findings in this study showed that it is best for seedlings of both species of plants to be raised in nurseries free of NaCl to attain 100% germination and after which, the seedlings could then be transplanted to moderately saline soils for maximum growth and development. This has strong implications for maximizing food productivity and ensuring food security.

Key words: Germination, early seedling growth, NaCl, salinity, *Amaranthus hybridus, Celosia argentea*.

INTRODUCTION

Salinity refers to the salt content of any given system. According to Herr (2005), salinity results from the build-up of the following minerals which are deposited by evaporating water: Na+, K+, Ca²+, Mg²+, Cl⁻, HCO³⁻, and

$SO_2{}^{4-}$, respectively. Addition of salts to water lowers its osmotic potential, resulting in decreased availability of water to the root cells (Sairam et al., 2002). High salt concentrations could affect various physiological processes in plants. Ratnakar and Rai (2013) stated that high salt concentration hampers vital processes such as seed germination, seedling growth and vigour, vegetative growth, flowering as well as fruit set. Thus, high salt concentration ultimately reduces crop yield and the quality of the produce (Sairam and Tyagi, 2004).

According to Galston et al. (1980), soil salinity is becoming a serious worldwide problem as more land is irrigated thoroughly and heavily fertilized. Salinity is one of the major abiotic stresses in arid and semi-arid regions that substantially reduce the yield of major crops by more than 50% (Bray, 2000). Salinity affects agricultural pro-duction in a large proportion worldwide (Byordi et al., 2010). Salinity affects about 7% of the world's land area, amounting to about 930 million ha (Munns, 2002), thus seriously limiting crop production, especially the sensitive ones (Zadeh and Naeini, 2007). The problems of salinization are increasing, either due to bad irrigation, drainage or agricultural practices (Al-Seedi and Gatteh, 2010).

Cuartero et al. (2006) opined that although salt stress affects all growth stages of a plant, but that seed germination and seedling growth stages are known to be more sensitive for most plant species. In addition, Ibid (2006) further stressed that germination and seedling stages are predictive of plant growth responses to salinity.

Amaranthus hybridus is a robust annual herb (Olorode, 1984), that is cultivated for its nutritional value (Oguntona, 1998) and used as food by man and other animals. *C. argentea*, on the other hand, is a short-lived annual herb, slow growing and more drought-resistant than *A. hybridus* (Ogunwenmo et al., 2010). Both *A. hybridus* and *C. argentea* belong to the family, Amaranthaceae (Dutta and Dutta, 2008).

Byordi (2010) studied the influence of salt stress on seed germination, growth and yield of Canola cultivars. It was found that significant differences existed between influence of salt stress on the cultivars during germination and vegetative growth respectively. Al-Seedi and Gatteh (2010) while studying the effects of salinity on seed germination, growth and organic compounds of Mung bean plant [*Vignia radiate (L.) Wilczek*] found that an increase in the salinity caused a corresponding decrease in germination rate, growth parameters and the carbohy-drate content of the Mung bean plant. Ratnakar and Rai (2013) observed while studying effects of NaCl salinity on seed germination and early seedling growth of *Trigonella foenum-Graecum L. Var Peb* that increasing NaCl concentrations caused a gradual decrease in root length, shoot length, fresh weight and dry weight of the growing seedling. In addition, Katambe et al. (1998) stated while studying the effects of germination and seedling growth

of two *Atriplex* species *(Chenopodiaceae)* that NaCl caused a greater increase in nuclear volume than iso-osmotic PEG solutions. In addition, Ogunwenmo et al. (2010) studied effects of brewery, textile and paint effluent on seed germination of *A. hybridus* and *C. argentea* and stated that industrial effluents affected seed germination at different rates.

However, information pertaining to the effects of salinity due to varying concentrations of NaCl on *A. hybridus* and *C. argentea* are hard to come by. It is important to study the effects of different NaCl concentrations on germination and seedling growth of both crop species as that would help in establishing the tendencies of both crop species to be used in saline environments, most especially as there appears to be some level of universality in the occurrence of NaCl in most saline environments.

MATERIALS AND METHODS

Salt preparation

Salt solution of 1 M NaCl was prepared by dissolving 58.8 g of NaCl crystals in a universal bottle upon which distilled water was added onto to make up 1 L. Corresponding rations of 25/1000, 50/1000, 75/1000, 100/1000 and 150/1000 gave 25, 50, 75,100 and 150 mM respectively. Pure distilled water was considered to be 0 mM, thus represented the control. The experiment was conducted in two phases; germination and growth tests, respectively.

Germination test

This was conducted in the Botany Laboratory of Ambrose Alli University, Ekpoma, Edo State, Nigeria. It is located on latitude 06° 42 ´´N and longitude 06° 08 ´´E. It lasted for ten (10) days, from 20th June, 2001 to 30th June, 2001. Seeds of both *A. hybridus* and *C. argentea* used for the study were obtained from the Federal Department of Agriculture, Ubiaja, Edo State, Nigeria. Approximate seed sizes of both species were randomly selected and soaked in distilled water for 2 h before being transferred into glass Petri dishes. Ten (10) seeds of each crop species were sown into each glass Petri and these were replicated ten (10) times each for 0, 25, 50, 75, 100 and 150 mM respectively. Thus, total number of seeds per concentration (from 0 to 150 mM) amounted to 100 seeds each. The seeds were placed between folds of moistened filter paper in the glass Petri dishes at room temperature of 27.5°C. The seeds of both species in the glass Petri dishes were moistened every 12 h with varying concentrations (0, 25, 50, 75, 100 and 150 mM) of NaCl salt and observations were recorded every 24 h for radical emergence as indicative of germination. Seeds were considered to have germinated when up to 1 mm radicle emergence from the seed was noticed.

Seedling growth test

Black polythene bags measuring 25 x 25 cm were all filled with sandy-loamy soil from the Experimental Garden of Botany department, Ambrose Alli University, Ekpoma, Edo State, Nigeria. Fifteen seeds were randomly chosen and sown into each potted bag at a depth of 1 cm and after germination; only ten (10) seedlings considered 'healthier' were allowed to grow. Masking

Table 1. Effect of varying concentrations of NaCl on seed germination of *Amaranthus hybridus* in percentages.

NaCl (mM)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
0	81	87	94	100	100	100	100	100	100	100
25	54	68	76	79	80	80	80	81	81	82
50	49	63	70	71	72	72	73	74	74	75
75	31	48	51	55	58	61	62	62	62	63
100	27	36	50	53	54	54	54	55	55	55
150	21	39	42	44	45	46	46	47	47	47

tapes were used to label the bags appropriately. Salt solutions of NaCl corresponding to 25, 50, 75, 100 and 150 mM were used for watering the plants in the potted bags on twelve (12) hourly bases, throughout the period of experimentation. Distilled water was labeled 0mM and considered as the control. The experimental period lasted for eight (8) weeks. At the end of the eighth (8th) week, results were collected for parameters like shoot length, root length, root/shoot ratio, total length, fresh weight, dry weight, dry matter content, leaf area index, leaf number as well as relative water content, respectively.

Shoot length, root length and total length were measured with a ruler. Shoot to root ratio was determined mathematically through simple ratio. Numbers of seeds were determined manually. Before shoot and root lengths were determined, seedlings were uprooted carefully to avoid breakage from the medium. Particles stuck to the roots and shoots were carefully removed before measurements were taken. Each seedling was then measured on a weighing balance for fresh weight while for dry weight, the same seedlings were dried at 80 °C till constant weights were obtained and records taken. Leaf area index was determined following the methods of Gunkel and Mulligan (1953) in which leaf discs were punched from five (5) leaves using a cork-borer of diameter 0.82 cm. The discs of known area of the punched leaves were dried to constant weight at 80°C for 24 h hand the total leaf area per plant was then calculated using the relationship:

$$\text{Leaf Area Index} = \frac{\text{Leaf Dry Weight} \times \text{Disc Area}}{\text{Disc Dry Weight}}$$

Relative water content was determined following the method of Handley and Jennings (1977). In which case, four (4) plants from each treatment in both plant species were separated into leaf, stem and root tissues. The materials were dried at 80°C for 24 h and their corresponding dry weights measured. It is then calculated using this relationship:

$$0 \text{ Relative Water Content} = \frac{\text{Fresh weight} \times \text{Dry weight}}{\text{Dry weight}} \times 100$$

RESULTS AND DISCUSSION

From Table 1, it was observed that the control experiment attained 100% germination on the fourth day after sowing. Also, only the control was found to attain 100% germination at the end of the period of experimentation unlike other salinity levels that could not attain 100% germination. Generally, it was observed that germination percentage decreased steadily with increasing NaCl concentrations. This is in agreement with the works of several authors; Nasir (2002), Al-Seedi (2004), Herr (2005), Al-Seedi and Gatteh (2010) and Ratnakar and Rai (2013) to mention but a few. This could be attributed to specific ion effect (Hassen, 1999) or osmotic stress (Zekri, 1993) which later led to reduced water intake into seeds for enhancement of germination.

In addition, Begum et al. (2010) stated that germination of seeds depends on the utilization of reserved food materials of the seed and, Ratnakar and Rai (2013) opined that salinity interferes with the process of water absorption by the seeds which subsequently inhibits the hydrolysis of food reserves which ultimately delays and decreases seed germination.

Table 2 shows that germination percentages were highest in the first three days after planting than the other days. The control attained 100% germination within the first three days whereas the other experimental sets could not attain up to 90% even on the tenth day after sowing. Also, apart from 25 mM NaCl level which attained 50% germination on the third day, no other experimental set (50, 75, 100 and 150 mM NaCl) attained up to 50% germination rate.

According to Ratnakar and Rai (2013), this may be due to the fact that the increased amount of NaCl disturbed ionic balance of plant cells and also caused imbalances in plant nutrients which must have affected germination percentages. In addition, it could be deduced that *A. hybridus* tolerated varying concentrations of NaCl better than *C. argentea* during seed germination. Hence, *A.hybridus* is a better halophyte than *C. argentea*.

Length measurements

According to Ratnakar and Rai (2013), root and shoot lengths are the most important parameters for studying salt stress. This is obvious as roots are in direct contact with soil salinity and the effects are then translocated and manifested along the shoot, thus the need for evaluation of salt stress effects in terms of root/shoot ratio as well as total lengths. Shoot length, root length and total length behaved in a similar pattern in both *A. hybridus* and *C. argentea* (Table 3). Growth was steadily stimulated in

Table 2. Effect of varying concentrations of NaCl on seed germination of *Celosia argentea* in percentages.

NaCl (mM)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10
0	86	93	100	100	100	100	100	100	100	100
25	41	47	50	51	52	52	53	54	55	55
50	18	29	35	40	40	41	41	42	43	43
75	14	26	29	31	32	33	33	33	33	33
100	11	16	18	20	22	22	22	22	22	22
150	6	11	12	14	15	15	15	15	15	15

Table 3. Effect of varying concentrations of NaCl on growth parameters of *Amaranthus hybridus*.

NaCl (mM)	Shoot length	Root length	Root /shoot ratio	Total length	Fresh weight	Dry weight	Dry matter	Leaf area index	Rel. water index	Leaf No.
0	19.21±0.24	5.06±0.12	0.26	24.29±0.53	7.24±0.32	0.68±0.01	9.39	2.03±0.11	757.11	10
25	12.43±0.21	5.87±0.18	0.47	18.37±0.41	4.22±0.37	1.46±0.03	34.61	3.08±0.09	2284.21	13
50	13.46±0.19	6.74±0.24	0.50	20.25±0.43	7.03±0.43	0.63±0.02	8.96	2.15±0.07	2166.67	14
75	10.81±0.18	4.79±0.15	0.44	15.66±0.31	6.84±0.39	0.56±0.02	8.19	1.62±0.06	1125.81	11
100	9.43±0.17	4.18±0.13	0.44	13.69±0.29	3.01±0.14	0.51±0.01	16.94	1.28±0.05	1105.71	10
150	7.97±0.15	3.34±0.09	0.44	11.42±0.26	2.43±0.09	0.49±0.02	20.17	1.04±0.03	244.83	8

both species at lower NaCl salinity levels with best growth stimulation at 50 mM NaCl where they achieved highest values respectively. However, both species were adversely affected by higher NaCl salinity levels (75 mM, 100 and 150 mM) where increased NaCl salinities caused a corresponding decrease in root length, shoot length as well as total lengths owing to adverse salinity effects on cell differentiation and elongation. Hence, at lower NaCl salinity levels, both studied parameters are good halophytes.

Osmotic differences could explain this phenomenon where by lower NaCl salinity levels (25 and 50 mM) positively influences solutes to readily cross the cell membranes into the cytoplasm of the cells but at higher salinity levels, active metabolic pumps prevents accumulation of these ions (Katembe et al., 1998). Built up toxic ions emanating from continuous exposure to higher NaCl levels could lead to decreased availability of some essential nutrients (Werner and Finkelstein, 1995). In addition, Heidari et al. (2001) while studying the effects of NaCl concentrations on *Helianthus annus* suggested that reduction in plant growth is due to decreasing turgur pressure in the soils under saline environment. Further-more, evidence from root/shoot ratio showed that shoot length was more stimulated at 25 and 50 mM that root length where as the effects remained the same at higher salinity levels (75, 100 and 150 mM) in *A. hybridus* (Table 3) as compared to *C. argentea* where root length was more negatively affected than shoot length with increasing NaCl levels (Table 4).

Weight measurements

This includes fresh weight, dry weight and dry matter contents. Fresh weight was most stimulated at 0 mM NaCl level in *A. hybridus* whereas 50 mM NaCl concentration influenced fresh weight more than the other NaCl levels in *C. argentea*. Both species showed decreasing fresh weights with increasing NaCl levels, from 50 mM to 150 mM NaCl concentrations. This implies that 50 mM NaCl concentration most positively stimulated water uptake into cytoplasm of cells in both species, apart from 0 mM NaCl in *A. hybridus*. Reduced fresh weights could be attributed to water deficits as established by Cha-Um and Kirdmanee (2009) while studying maize seedlings under NaCl influences and Ratnakar and Rai (2013) who observed a similar trend while investigating *Trigonalla foenum-graecium L. Var. Peb* under NaCl exposure.

Dry weight

Dry weight was highest at 25 mM NaCl concentration in *A. hybridus* as compared to *C. argentea* where highest value occurred at 50 mM NaCl level. Also, both species showed decreasing dry weight values with increasing salinities from 25 mM NaCl in *A. hybridus* and 50 mM NaCl concentrations in *C. argentea*. This is in line with the study of Turan et al. (2009) while investigating NaCl salinity effects in maize plants. Dadkhan and Grifiths

Table 4. Effect of varying concentrations of NaCl on growth parameters of *Celosia argentea.*

NaCl (mM)	Shoot length	Root length	Shoot /root ratio	Total length	Fresh weight	Dry weight	Dry matter	Leaf area index	Rel. H_2O index	Leaf no.
0	15.33±0.32	5.21±0.19	0.34	20.54±0.27	3.61±0.31	0.38±0.01	10.53	1.36±0.12	545.16	10
25	16.97±0.35	5.84±0.21	0.34	22.85±0.29	3.04±0.27	0.41±0.01	13.49	2.88±0.15	1172.73	15
50	18.28±0.28	5.97±0.18	0.33	24.26±0.24	8.64±0.38	0.76±0.02	8.80	2.47±0.14	1142.86	16
75	13.46±0.22	4.07±0.12	0.30	17.54±0.21	5.58±0.27	0.33±0.02	5.91	2.24±0.12	1066.67	11
100	12.22±0.18	3.23±0.11	0.26	15.45±0.17	5.41±0.22	0.31±0.01	5.73	2.19±0.10	1004.35	10
150	12.16±0.13	3.04±0.09	0.25	15.21±0.13	3.24±0.18	0.21±0.01	6.48	2.11±0.08	900.08	9

(2006) attributed such a decrease in dry weight to greater reduction in uptake and reduction in utilization of mineral nutrients by plants under salt stress while Jafari et al. (2009) opined that it could be due to reduced rate of photosynthesis.

Dry matter was highest at 25 mM NaCl level in both species studied. There was a gradual decrease to 75 mM NaCl concentration until an increase started occurring from 100 up to 150 mM NaCl concentration in both species. This could be attributed to accumulation of salt particles within the tissues of both species.

Leaf area index

Mean leaf area index was found to be highest at 25 mM NaCl level in both species studied. After which, there was a corresponding decrease in average leaf area index in both species with increasing NaCl salinities. Reduction in leaf area index could have serious implications for chlorophyll content, thus a reduction in photosynthetic ability of plants. This explains the direct relationship existing in this study between leaf area index and parameters as root length, shoot length as well as total lengths of the species under study. Ungar (1991) opined that higher salinities cause decreases in assimilation of CO_2 through the effect of stomatal opening and sufficiency of photosynthesis process. High salinity could affect stroma volumes of chloroplasts (Price and Hendry, 1991) and the protein bonds of green pigments, thus causing a decrease in chlorophyll content (Rivera and Heras, 1973) in plants.

Relative water concentration (RWC)

RWC decreased with increasing salinities in both *A. hybridus* and *C. argentea* from 25 mM through 150 mM NaCl concentrations. This phenomenon could best be explained by salt induced stress since increasing NaCl levels have tendencies of decreasing water absorption into the cells of plants thereby causing physiological desiccations. This is in agreement with the findings of

Abbas and Latif (2005) who established a decrease in the growth of jute seedlings under NaCl stress, which they attributed to low water absorption into cells as the salinity increased.

Leaf number

Both *A. hybridus* and *C. argentea* are cultivated chiefly for their vegetative parts, thus, it becomes pertinent to evaluate their leaf number. Highest number of leaves in both species was noticed among seedlings growing in 50 mM NaCl concentration. In addition, seedlings with higher total shoot lengths seemed to have higher number of leaves. The numbers of leaves first increased from 0 to 50 mM NaCl concentrations, before a gradual decrease from 75 mM through 150 mM NaCl levels were observed. This shows that moderate NaCl levels (50 mM) positively influenced leaf formation and development as compared to lower (0 and 25 mM) and higher (75, 100 and 150 mM) NaCl concentrations in both *A. hybridus* and *C. argentea*. This shows that both species would be most productive and best cultivated under moderate than low or high NaCl concentrations.

Conclusion

Findings in this study have shown that both *A. hybridus* and *C. argentea* are good halophytes that could sustainably be cultivated in farmlands contaminated with NaCl-induced salinities either due to natural aridity or man-made soil salinization through buildup of salts as a result of extensive use of fertilizers and/or irrigation practices. Although, both species responded to varying NaCl concentrations in different ways, however, both tended to show almost a similar trend.

On the one hand, germination of seeds of both species was adversely affected with increasing NaCl concentrations. Conversely, seedling growth was positively stimulated at moderate levels and adversely affected at varying rates at low (25 mM) and higher (100 and 150 mM NaCl levels in *A. hybridus* and 75, 100 and 150 mM

NaCl levels in *C. argentea*), respectively. Thus, it is being recommended that seedlings of both species of *A. hybridus* and *C. argentea* should be raised in nurseries free of NaCl influences (0 mM), that is, salt-free soils and as soon as maximum germination has been attained, the seedlings could then be transferred to moderately NaCl saline soils for maximum growth and development. There is therefore need to enlighten farmers on these findings to enhance maximum productivity and help ensure food security.

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Full Length Research Paper

Potential carbon credit and community expectations towards viability of REDD project in Ugalla- Masito ecosystem: A case of Ilagala and Karago villages, KigomaTanzania

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The paper presents results of the potential carbon credit and community expectations towards viability of REDD+ projects in Ugalla- Masito ecosystem using a case of Ilagala and Karago villages whereby REDD+ is being piloted. Various data collection methods were employed and these included focused group discussion, interview, structured questionnaires and document analysis. Results of the study indicate that, there are two suggested payment sharing approaches associated with different preferences at both household and village government levels. These include cash payments to households for compensating the opportunity costs incurred and the second is that funds should be given to village government for community developmental projects. Analysis of the opportunity costs, marginal (incremental) revenues from forest carbon stock as well as the conceptual trend of forest biomass indicates that, there is probability for the project to flop in a very short time. Therefore, in order to ensure the future viability of REDD+ and its associated projects as well as ensuring sustainability of people's livelihoods, any REDD+ associated activities should harmonize community preferences and balance them with project goals by supporting communities in their alternative livelihood activities.

Key words: Carbon stock payments, community preferences and REDD+ project viability.

INTRODUCTION

Carbon exists on the earth's atmosphere primarily as the gas-carbon dioxide (Vashum and Jayakumar, 2012). In the recent past, it has gained a lot of attention as a chief among the greenhouse gases, as it has potential to influence the climate pattern of the world. Why carbon emission drew much attention is because carbon dioxide has long residence time in the atmosphere compared to other greenhouse gases (Brown, 1993).

Forest's ecosystem is one of the most important carbon sinks of the terrestrial ecosystem. It removes the carbon dioxide from the atmosphere during photosynthesis and stores the carbon in the plant tissues, forest litter and soils. This process is more prolific in a relatively new forest where the growth of the trees is still rapid and it

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decreases as the forest gets old. The carbon stored on the forest trees are mostly referred to as the biomass of the tree or forest, and the carbon concentration of the different parts of a tree is assumed to be 50% (Brown, 1986) or 45% of the dry biomass (Whittaker, 1973). Nevertheless, according to a study conducted by Lugo and Brown (1992), it was revealed that half of the so called matured forests could also sequester carbon in a rate that could be further increased if human pressures like deforestation and forest degradation activities are reduced or removed from the forests.

These activities have tremendous impacts on biodiversity and carbon emissions and hence on the world's climate. IPCC (2007) highlighted that, tropical deforestation and forest degradation accounts for approximately 18-20 % of global greenhouse gas emissions. As a result, current approaches to address climate change include strategies to reduce emissions from deforestation and forest degradation (REDD) through forests conservation practices of which has captured international attention (Stern, 2006; IPCC, 2007). The United Nations Framework Convention for Climate Change (UNFCCC) of 2010 introduced REDD strategy as the financial mechanism compensating countries for the prevention of deforestation and forest degradation that would otherwise occur.

The 2009 Copenhagen accord of the UNFCCC recognized REDD as a valid mitigation strategy and has increased interest in and funding it. Alongside effective greenhouse gas mitigation, the international accord emphasized that REDD may offer other co-benefits like ecosystem restoration, improved land tenure and socioeconomic development due to carbon market that will increase the income of forest communities which has been referred to as REDD+.

Carbon market mechanisms convert emissions reductions from REDD initiatives into carbon credits that industries and countries can use to comply with emissions commitments. The basis for carbon market community-based forestry initiatives, from a business perspective, is a legal contract between the buyer of the carbon credits and the seller (the communities). In many instances intermediaries will pay a key role moving the credits from the level of production (the community forest) to the marketable place (TNRF, 2008). Several payment mechanisms under REDD initiatives does exists. One of them is based on a national level carbon fund that would be the recipient of financial flow for avoided deforestation, carbon credit sales and so on.

In Tanzania, the fund-based approach has been argued to fit with the realities of communal land and forest tenure under village governance and participatory forest management (Burges et al., 2010). The first is an effort-based payment, which rewards communities for improved forest management activities. The second is an output-based payment, which rewards forest managers for empirically verified outputs such as improved forest condition and reduced deforestation (TFWG, 2010). The effort-based approach would reward villages equally even when their ownership of forest resources and utilization of village differs. The output-based approach would benefit more communities who have increased their carbon stocks and are able to demonstrate it by carbon baseline, monitoring and calculation (Bolin et al., 2012).

Kigoma region is one among the areas in Tanzania where REDD project has been piloted. Communities have accepted REDD project implementation with anticipation that the project will be compatible with their local poverty reduction strategies and development goals. In this regard, communities in REDD project areas have been foregoing forestry products despite the fact that their demand is very high compared with what the district or region can supply. These include firewood and charcoal (frequently used for sale or fuel) and timber and building poles (URT, 2009). Thus, there is opportunity cost behind acceptance of REDD project implementation since local communities have been losing income they used to accrue from forestry products. This paper, therefore, confines itself at implication of the potential carbon credit and community expectations towards viability of REDD projects using a case of Ilagala and Karago villages located in Kigoma whereby REDD+ has been piloted. This paper therefore presents the results of the study on the adequacy of potential carbon credit in meeting local priorities and needs as far as the viability of REDD project is concerned using the case of the two above mentioned villages in Kigoma Tanzania.

MATERIALS AND METHODS

Study area

Presence of REDD pilot project and low income communities depending on the forest ecosystem goods and services, were used as the basis for selecting Ilagala ward where Ilagala and Karago villages are situated (Figure 1). The villages are among the seven villages forming Masito-Ugalla Ecosystem where the international Non-Governmental Organization (NGO) (Jane Goodall Institute (JGI)) has been implementing REDD+ pilot project. The villages are located along Lake Tanganyika shoreline within Kigoma rural District. The REDD implementation approach in these villages link with participatory forest management (PFM).

Karago village is bordered to the north by the Ilagala village, to the south by Sunuka village, to the east by Masito-Ugalla forest reserve and southeast by Songambele, and to the west by Lake Tanganyika. It has 8,703 people (about 1600 households) (2012, census) and a land area of 11,218.88 ha has reserved five forests with a size of 5646.49 ha (Figure 2). However, the village has agricultural land of 5137.88 ha and 432 ha for settlement.

On the other hand, the Ilagala village is bordered to the north by Mwakizega village, to the south by Karago and Songambele villages and east by Masito-Ugalla forest reserve, and to the west by Lake Tanganyika. The village has 21, 246 people (about 3500 households) (2012, census) with a land area of 23,840.13 ha and has reserved three forests with a size of 3402.2 ha (Figure 3). However, the village has agricultural land of 14879.91 ha, 4904.85 ha for settlement and a reserved forest for mining activities of 653.17 ha.

Agriculture is the major source of income in Karago and Ilagala villages. If the area under crop cultivation is distributed equally to
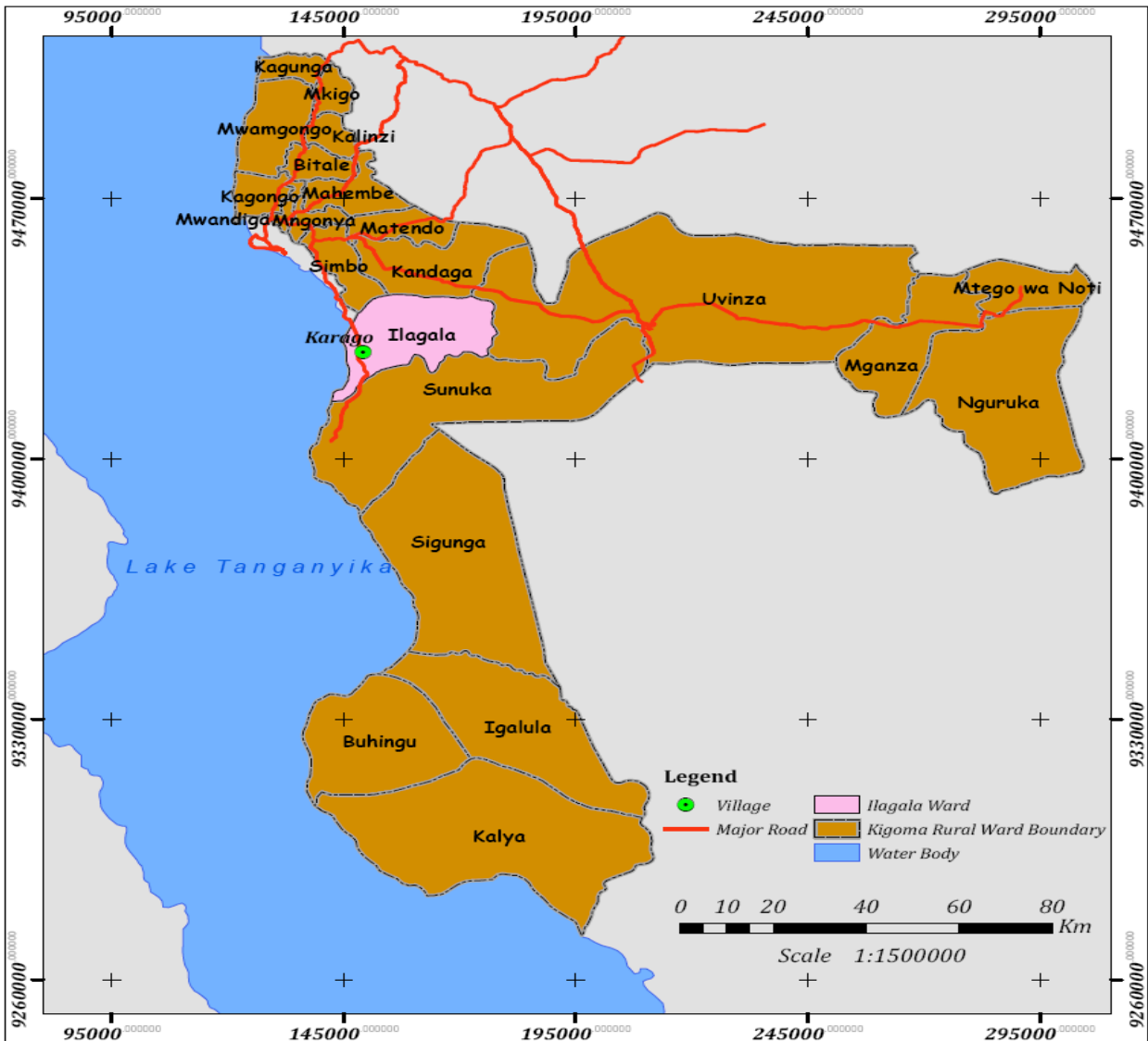
Figure 1. Selected case study villages in Ilagala ward, Kigoma Tanzania.

the total population based on 2012 census every single person in Karago village will be cultivating an area of about 0.6 ha while in Ilagala it will be 0.7 ha.Agricultural production in Karago and Ilagala villages depend mostly on rains for crop growing. Major crops grown include maize, beans, cassava, bananas, groundnuts and oil palm. However, despite of cultivation, there are other socio economic activities like beekeeping, cattle keeping, carpentry and petty business.

Data collection methods and analysis

A combined methodology that involved qualitative and quantitative approaches was adopted. Consequently, multiple methods and techniques for data collection and analysis were used. Data collection methods which were applied included key informants interviews, focus group discussions and in-depth interviews using a standard questionnaire that was structured to obtain the information on potential carbon credit and community expectations towards

viability of REDD project. Under the key informants' interviews, different well knowledgeable representatives of the actors at Kigoma rural district level and in the respective villages were interviewed. The interviewee also included the representatives of the NGO which was Jane Goodall Institute (JGI) that is implementing the REDD pilot projects in the respective villages. Other key informants interviewed included ward and village officials, religious leaders and primary school teachers who were regarded as well knowledgeable people at the local level regarding the natural resources issues and again they were useful in advising on the specific community to be interviewed during the in-depth interviews that were carried out in their respective areas. Under the focus group discussions, meetings with village representatives in the selected communities were held to discuss issues related potential carbon credit and community expectations towards viability of REDD project in their respective villages. More information was collected through in-depth interviews using a structured questionnaire which had both open and close ended questions. Under the in-depth interviews, a total of 70 household
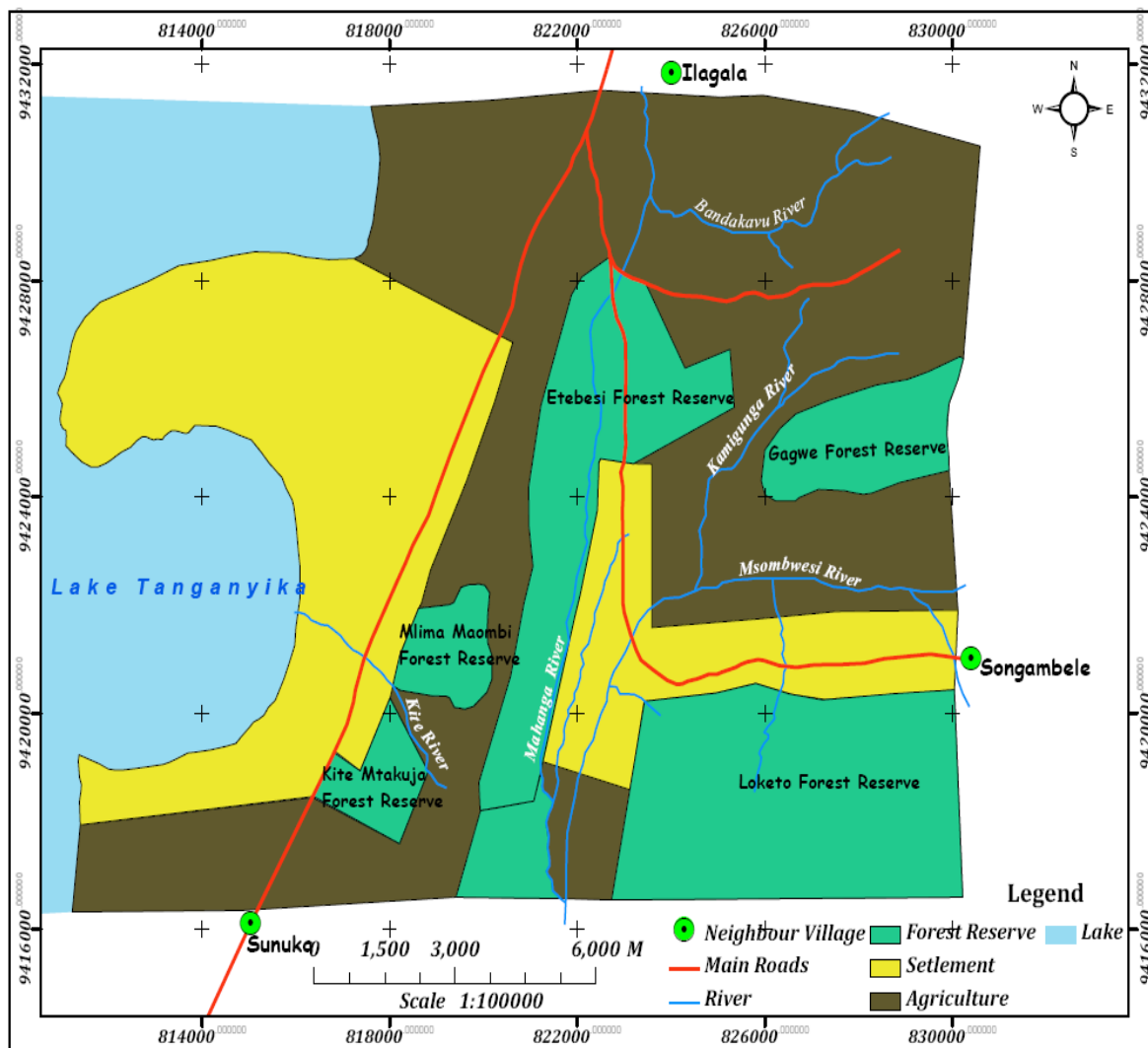
Figure 2. Map showing the land use of Karago Village.

Table 1. Characteristics of the interviewed households.

Village	Households interviewed	Sex		Age (%)			Education level (%)			Residence history (%)	
		%Male	%Female	18-35	36-60	>60	Illiterate	Primary	Secondary	Born in the Village	Born in other village
Karago	30	80	20	30	70	0	3.3	86.7	10	86.7	13.3
Ilagala	40	65	35	25	72.5	2.5	2.5	97.5	0	72.5	27.5

representatives were interviewed. Table 1 gives the characteristics of the interviewed households. However, during the field study, the following criteria were used in selecting respondents especially households: 1) market access – people living near the roads andfar from the roads or people living near or far from the forests; 2) Socio-economic activities for example people who are involved with fishing activities; deforestation rates - areas with high and low deforestation rates.

Most of the qualitative data collected were analyzed using content analysis. Content analysis was carried out for the data that were collected through focus group discussions. Data collected

from the questionnaire were analyzed by SPSS whereby descriptive statistics such as mean, standard deviation and percentages were determined.

Opportunity cost estimation for fuel wood accessibility

In order to estimate the opportunity costs for fuel wood accessibility per household in the case study villages, the monetary valuation was done by using the method(s) adopted from Chopra, (1993) as presented in Table 2.
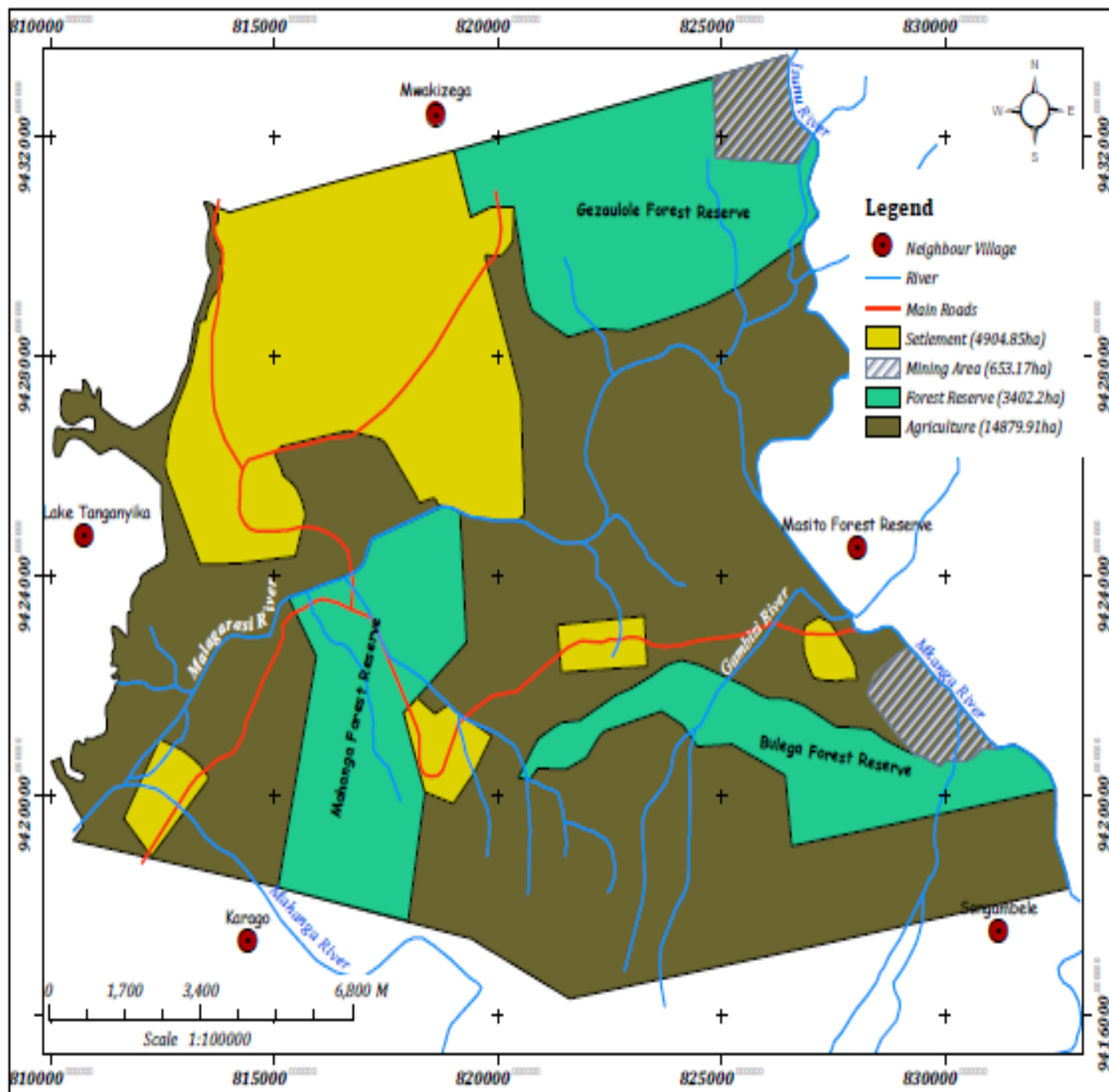
Figure 3. Map showing the land use of Ilagala village.

Table 2. Total Monetary Valuation of foregone fuelwood per household.

Type of Fuelwood	Cost code	Method of Approximation
Firewood	Cost of firewood (PF)	PF= Household consumption per week X UNDP nominal price per m^3 X Number of weeks per year
	Cost of Labor (Time in collection) (CL)	CL=Time taken for firewood collection per day X Firewood Collection Frequency per week X UNDP nominal cost per effective hour X number of weeks per year
Charcoal	Cost of charcoal (MP)	Village current market price

RESULTS AND DISCUSSION

Forests and community livelihoods before and during REDD project

As is the case in many parts of Tanzania, forests have a significant role of securing livelihoods to the surrounding communities. Forest plays three roles to the communities. These include safety netting, supporting consumption, and being an out of poverty pathway (Kajembe et al., 2012). Communities in Karago and Ilagala villages where this study was conducted use surrounding forests for collecting fuel wood, construction materials and non-timber products.

Community representatives interviewed in this study mentioned that during the implementation period of the REDD+ project in the case study area, construction materials and non-timber products have been exploited in sustainable manner but there has been a big concern on fuel wood accessibility. During this implementation period, although forest conservation was highly encouraged to the selected forest reserve, there are no clear identified forests for fuel wood collection and instead, majority (45% -77%) of community members in the case study villages used their agricultural fields for fuel wood collection. This has affected accessibility of fuel wood to residents in terms of space, time and quantity. People who were close to the forest reserves are now obliged to walk a long distance in search of firewood. The average time taken by household for firewood collection per trip was reported to have increased from 5 to 7 h per day and they do that twice a week. Changes in fuel wood accessibility has compelled 43 and 13% of the respondents to buy fuel wood in Ilagala and Karago villages respectively which implied the need for more money to support energy availability for the respective households.

The study has further revealed that, REDD+ project has reduced fuel wood consumption at household level of which is essential for forest ecosystem restoration in the case study villages. The current household consumption of firewood is 1 m^3 per week for Karago and 1.5 m^3 per week for Ilagala while for charcoal is 0.75 of a sack (22.5 kg) and 0.7 of a sack (21 kg) per month for Karago and Ilagala villages respectively. The acceptance of REDD+ project has therefore been associated with opportunity costs of which the respondents were willing to take with anticipation that the project will be compatible with their local priorities and needs.

Potential carbon credit and community expectations

Carbon stock estimated in the village forest reserves indicated that Karago and Ilagala villages were required to receive a total $15,625 and$ 11,250 respectively for the first year of the project (phase one). Payments may vary for the next years with respect to amount of the esti-

mated incremental carbon stock of the forest reserves. In these villages, two different payment sharing approaches associated with different preferences at both household and village government level were suggested; these are cash payments to individuals for compensating the incurred opportunity costs which include labour and procurement costs. This was suggested by 20% of the respondents. The second modality was suggested by 80% of respondents. The interviewed community repre-sentatives further indicated that funds should be given to village government for development projects and protecting forest reserves (Figure 4).The differences in payment modalities imply that there is need for a harmonized payment mechanism.

Potential carbon credit at household level

Due to spatial and temporal changes of fuel wood accessibility brought by the implementation of the conservation project through REDD+ in the area, some households needed the potential carbon credit for compensating the incurred opportunity cost. People use more time than before the start of the implementation of the REDD+ project. The increased time is used in search of firewood due to the increase in distance. Results revealed that 3% of interviewed households in Karago buy fuel wood while 43% in Ilagala buy fuel wood. In this regard, people may need to be paid $ 1239-$ 1,664 per household per year as compensation for firewood, and $ 40-$ 60 per household per year as compensation for charcoal.

Therefore, in general, the total amount of money to be paid directly to each household in the villages is supposed to be $ 1279-$ 1,724 per year for fuel wood consumption. This amount is far by 92-94 percent compared to the amount that the potential carbon credit which could be divided to households. The amount of money to be given to each household as compensation could not be compared in any case by the forgone opportunity costs.

Potential carbon credit at village government level

In the key informant interviews with the village leaders, it was reported that amount of money to be given to each village government was reported not to be enough to complete even one development project. For instance the amount of money required to complete a water project for the people of more than 1500 households was not less than 200 million (Carlevaro and Gonzalez, 2008). This amount of money is higher by 86 - 88% than the amount of money expected to be given to the households and village government put together. On top of that, the money will be decreasing due to the fact that the incremental carbon stock present in the forests will keep on decreasing too. The achievement of such water
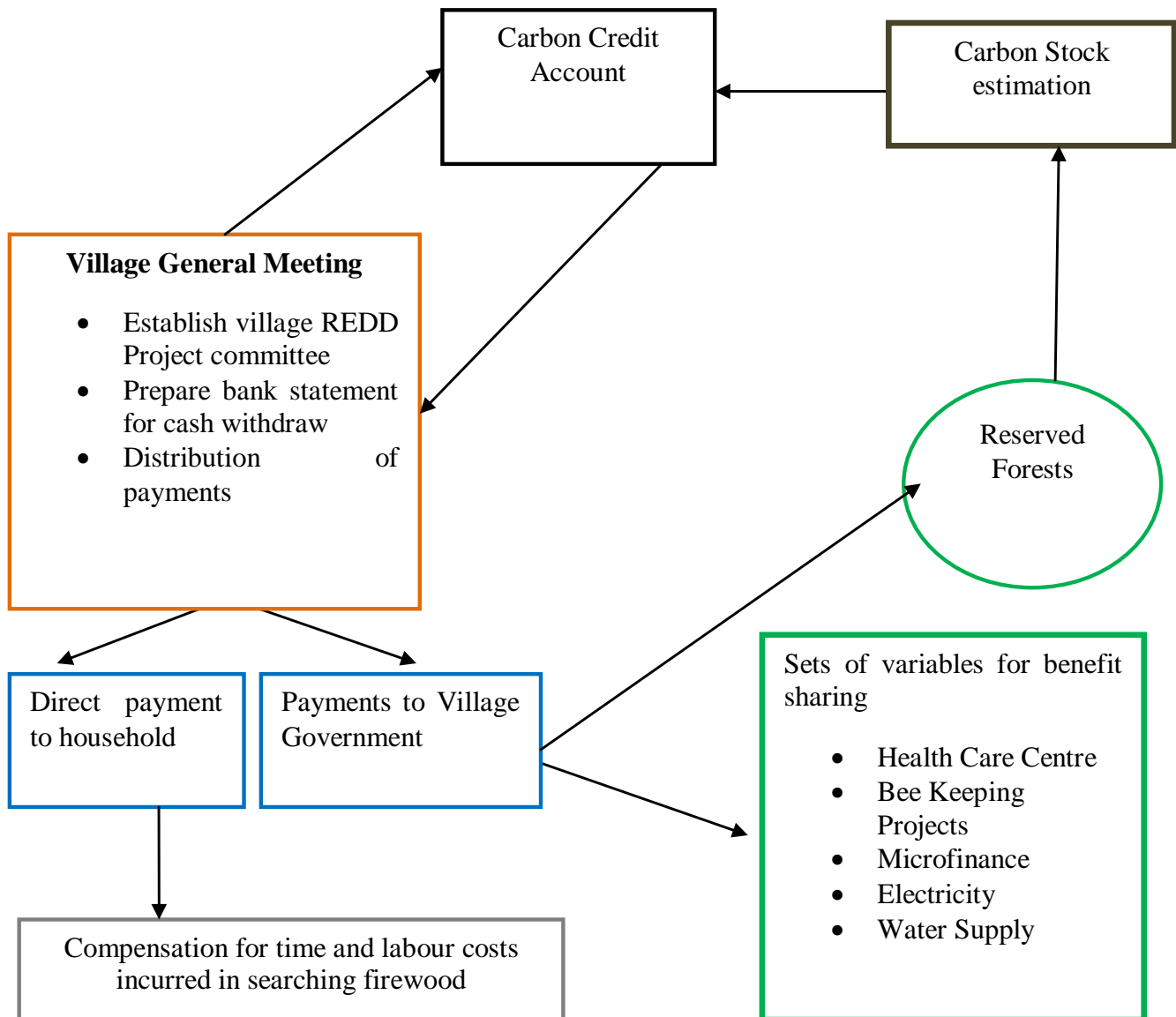
Figure 4. Model for REDD project revenue benefit sharing and payment mechanism for potential carbon credit.

project for example would need an accumulation of money for more than 8 years consecutively under assumption that the amount of money given will not change ($15,625 for Karago and $11,250 for Ilagala) which will not be the case especially when considering the incremental carbon stock.

According to Kabura et al. (2013), the cost of managing a hectare per year is about $6.5. Translating this cost to the case of Karago forest reserve with an area of 5137.88 ha, about $33, 400 per year while for Ilagala forest reserve with an area of 3402.2 ha, about $22, 114 per year is needed for the management cost. These costs are still higher by 45-50% than the financial payments to be received which was $15,625 and $11,250 for Karago and Ilagala respectively.

Trends of opportunity cost, carbon stock and potential carbon credit over time

Analysis of the opportunity cost, marginal (incremental) revenues/potential carbon credit and carbon stock shows that the project will have four major phases (A, B, C and D), each with different behaviour (Figure 5).

In general, there will be a decrease in incremental revenues in each project phase because; the revenues are the function of incremental carbon stock. The incremental carbon stock is also the function of forest age of which increases as the project lifetime increases. Therefore, the project seems to be helpful during the first phase of the project. The probability for the project to flop in near future is high if there will be no means to reduce
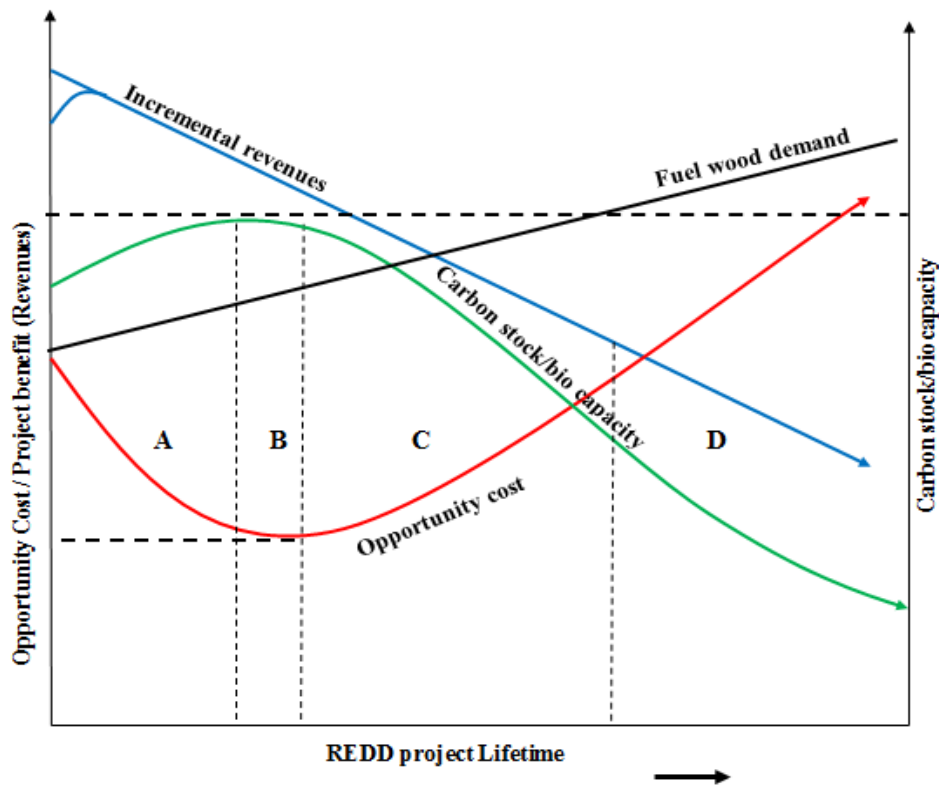
Figure 5. Trends of opportunity cost, carbon stock and potential carbon credit over time.

the opportunity cost and improve forest biomass.

In phase one (A), there will be an increase of carbon credit due to increase of carbon stock in the forest. The bio capacity is slightly higher than the village demand on forest goods. The opportunity cost of forest goods will also have a tendency of decreasing due to the fact that, as the project start operating, there will be additional co-benefits that will lower the opportunity cost. Among the co-benefits from the forest are climate regulation and the increase of food products from the forest such as mushrooms.

Phase two (B) is the positive turning point for the opportunity cost and negative turning point of carbon stock in REDD project forests due to forest age. The opportunity cost will stop decreasing and instead start increasing. The reason is that the forests allocated for fuel wood collection will fail to meet the fuel wood demand and hence raise the labour and procurement costs of fuel wood. It is at this phase when the carbon credit will start decreasing.

Phase three (C) will be associated with high increase of opportunity cost since the revenues from carbon credit will keep on decreasing. On the other hand fuel wood demand will be high if considering no substitute for goods and technologies while bio capacity is low. It is at this time there will be an increase of land degradation and people may start returning to the REDD project forests

upon no strict supervision.

Phase four (D) will be associated with unusual increase of opportunity cost which will be far be bigger than the marginal (incremental) revenues from carbon stock increment. This is the time when the ability of forest to sequester carbon will be low due to forest age and hence more less forest revenues to the village. Due to very low bio capacity at constant fuel wood demand, there will be more environmental and social economic problems in the villages. This situation will be worse right from the point (time) when the marginal revenues will have exceeded the opportunity cost. This is the phase when the project will flop.

The role of energy efficient cooking technologies on REDD project viability

The findings from the study indicate that unless energy sources and energy efficient cooking technologies are well addressed, viability of REDD+ initiatives are will still be low. Adoption of high energy efficient cooking techno-logy (HEECT) will reduce pressure in the forests of which is essential for viability of REDD+ project.

According to Tanzania Traditional Energy Development Organization (TaTEDO), the efficient cooking technolo-gies (EECT) include improved charcoal stoves which
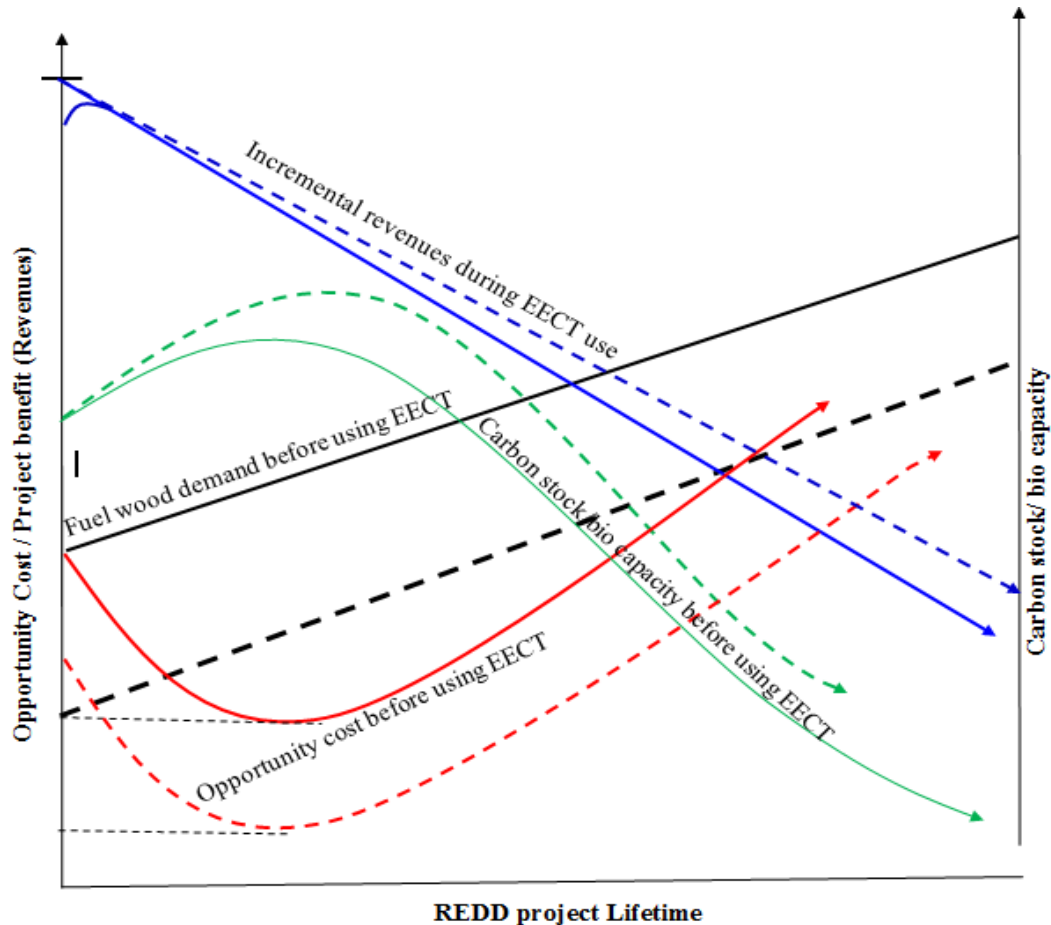
Figure 6. The sketch showing the behaviour of opportunity cost, incremental Carbon stock revenues, fuel wood demand, bio capacity of forest ecosystem before (solid lines) and during EECT application (dashed lines).

have capacity of reducing consumption of charcoal by average of 71% and improved firewood stoves (Improved Okoa Firewood Stove) of which have capacity of reducing consumption by more than 65%. The improved firewood stoves use one or two pieces of firewood. In this regard, by adopting these kinds of technologies, the costs for purchasing firewood will have been reduced significantly for those purchasing firewood as they will consume less fuel wood.

Reduction in fuel wood consumption will in turn reduce further the frequency of fire wood collection. This will help women and children in Karago and Ilagala villages to save around 2,912,000 - 3,328,000 hours per year for collecting firewood with estimated value of $1,456,000 – $1,664,000 per year - at nominal cost of $0.5 per effective hour used for fetching firewood. The time saved can be used for implementing other development activities.

Adoption of EECT will cut down carbon dioxide emissions by 80% since the use of unimproved biomass stove by the 4,000 households in two villages contributes around 1,105,416 tons of carbon dioxide (tCO2) per year at the average of 4tCO2 per cubic meter of firewood but through the use of EECT (improved charcoal technology), the emission could be reduced to 232,137.4 per year.

Moreover, adoption of these technologies may reduce the opportunity costs (labour and procurement costs) for fuel wood accessibility by 67.9 to 70.5%. This is because the opportunity cost for fuel wood accessibility will decrease from $1279-$1724 to $410-$508 per year. The reduction in fuel wood consumption is associated with reduction in frequency of fire wood collection of which has implication on labour costs. Reduction of opportunity cost will increase project viability as there will be a shift of the point at which opportunity cost starts becoming higher than incremental revenues. Also, the decrease in fuel wood demand prompted by the use of EECT will increase project viability in terms of forest biomass as there will be shift of the point at which bio capacity starts becoming lower than the fuel wood demand (Figure 6).The point can be shifted further if communities will be encouraged to have their own woodlots. Thus, application of appropriate

measures for opportunity costs reduction and improving forest biomass may make the project more viable in the case villages.

Conclusion and Recommendation

The study reveals that, there is high opportunity cost behind REDD+ project implementation in the case study villages of which 80% of the respondents were willing to take with anticipation that the project will be compatible with their local priorities and needs. The study has further revealed high expectations on the benefits to be gained by the communities in the respective villages. The REDD+ project, local governments and people should therefore, harmonize the community preferences so that project goals become compatible with community priorities and needs. Careful selection of the already proposed alternative livelihood projects like bee keeping project and microfinance must therefore be done in the case villages to ensure sustainability of REDD+ project and people's lives. Notwithstanding the social economic effects, REDD+ project has brought positive changes in the case villages as there is already climate regulation in terms of rainfall, rejuvenation of river water tributaries flowing from the forests and increase of Non wood products in the forest reserves. The study recommends that, in order to maximize the environmental and socio-economic benefits in the case villages, there is a high need for conservation projects such as REDD+ project to cooperate with village government in tree planting campaign in the farm fields and encouraging the use of improved stoves to cut downcosts of fuelwood access and its consumption in the foreseeable future.

Conflict of interest

The authors did not declare any conflict of interest.

ACKNOWLEDGEMENTS

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Full Length Research Paper

Diffusion coefficients of *Grewia* spp. biopolymers in water

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Diffusion coefficients of biopolymers extracted from *Grewia* spp. barks in water were studied under various physicochemical conditions. Extractions were carried out on barks of 3 cm in length at different pH (5-9), temperature (25-50°C) and ionic strength (10^{-3}-10^{-2}M), using $CaCl_2$ and NaCl as background electrolytes. Factorial experimental plan design was used and diffusion coefficients were determined using second law of Fick equation, with linear and logarithmic approximation. Obtained results show that diffusion coefficients of *Grewia* spp. biopolymers are in the range of 9.78458E-06±1.6462E-08 cm^2/min, and are not significantly influenced by the pH, the ionic strength and the temperature. Maximum diffusion was obtained with $CaCl_2$ at high ionic strength. Both linear and logarithmic approximations were found to be suitable for diffusion coefficients and were dependent on the background electrolyte used.

Key words: Biopolymers, diffusion coefficient, *Grewia*.

INTRODUCTION

Different plants extracts have been used or tested as biopolymers for coagulation; *Moringa oleifera, Strychnos potatorum, Jatropha curcas sabdariffa, Curcuma angustifolia* (Pritchard et al., 2010**)**, *Phaseolus vulgaris* and *Grewia*. *Grewia* spp. is a flowering plant from the family of *tiliacées* that grows in the shade of nearby rocks and reeds, native to warm tropical regions of Africa, Asia and Australia (Emeje et al., 2008). It is used as a thickener, stabilizer in food process and in some cases it may act as a coagulant /flocculant (Ndi et al., 2013).

In water clarification processes, studies on efficient bio-polymers for coagulation purposes are widespread due to the environmental impact of those coagulants (Chun-Yang, 2010). Biopolymers can be extracted from different parts of the plant including barks, leaves and roots but, when powders are used, fine particles are released, increasing the suspended material and the turbidity of the suspension, and may act as a support for bacterial growth (Kebreab et al., 2005). Therefore, purification of extracted biopolymers is often required. Unfortunately, these methods include a combination of lyophilisation, chromatography and dialysis, which are complex

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Table 1. Factors range.

Factor	Values
pH	5- 9
Salt concentration (M)	0.001- 0.01
Temperature (°C)	25-50

Table 2. Complete factorial design matrix.

Run	pH	Ionic strength	Temperature
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1

and expensive for implementation in rural areas of developing countries (Kebreab et al., 2005). Thus, looking for an optimum in the extraction of biopolymers with fewer amounts of fines released is of great importance for coagulation purposes. Using barks instead of powders as coagulant/flocculant may increase the settling velocity of flocs, reducing considerably the amount of fines released in the suspension, and further accelerate the clarification step.

During flocculation, the required amount of coagulant or flocculant for good clarification purpose is directly linked to the initial water quality. Thus, knowledge of biopolymer concentration in the suspension is of great importance for coagulation process. When barks are soaked in water, biopolymers are released from the bark to the suspension. This extraction process can be improved by agitation of the suspension, but in a house hold scale it is generally done without any agitation, as it is easily carried out, leading to natural diffusion of biopolymers from the bark to the suspension. As natural diffusion is a mass transfer process, induced by gradient concentration, there's need to evaluate the amount of biopolymers released within the contact period time of the bark in the liquid. This can be done knowing diffusion coefficients.

Diffusion coefficient is a key parameter of mass transfer process and describes how fast the amount of released biopolymers in the suspension is. Diffusion coefficient although generally assumed as constant depends on many parameters like ionic strength, pH, temperature and bark concentration (Giovana et al., 2011).

Diffusion coefficients are well determined by direct methods including technique of fluorescence recovery after photo bleaching (FRAP) which has been refined

through the use of a laser scanning confocal microscope (LSCM) or by indirect methods like spectroscopy, chromatography and mass balance in the system (Matthew et al., 2000). When indirect methods are used, plotting the amount of biopolymer released as a function of the concentration as described by the second law of Fick equation gives the diffusion coefficient. Approximation of the Fick equation commonly used is linear and logarithmic ones which were found to be suitable for biopolymers diffusion in water system. The linear model corresponds to the earlier part of the slope of the diffusion process while logarithmic is mainly used when the required time for extraction is high (Poirot, 2007).

The aim of this study is therefore to evaluate diffusion coefficients of *Grewia* spp. biopolymers and to find suitable models describing it under different physicochemical conditions.

MATERIALS AND METHODS

Biological material

Grewia spp. was collected from Mokolo, a town located in the far Northern region of Cameroon. *Grewia* spp. barks of 3 cm length were used as biological material for biopolymer extraction. They were dried at 45°C using a forced convection dryer (CKA2000AUF) for 24 h, allowed to cool in a desiccator, and kept in sealed plastic bags prior to their use. The thickness (L) of *Grewia* spp. bark used was obtained by measuring the average size of 100 barks selected randomly.

Characterization

FTIR analyses were carried out before and after biopolymer extraction.

Polymer extraction

Polymer extraction was carried out in batch mode without any mechanical stirring of the solution, with distilled water of pH (5-9) adjusted using 1 M hydrochloric acid (Sherman Chemicals limited) or 1 M NaOH solutions (Prolabo), and ionic strength (0-0.01 M) adjusted using NaCl (Jeulin) and $CaCl_2$ (Jeulin) salts. Conductivities were monitored using conductimeter (HI 8733, HANNA Instrument) and biopolymer mass was determined after each extraction by drying in an oven (Memmert) at 105°C and weighing the resulting extract on a mass balance of 10^{-3} precision (Gibertini).

Extraction kinetics were done with a ratio of barks mass (5, 10 and 20 g) over extraction solvent volume of 250 mL.

Experimental design

Complete factorial design was used. Selected factors are presented in Table 1. The experimental matrix is described in Table 2, and the diffusion coefficient was defined as the response.

Diffusion coefficients determination

Diffusion coefficients were derived from the slopes of the following equations (Aghfir et al., 2008; Claudia et al., 2009). Taking into
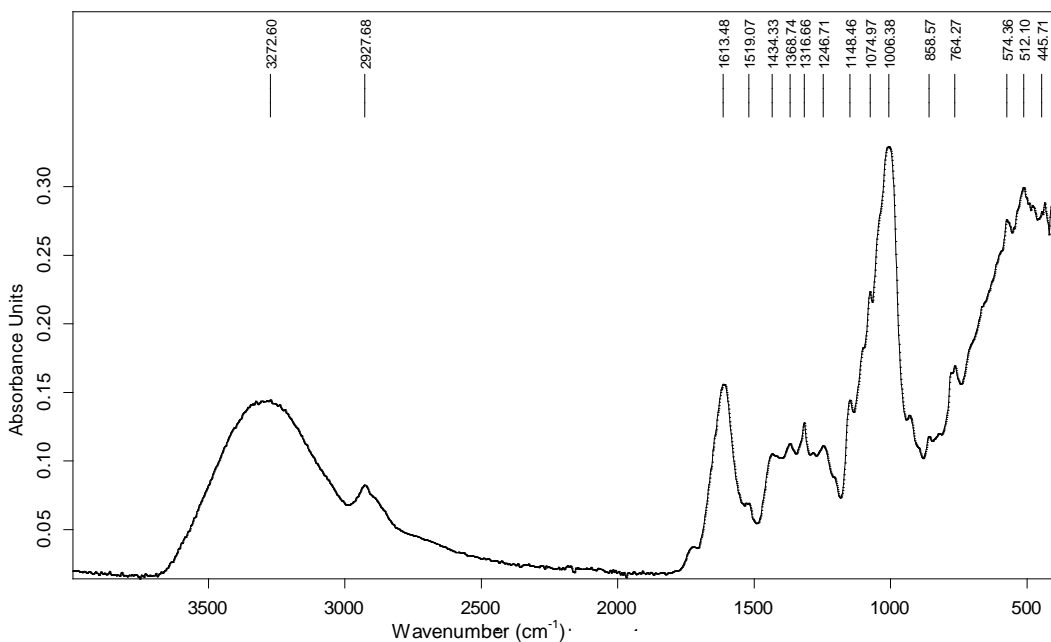
Figure 1. The FT-IR spectroscopic spectrum of the powders of *Grewia* unextracted.

consideration the hypothesis that:

1. The particles have the shape of a plate;
2. Uniform initial distribution of moisture;
3. Simplification of the movement of moisture by diffusion;
4. Negligible contracting;
5. Constant coefficient of diffusion.

The diffusion coefficient can be calculated by using the following equations for the two models:

$\frac{M_t}{M_\infty} = \frac{4}{L}\left(\frac{D_m \cdot t}{\pi}\right)^{\frac{1}{2}}$ Equation1 (for the linear approximation),

$Ln\left(1 - \frac{M_t}{M_\infty}\right) = Ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_m \cdot t}{4L^2}\right)$ Equation 2 (for the logarithmic approximation).

Where M_t is the mass of polymers at the moment t, M_∞ is the mass of polymers at infinite time, L is the thickness of the barks, t the time and D_m the multidirectional diffusion coefficient. The obtained quadratic equation was expressed as:

Diffusion coefficient = C_{ST} + C_A*A + C_B*B + C_C*C+ C_{AB} *A*B + C_{AC}*A*C - C_{BC} *B*C

Where, C_X denotes the coefficient factor related to the factor X studied.

RESULTS AND DISCUSSION

Characterization of *Grewia* spp.

The FT-IR spectroscopic spectra of the powders of *Grewia* unextracted and extracted are presented in the

Figures 1 and 2, respectively. The main difference between these two spectra is at the level of the intensities of the peaks.

The spectra exhibit the typical bands and peak characteristic of polysaccharides. The broad band occurring at 3272.60 cm^{-1}, results from the presence of hydroxyl (-OH) group. The peak obtained at 2927.68 cm^{-1} results from stretching modes of the C-H bonds of methyl group (-CH$_3$). Natural gum usually contains fractions of sugar acid units which would usually impart a weakly anionic character to the gum macromolecule (Wang et al., 2003).

Absorption bands around 1618 and 1430 cm^{-1} are typical of carboxylate group of the galacturonic acid residues (Figueiro et al., 2004). The peak obtained at 1519.07 cm^{-1} is typical of carboxylic group. The peak obtained at 1074.97cm^{-1} result from the presence C-O-C group. The peaks obtained at 1720.23 and 1607.16 cm^{-1} results from the presence of C=O group. The wave numbers between 800 and 1200 cm^{-1} represents the finger print region for carbohydrates (Fillipove, 1992).

Physicochemical effects on released G*rewia* spp. biopolymers

Figure 3 presents the effect of bark mass/water solution ratio (5/250, 10/250 and 20/250) on biopolymer extraction over time on the ratio of biopolymer mass (EP) recovered over the initial mass of the bark introduced (BM). As shown, less than 4% of the bark mass is released in the
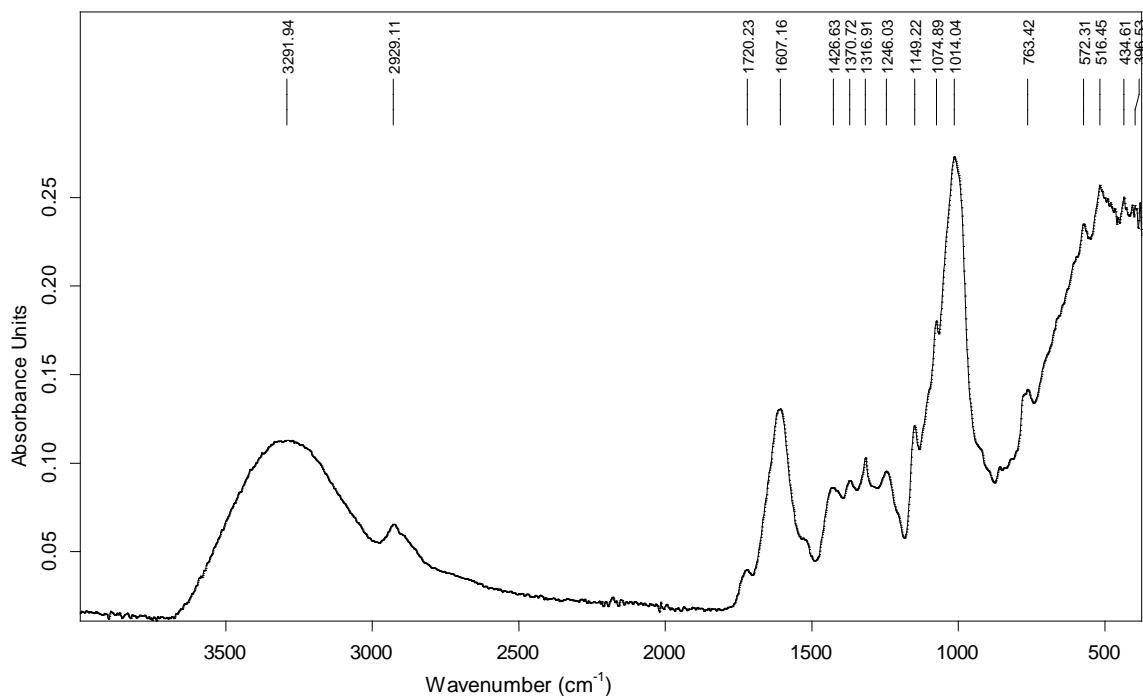
Figure 2. The FT-IR spectroscopic spectrum of the powders of *Grewia* extracted.
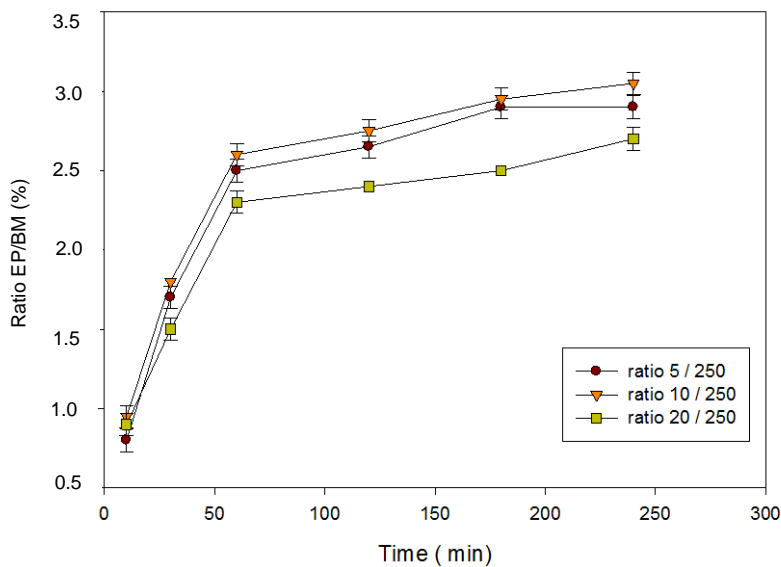
Figure 3. Kinetics of biopolymer extraction for different bark mass/water solution ratio.

suspension during batch operations whatever the ratio. From 0 to 60 min, rapid transfer of biopolymer from the bark to the suspension is observed. Further, the biopolymer is still recovered, but at a low rate. When 20 g of bark is introduced in 250 mL of suspension, the amount of polymer recovered slightly decreases. Polymer extraction in dilute solutions is coherent with other works related to polymer transfer. Reduction of the amount of polymer when bark ratio increases is due to the well-known resistance of transport due to the gradient of

Table 3. Factors coefficients and interactions for modeling of diffusion coefficient with NaCl for linear and logarithmic model, using complete factorial design plan.

Term	Linear model with NaCl		Logarithmic model with NaCl	
	coefficient	Probability	Coefficient	Probability
A:PH	2.93E-8	> 0.05	6.61E-7	> 0.05
B:FI	1.19E-6	> 0.05	1.26E-5	> 0.05
C:TEMP	3.99E-6	> 0.05	5.09E-5	> 0.05
AB	2.98E-8	> 0.05	-3.31E-6	> 0.05
AC	1.65E-7	> 0.05	3.31E-6	> 0.05
BC	4.44E-7	> 0.05	6.61E-7	> 0.05
Constant	1.02E-5		1.36E-4	

Table 4. Factors coefficients and interactions for modeling of diffusion coefficient with $CaCl_2$ for linear and logarithmic model, using complete factorial design plan.

Term	Linear model with $CaCl_2$		Logarithmic model with $CaCl_2$	
	Coefficient	Probability	Coefficient	Probability
A:PH	3.62E-7	> 0.05	3.31E-6	> 0.05
B:FI	2.27E-6	> 0.05	9.92E-6	> 0.05
C:TEMP	3.52E-6	> 0.05	4.69E-5	> 0.05
AB	1.65E-7	> 0.05	4.63E-6	> 0.05
AC	1.96E-7	> 0.05	-3.31E-6	> 0.05
BC	-8.78E-8	> 0.05	6.61E-7	> 0.05
Constant	1.07E-05		1.43E-4	

concentration in the solution which becomes low and then reduces the transfer of the polymer inside the suspension.

Modeling diffusion coefficients of *Grewia* spp.

Using complete factorial design followed with linear and logarithmic approximation, coefficients of factors involved in the extraction process and quadratic interactions are presented in Table 3 for diffusion with NaCl salt and in Table 4 for diffusion with $CaCl_2$ salt.

The obtained quadratic equation with NaCl was expressed as:

Linear model
Diffusion coefficient = 1.02E-5- 2.93E-8*A+1.19E-6*B+3.99E-6*C+ 2.98E-8*A*B + 1.65E-7*A*C + 4.44E-7*B*C

Logarithmic model
Diffusion coefficient = 1.36E-4+6.61E-7*A+1.26E-5*B+5.09E-5*C-3.31E-6*A*B+3.31E-6*A*C+1.98E-6*B*C

The obtained quadratic equation with $CaCl_2$ was expressed as:

Linear model
Coefficient diffusion = 1.07E-05+3.62E-7*A+2.27E-6*B+3.52E-6*C+1.65E-7*A*B+1.96E-7*A*C- 8.78E-8*B*C

Logarithmic model
Coefficient de diffusion = 1.43E-4+3.31E-6*A+9.92E-6*B+4.69E-5*C+4.63E-6*A*B-3.31E-6*A*C+ 6.61E-7*B*C

Tables 3 and 4 present the coefficients of parameters involved in the quadratic equation resulting from the factorial design plan. The observed probability of all the factors was found to be greater than 0.05, showing that at a probability of 95%, these factors did not have a great influence on the diffusion coefficient.

Table 5 presents the values of statistic parameter used to validate the model. Since the values obtained R^2, AADM, B_f is near the values expected, the mathematical model obtained is considered as valid.

But by taking into account the parameters of validation of the model, one notes that the model logarithmic model

Table 5. Validation of the models.

Parameter	Expected values	CaCl$_2$		NaCl	
		linear model	logarithm model	Linear model	logarithm model
R^2	1	0.989	0.999	0.995	0.988
AADM	0	0.030	0.005	0.000	0.040
Bf	1	1.000	0.999	1.000	1.002
A$f1$	1	1.030	1.005	1.000	1.041
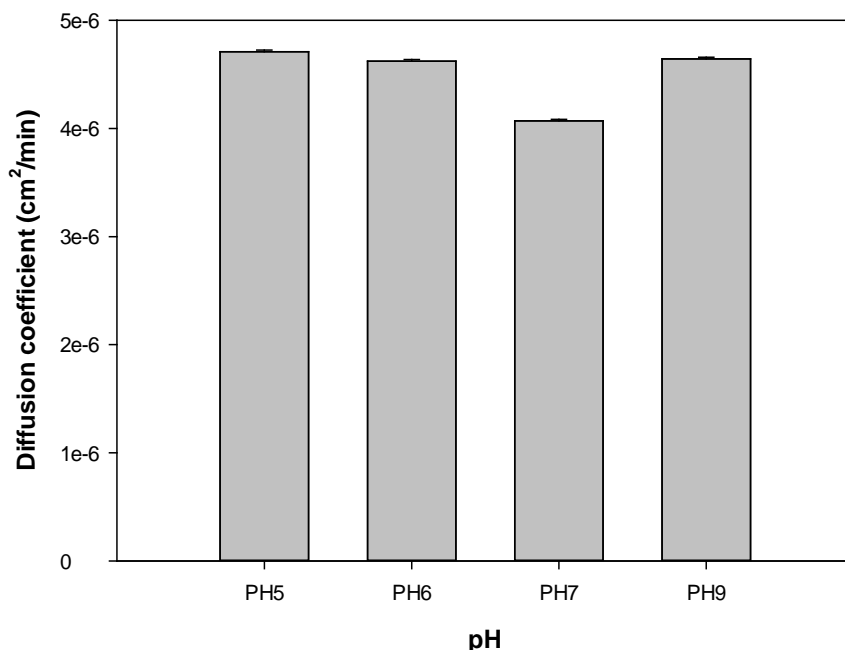
Figure 4. Biopolymers diffusion coefficients with the pH.

presents itself as an explanation of the interaction between the various factors of the extraction of polymers of *Grewia* in the presence of CaCl$_2$, whereas the linear model presents itself rather better than the extraction in the presence of NaCl.

Figure 4 presents the pH effect on extraction ratio on polymer removal and extraction time on polymer mass recovered over the mass of the bark as shown for a ratio bark/volume equal to 10/250. At the beginning of the diffusion of polymers into the solution (from 0 to 60 min), less influence of pH on polymer transfer is observed. Net pH influence is found after 120 min of extraction, and the lowest extraction ratio is obtained at pH 7, while the highest one is obtained at pH 6.

Plants polymers are mainly polysaccharides. They possess a high tendency to associate, caused by the abundance in hydroxyl or amino groups present in the macromolecules that easily undergo hydrogen bonding, and are very sensitive to pH variations. In acidic solutions, protonation of carboxylic and amino groups will increase electrostatic repulsion and solubilize the polymer, increasing its diffusivity (Nandhini and Abhilash, 2010; Lawrence et al., 2006). This behavior is also observed at high pH (9), but in this case, deprotonation is involved. At neutral pH 7, hydrogen bonds existing inside the polymers will increase the size of polymer which will result in a decrease of polymer diffusivity.

Figure 5 presents the effect of salts and salt concentration on polymer. Without any salt, the released amount of polymer is low (2.5 %) and increases with the type of salt and the concentration. As ionic strength increases, the solubility of the polymers increases as predicted by the salting in theory (Djamen, 2011). The solubilisation will induce a rapid diffusion of the polymer in the medium. In this particular case, traction is more pronounced with Ca than Na salts. These differences could be explained by the ionic conformation of the different salts used; Ca ions of greater ionic radius than

Figure 5. Effect of salts on diffusion coefficient.

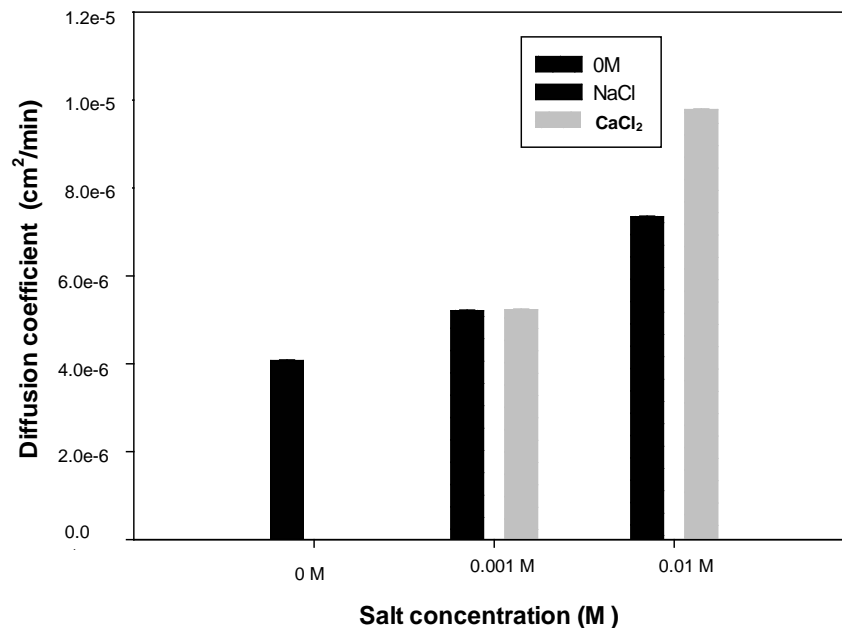Na ones release their solvation water more quickly, thus increasing the solubility of polymers and in fine the diffusion coefficient (Djamen, 2011).

From the above results it is obvious that physicochemical properties of the solution greatly affect the yield of polymer extraction.

Conclusion

The principal objective of this work was to determine the diffusion coefficient of polymers of *Grewia* spp. under various operating conditions. The results show that the polymers of *Grewia* spp. diffuse more quickly in the salt solutions and is effective at high temperatures than in distilled water; with diffusion coefficients of 9,78458e-06±1,646e-08, 7,3456e-06±1,746e-08 and 4,07001e-06±1,55077e-08 cm^2/min, respectively with $CaCl_2$, NaCl and distilled water. These results also show that the diffusion coefficients of *Grewia* spp. polymers in the presence of $CaCl_2$ are higher than those obtained in the presence of NaCl, and that it is not preferable to extract polymers from *Grewia* spp. with neutral pH. According to the type of salt, one can make use of either the linear model or the model logarithmic curve for the expression of the interaction between the parameters of extraction.

Conflict of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Urban water pollution by heavy metals and health implication in Onitsha, Nigeria

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Studies of common heavy metals were conducted at Onitsha, Anambra State, the most urbanized city in Southeastern Nigeria. It was discovered that both surface and subsurface water were heavily polluted. Seven (7) heavy metals namely: arsenic (As^{+2}), cadmium (Cd^{+2}), lead (Pb^{+2}), mercury (Hg^{+2}), zinc (Zn^{+2}), copper (Cu^{+2}) and iron (Fe^{+2}) were studied. Their major sources include wastes like refuse dumps, effluent from industries, sewage, fuel spills from dumps and mechanic workshops, hospital and pharmaceutical wastes, agricultural materials, fossil fuel combustion, metallurgical industries, electronic components and semi-conductors, batteries, pigments and paints. Further data were collected in ongoing research works in the area and public enlightenment was done in a small scale. Recommendations are made to government to note the impending dangers of further urban environmental pollution by these trace metals.

Key words: Polluted, effluents, research, urban.

INTRODUCTION

Effluent from industries in Onitsha, Anambra State, Nigeria, together with sewerage and waste spills from households and markets has become a nuisance in the state. These vary from nuisance from the odour to obstructions of traffic to more serious problems of land degradation and water pollution. It is feared that some of the adverse consequences are the noticed increase in disease incidence especially cancer, kidney infection and damage, as well as problems of the cardiovascular system and gastroenteritis (Agbozu et al., 2001; Rajappa

et al., 2010). Industrial effluents and effluent from sewerage, as well as those from households contain solvents and other chemical ingredients that have key heavy metals like arsenic, lead, cadmium and mercury. Wastes also derived from shops and small-scale industries like dry cleaning, bleaching, breweries and hospitals has become numerous and may contain plastics, batteries and unused drugs. These wastes require special control, treatment and disposal methods); the practice of dumping of refuse and wastes is common

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Table 1. Industries in sampling location (within Onitsha metropolis).

Major industry type	Code	Location	No.	Products
Food, beverage and Tobacco	A	Onitsha	25	Beer, starch and other miscellaneous food products, flavouring, soft drinks, floor and grain milling, meat, poultry and fish, tea, coffee and other beverage, dairy products, etc.
Chemical and Pharmaceutical	B	Onitsha	44	Paints, vanishes, soap and detergents, agro-chemicals, pharmaceuticals, dry cell batteries petroleum products. Toiletries and cosmetics, industrial chemicals
Domestic and industrial plastic, rubber and foam	C	Onitsha	26	Rubber products, plastics, foam
Metal, iron and steel	D	Onitsha	26	Foundry, metal manufacturing & fabrications, aluminum producers, etc.
Electrical and electronics	E	Onitsha	4	Electronics, refrigerators, bulbs, power control & distribution equipment
Textiles, carpet, leather and footwear	F	Onitsha	5	Textile materials, leather products ropes, etc.
Wood and wood products	G	Onitsha	3	Furniture
Non-metallic minerals products	H	Onitsha	8	Glass, ceramic, asbestos, chalk, cement packaging.
Motor vehicle and miscellaneous assembly	I	Onitsha	7	Boat fabrication, automobile manufacturers, etc.

Source: MOI, Anambra State.

in both the old urban areas and the new-urban areas adjoining them (Bhaskar et al., 2010). Efficient waste management requires provision of well selected, designed and operated sanitary landfills. Due to the importance of good water quality, monitoring of pollutants has become imperative. The effectiveness of treating waste before they are released to the environment has been recognized worldwide especially in the developed world, where laws are strictly enforced (Agarwal and Manish, 2011). This is important so as to ensure that permissible concentration of a particular chemical is not exceeded.

Location of study area

Onitsha is located in Anambra State in Eastern Nigeria and lies within latitudes 5°22[1] and 6°48[1] and longitudes 6°32[1] and 7°20[1]. Onitsha in Anambra State is located on the east bank of River Niger and covers an area of about 49,000 km². It is one of most important commercial centres in sub-Sahara African, as well as a transit city in Nigeria. It has an estimated population of about one million inhabitants. The socioeconomic characteristics of Onitsha consist of about 75% labour force that is engaged in tertiary sector, such as, trading and services. The remaining 25% of labour force is engaged in manufacturing and industrial activities. However, Onitsha is a centre for the production of local goods and services, as well as, a market for the sale of foreign goods. The Onitsha main market, which is reputed as the largest market in sub-Saharan Africa, has increased the tempo of commercial activities in the city in recent times. There are two main seasons: the dry season, October - March and the rainy season (April - September) approximately

corresponding to the dry and flood phase, respectively of the hydrological regime. The vegetation is derived guinea savannah (Awachie and Ezenwaji, 1981).

METHODOLOGY

Random sampling technique was employed in choosing water samples from surface and groundwater samples in Onitsha, Anambra State (Table 2). Water samples were collected in a properly washed and sterilized 500 ml screw-capped glass bottles transported in ice pack and analyzed immediately. An experimental method of research was performed to assess the presence or absence of toxic heavy metals in selected samples and the concentration of each heavy metal when present.

The selected heavy metals were arsenic (As^{+2}), cadmium (Cd^{+2}), lead (Pb^{+2}), mercury (Hg^{+2}), zinc (Zn^{+2}), copper (Cu^{+2}) and iron (Fe^{+2}). Analysis of the heavy metal contents in the water samples was done with the use of the atomic absorption spectrophotometer (AAS).

This method is based upon the absorption of radiant energy, usually in the ultra-violet and visible regions by neutral atoms in the gaseous state. Water sample were stored in 50 ml of PVC bottles, analysis was done using AA210FC, Varian instruments, Fast Sequential, Analytical grade chemicals (HNO_3, Sigma chemicals, Australia and standard heavy metal solutions, Varian instruments, Australia) after preserving at 4°C for a short period of time. Samples for heavy metal analysis were digested using nitric acid (65% purity) as described in the APHA methods (APHA, 2005).

RESULTS AND DISCUSSION

Major sources of pollutants in Onitsha

Effluent discharge from industries

Data from the Ministry of Industries, Anambra State were analyzed statistically (Table 1 and Figure 1). Investigation carried out showed that effluent is discharged directly into
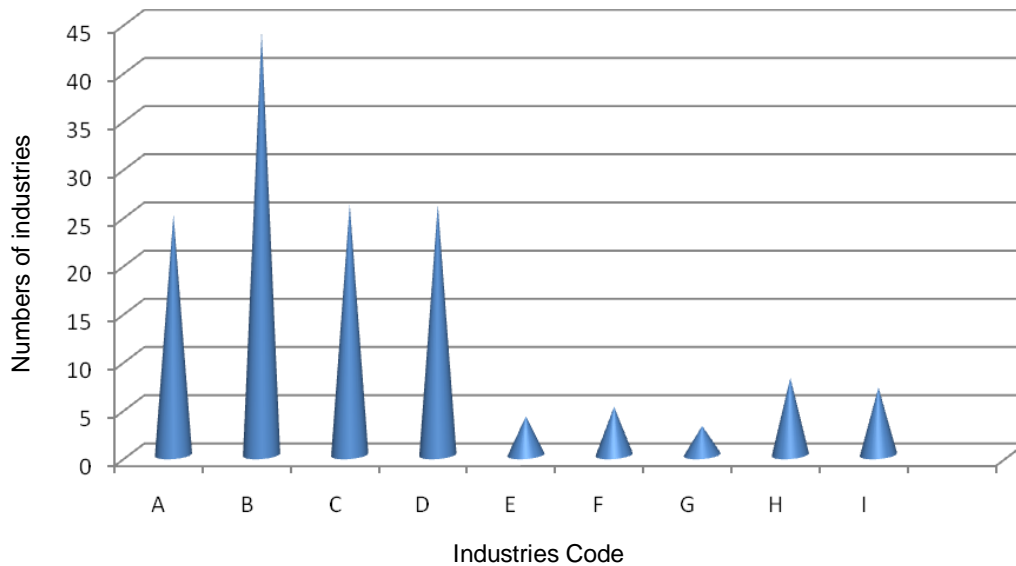
Figure 1. Industrial density in the study locations.

the environment. Motor vehicle and miscellaneous assembly, chemical and pharmaceuticals, domestic and industrial plastic etc, a few of the industrials are located in sampling sites. Onitsha is more prone to pollution because of the vast surface water and the more shallow subsurface water with more permeable soils having little of Imo shale formation. The contributions of these industries are no doubt pronounced in the research results. The skewed distribution of these industries

Refuse dump sites

Refuse dumps are found in various zones as approved by the Anambra State Environmental Sanitation Agency as well as in zones not so approved. It was discovered that various gully sites are used both by communities, individual households, and the agency for disposal of refuse.

However, the agency has designated two sites each at Omogba phase I and II as final dump sites for the zone. These final dumpsites are not designed landfills and therefore are outlets for the pollution of shallow ground waters around the highly permeable soils of the areas. Other temporary refuse dumps are found at over 20 other sites from where they are emptied in the final dumps at the convenience of the sanitation authority.

Other major dumps are found at Creek road around the Rivers Niger and Nwangene. These dumps constitute the temporary major dumps on land surface of all other dumps in the vicinity. The Ochanga Market and the main markets are also sources of refuse dumps which generate effluent that contain mainly biological and chemical pollutants that contaminate both surface and subsurface water in the coastal area aquifer of the zone.

toward the River Niger and Nwangene stream would be responsible for pollution of the rivers. The shallow coastal plain aquifer of the main market environs is also responsible for the ease of pollution of subsurface water in the area (Igwe et al., 2008). None of these industries has any programme for effluent treatment nor are there intense pressures from the government on them to provide for effluent treatment.

Fuel (petrol, diesel, kerosene and oil) from filling stations and vehicle exhaust fumes

Fuel filling stations are fastest growing industries in the state. Most of these stations are concentrated along the highways while the rest could be found along major streets of the city. It is therefore easy to identify these stations and their areas of influence where leakages in the underground tanks and spills during discharge pollute the environment. Onitsha has over one hundred and six (106) functional stations. Exhaust fumes of internal combustion engines also contribute to the pollution of soil and water resources in the areas due to the high number of vehicles on the road (Ogbuagu and Ajiwe, 1998).

Previous studies in this area have shown the presence of lead and other heavy metals (Ajiwe, 1996; Ibe, 2000; Okoye, 2004). Although, the values of lead may not have been higher than the WHO standards in many cases, it is feared that the buildup of this metal if not controlled may become major health problems in the next few years. Mechanical workshops, which are spread across Onitsha, are numerous and their contribution to pollution especially lead is obvious. It is also known that car battery and other battery types like those for clocks, torch lights dumped into the system also contribute very much

Table 2. Groundwater and surface water sampled locations.

Sampling points	Code as used in figures 2 and 3
Borehole (Bany water)	1
Borehole (Onitsha South)	2
Borehole (Afasa, Onitsha)	3
Borehole (Life Brewery)	4
Borehole (Metal Industry)	5
Borehole (Otumoye)	6
River Niger (Upstream)	7
Nwagene stream	8
River Niger (Otumoye)	9
River Niger (Central drain)	10

Table 3. Descriptive statistics of heavy metals in sampling points.

Parameter	As	Cd	Pb	Hg	Zn	Cu	Fe
Range	2.61	0.98	1.99	1.91	1.26	0.97	1.24
Minimum	0.00	0.00	0.01	0.00	0.07	0.02	0.12
Maximum	2.61	0.98	2.00	1.91	1.32	0.98	1.36
WHO (2011)	0.01	0.003	0.01	0.006	3.00	2.00	0.30

to the present elevated value of lead in surface and subsurface water (Danquah et al., 2011).

Hospitals

Hospitals are spread over Onitsha and the numbers of private Hospitals have soared because of the confidence of the people and the quick services rendered by the private hospitals. These hospitals, especially the private ones, do not have waste dumps or lined landfills for the special types of pollutants; chemical, biological and even radioactive which emanate from wastes of special drugs and other wastes generated therein. These wastes are either dumped into the popular refuse dumps or buried in shallow dumps. Hospital wastes no matter their quantity remain one type to be given special treatment (Coker et al., 2008). Onitsha metropolis has about 220 hospital/ clinics of different sizes.

Other sources of pollution

Other sources of pollution include soil and gully erosion and flooding that have polluted streams and reservoirs. Presently, soil erosion remains the greatest ecological problem in the state, sewage disposal systems are not adequate and so sewage from septic system, pit latrine also contribute a lot to pollution in the areas as thousands of private and residential buildings have sprung up in the past twenty years. Recent construction works on roads

has increased with little attention paid to all the environmental effects of the wastes generated, Agricultural wastes and chemicals are washed down to these cities from the hinterlands. These wastes include nitrate, heavy metals, fluorides and some radioactive wastes that find their way through runoff water to the main rivers of the area and into subsurface water too (Adeyemo and Sangodoyin, 2005).

Appraisal of pollution level in the area of study

Table 3 depicts the concentration of Arsenic level in surface and groundwater samples. Arsenic concentration was between 0.0000 (borehole, Onitsha South) and 2.6058 mg/l (Nwagene stream). Arsenic pollution in these areas are traced to anthropogenic pollution especially industrial pollution, refuse dumps and oil/fuel dumps that get washed down to streams/rivers of these major cities on daily basis (Danquah, 2011). The value of arsenic found in these areas is over and above the world Health Organization standard of 0.01 mg/l in both surface water and the boreholes adjacent and closest to these rivers and streams.

Lead was found in all water samples tested and the average values range from 0.0113 (borehole, Bany water) to 2.0013 mg/l (Nwagene stream). Petrol stations are sited all over the places. Surface spills and leakages from buried tanks that have been operating over 20 years without maintenance pollute water.

Cadmium values as seen in Figure 2 are moderately high with range of 0.0000 to 0.9800 mg/l. As previously discussed, refuse dumps littering everywhere and the reckless disposal of sewage and wastewater, all over the areas are responsible for appreciable high values recorded, with highest values recorded for Nwagene stream.

Apart from the numerous dump sites containing discarded vehicle batteries and small batteries for various uses and some of the manufacturing industrial effluent; appreciable quantities of mercury were detected with
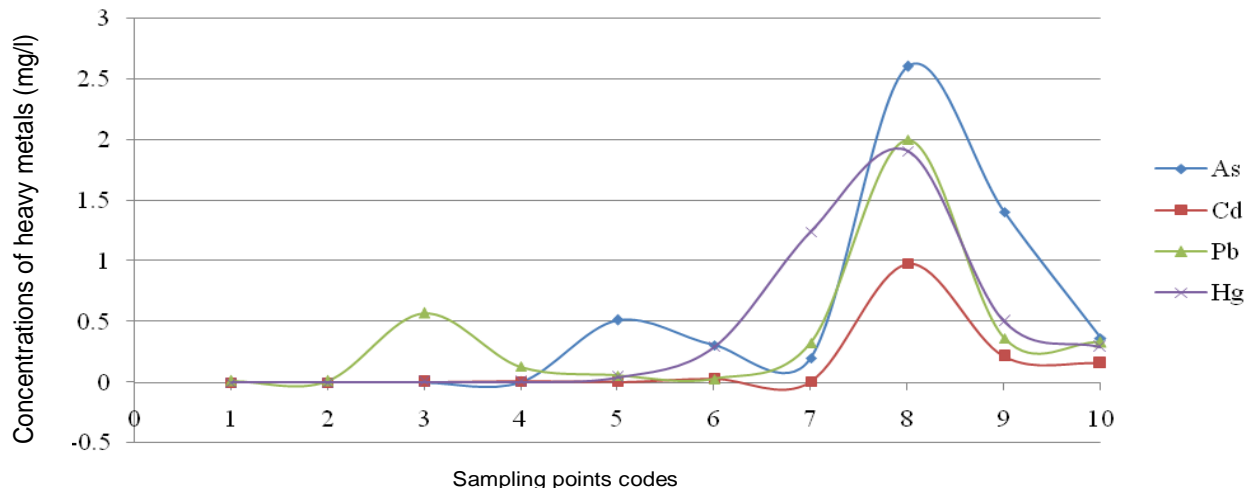
Figure 2. Concentrations of arsenic, cadmium, lead and mercury in the sampling points
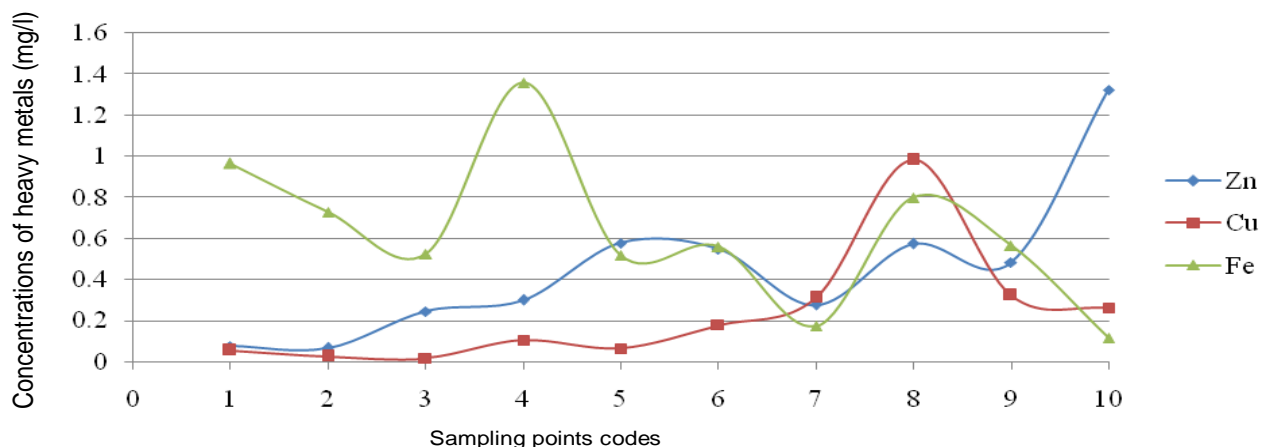
Figure 3. Concentrations of zinc, copper and iron in the sampling points.

values from 0.0000 (borehole Onitsha south) to 1.9076 mg/l (Nwagene stream). Most of the values are far above the World Health Organization standard of 0.006 mg/l.

Zinc is likely to have found its way into the environment from industrial producers in these cities. Galvanized steel is however identified as a major source of zinc in this area. They may come as wire fencing which eventually dissolve in rain and drops to the ground below. Sewage and animal manures has also contributed to the significance presence of zinc in the surface and subsurface water. Onitsha have high values of zinc encountered and this is attributable to the numerous "zinc" roofs that are used for thousands of buildings that have rusted away for up to thirty years in most cases because these are old cities. Fencing with galvanized steel barbed wires and nails are also common contributors. The indiscriminate disposal of sewage and similar wastes from refuse dumps over the areas also

contribute to zinc pollution in the area. The standard values for zinc is 3 mg/l for WHO standards. From Figure 3, the highest value of 1.3242 mg/l was recorded at River Niger central drain while the lowest of about 0.0675 mg/l was recorded at borehole (Onitsha South).

Values of copper recorded for both the subsurface water and the surface waters and rivers were generally much lower than the standard set by the WHO (2.0000 mg/l). The highest value of copper recorded in surface water was 0.9829 mg/l at Nwagene stream, and lowest 0.0169 mg/l at borehole (Afasa Onitsha). Copper poisoning is therefore not yet contemplated but the values of copper content remains a pointer to impending problems.

From Table 3, the WHO standard for iron is 0.3 mg/l. The values ranged between 0.1179 (River Niger central drain) and 1.3580 mg/l (borehole, Life brewery). Table 4 reveals that significant interactions exist among

Table 4. Correlation analysis of heavy metals.

	As	Cd	Pb	Hg	Zn	Cu	Fe
As	1						
Cd	0.939**	1					
Pb	0.854**	0.948**	1				
Hg	0.781**	0.811**	0.822**	1			
Zn	0.277	0.274	0.188	0.160	1		
Cu	0.918**	0.957**	0.910**	0.930**	0.308	1	
Fe	-0.003	0.069	0.013	-0.215	-0.524	-0.062	1

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

heavy metals. At $P<0.01$, positive correlation existed between arsenic and cadmium ($r=0.939$), lead ($r=0.854$), mercury ($r=0.781$), copper ($r=0.918$); cadmium and lead ($r=0.948$), mercury ($r=0.811$), copper ($r=0.957$), e.t.c as depicted. Result affirms that some indicator parameters influence presence of others.

Impact of heavy metal pollution

Eni et al. (2011) noted that water pollution results to a gradual decline in general economic life of the populace. At Onitsha, the fish industry is affected by gradual poisoning of fish population in areas and periods of heavy pollution loads. Fish production is also reduced because heavy metals at the level of pollution cause stunted growth of the fishes in the River Niger (Ajiwe et al., 2002). As noted by Rish and Rishi (2011), consumption of fishes and other sea foods from the River Niger over long periods could lead to diseases like cancers of the bladder, liver and intestine, clogging of arteries, hypertension, stroke and heart diseases. This therefore, will lead to reduction of the life expectancy of the people. A general hazard in Onitsha includes the presence of odour and colour in the affected waters. Pollution of surface water affects water supply network, resulting in health risks and increased load on water treatment plants, increase in cost of water treatment and therefore obvious health consequences. The leachates and effluents containing heavy metals also contain organic compounds and synthetic material pollutants and contaminants with long half-lives. These remain hazardous for long time within the hydrogeologic environment and are very difficult to remove. High levels of iron bacteria have caused problems in water supplies, coating on piping systems, impellers and motors that reduce flow rates of pumps, total plugging of the wells after prolonged use. It also affects portability of water. Corrosive ground water easily eats off the screens and pumps of boreholes (Okun et al., 1971).

The effect of heavy metals in these areas of study is chronic in that they have a long term effect on health due to frequent exposure to small amounts. The combination

or synergistic effects of these metals are suspected to be responsible for notable ailments like cancer, kidney and cardiovascular diseases as attested for by records in the Nnamdi Azikiwe University Teaching Hospital, Anambra State. From the Public Health Department of the same institution, it is also recorded that symptoms of ailment like tiredness syndrome, lethargy, depression and rheumatoid arthritis are common. Other symptoms of heavy metal pollution encountered in treating patients include white lines across the toenails and finger nails, weight loss, nausea, diarrhoea alternating with constipation, damage of gastro-intestinal track and liver, kidney failure, hypertension and loss of hair all ascribed mostly to arsenic, cadmium and mercury (Ezeabasili, 2008).

It is anticipated that if the pollution of water by heavy metals is not abated, the incidence of the disease would increase and new forms of ailment could be experienced in these urban areas as in other parts of the world with similar experiences.

Conclusion and recommendations

Onitsha is generally littered with refuse dumps. Because of the large population density, the level of pollution is getting increasingly serious. The heavy metals in water come from these refuse dumps, industries, drug containers and hospital wastes, various forms of chemical dumps from the market and small scale industries.

In the light of the findings in this work, the author makes the following recommendations; the introduction of modern, sensitive and reliable methods for testing drinking water for physical, chemical and biological parameters is very important and urgent. The development of adequate infrastructure for water testing laboratories is necessary. The presence of AAS equipment in every institution is recommended. This would increase research work on all our water resources like that obtained in most developed countries now. Secondly, the Anambra State Government should strengthen and enforce existing laws bordering on pollu-

tion especially for dangerous chemical effluents from industries. The proper monitoring of industries through environmental impact assessment and environmental audit report (EAR) should be enforced by the Ministry of Environment. It would be better if industrial effluents were treated before discharged. Finally, the Anambra State Government should ensure that the concerned officials of the health departments should report results as and when the water quality deviates from the national and international norms, to the government and the concerning public.

The infrastructure of water quality testing laboratories requires improvement. It is noticed, that various research results cannot be reconciled because of faulty equipment. Water quality reporting system needs considerable change to alert concerned officials in inter-disciplinary sectors. As the drinking water testing laboratories are presently governed by the NAFDAC and Urban and Rural Drinking water supply agencies there should be interaction with health professionals/personnel of other sectors. Health education and health department's interaction need to be introduced and promoted at all levels at frequent intervals.

Conflict of interest

The authors did not declare any conflict of interest.

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African Journal of Environmental Science and Technology

Full Length Research Paper

The benefits of the use of biogas energy in rural areas in Ethiopia: A case study from the Amhara National Regional State, Fogera District

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This study was conducted to assess socio-economic and environmental benefits of biogas energy and its challenges. The study used descriptive type of research design consisting of quantitative and qualitative research approach. The data collection instruments were household survey, key informants interview and self-observation to collect quantitative and qualitative data types. The study revealed that the biogas installation made each household to save on average 144 min per day from fuel wood collection, cooking, cleaning utensils/kitchen materials) and the reduction in the physical stress was also remarkable. Use of biogas provide an annual saving of 3833.28 Birr from fuel wood, Birr 1243 .20 from charcoal, Birr 128.50 from dung cake and Birr 266 and 717.65 from kerosene and chemical fertilizer, respectively, with net cash flow of Birr 1530 per HH/year. The households encountered lack of skills for adding raw materials to the biogas digester and fertilizer application to their farm land. Training for operation and liquid bio-slurry application is vital for the continuity of the project and revision of feeding material to the digester in different season needs consideration.

Key words: Biogas energy, environment benefits, biomass, alternative energy.

INTRODUCTION

Energy is undoubtedly a fundamental means for meeting the needs of life support system and development efforts now and for the future. The energy supply and use system has also many implications in the household economy, the indoor environment, women's activities, child safety, family nourishment and other aspects including local and global climate.

Energy plays a central role in national development process as a domestic necessity and major factor of production, whose cost directly affects price of other goods and services (Amigun et al., 2008). It affects all aspects of development, such as social, economic, political and environmental, including access to health, water, agricultural productivity, industrial productivity, education and other vital services that improve the quality of life. There is currently intense interest and strong policy direction to increase the proportion of energy derived from renewable sources

(Thomas et al., 2010).

Worldwide, energy consumption and demand are growing since the past 50 years (OpenStax College, 2012). Most of the resources used like petroleum, natural gas, coal are not sustainable sources of energy. Numbers of countries in the world including Ethiopia are currently passing through the critical phase of population explosion and the growing population demands more energy inputs.

Global experience shows that biogas technology is a simple and readily usable technology that does not require overtly sophisticated capacity to construct and manage. It has also been recognized as a simple, adaptable and locally acceptable technology for Africa (Taleghani and Kia, 2005).

Fuel wood consumption is often portrayed as a cause of environmental degradation, and may lead to energy insecurity for rural African households; especially where the resource is commercialized (Hiemstra-van et al., 2009). The high dependence on wood fuel in the sub-Saharan Africa has resulted in an alarming rate of tree felling and deforestation that causes faster depletion of biomass resources. According to the UNEP (2010), nearly half of the forest loss in Africa is due to removal of wood fuel. On the other hand, rural women are the ones who are directly affected by the rural energy crisis (Amigun et al., 2012; Smith et al., 2005).

The price increase of fossil fuels (an economic process) boosts the demand for bio fuels, which causes changes in land-use cover through deforestation, increases greenhouse gas emissions through the drainage of peat marshes, expands use of agrochemicals and raises the likelihood of establishment of invasive species. A long-term intervention could be to reduce the demand for fossil fuel by changing consumer and producer behavior (UNEP, 2010).

Currently, many African countries experience frequent blackouts and the cost of electricity blackouts is not known. The continent's energy consumption and demand is expected to continue to grow as development progresses at rates faster than those of developed countries (Amigun et al., 2008).

Ethiopia has a population of 89.6 million people, of which 82.4% live in the rural areas (United Nations, 2007). Through the Ethiopia Rural Energy Development and Promotion Centre (EREDPC), the National Biogas Program (NBP) was also launched. The aim of the programme is to establish 14000 biogas plants between 2008 and 2012, in four regions of Ethiopia (EREDPC, 2008). The NBP utilizes cattle manure as the feedstock for biogas production (EREDPC, 2008). In 2009, some households had already started experiencing the benefits of the project such as: use of clean cooking fuel; income savings made in terms of time and money to search for fuel and purchase other traditional fuels (wood, charcoal and kerosene) respectively; and income generation from the sale of biogas to the neighboring towns (Hivos,

2009b).

According to Central Statistical Authority Welfare Survey of Ethiopia (CSA, 2004), the major types of cooking fuels used by all households are firewood, leaves/dung cakes and kerosene. At country level, about 81.4% of the households use firewood, about 11.5% cook their food by using leaves/dung cakes and only 2.4% use kerosene for cooking.

In Ethiopia, the demand for household energy is far greater than the availability. This can lead to vulnerability to deforestation, health impacts and increasing climate change. According to Fogera district Agriculture and Rural Development Annual Report (2010), in 2002-2006, the coverage of the forest in the district was 10,240 ha, while in 2009 the coverage declined to 4,795.26 ha which is a reduction of 53.17% from 2002 - 2006. This is due to over exploitation of fuel wood by the poor households to fulfill their basic needs.

The objectives of the study are to assess the social, economic and environmental benefits of biogas energy technology. This paper was aimed to identify the actual benefits of biogas energy, perception of users in terms of level of satisfaction on the biogas technology, the level of understanding their living environment, challenges encountered during usage/application and dissemination, identifying the indigenous knowledge of rural biogas user households to solve their problems regarding biogas energy application. Finally, the findings are used as input for government and nongovernmental organizations (NGOs) for the dissemination of biogas energy technology for the other target households.

MATERIALS AND METHODS

Description of the study area

Fogera district is one of the 106 districts of Amhara National Regional State and found in South Gondar Zone (Figure 1). The district is located in North West of Addis Ababa with a distant of 625 and 55 km north east of regional capital, Bahir Dar. It has an altitude of 1774-2410 m above sea level and characterized by an average rain fall of 1216.3 mm, minimum and maximum temperature of 16 and 20°C respectively, and black clay soil type. It has a population 228, 449 (52,905 households) that lives in an area of 117405 ha with an estimated population density of 108 people per square kilometer (CSA, 2007). The main resource of the district could be taken as forest area, which is presently encroached due to high population density and urbanization processes; in fact the forest is consumed in various purposes especially for fire wood, furniture and for house construction. It is observed that the forest will be surely destroyed in few years, if proper solutions are not taken in consideration (FDFED, 2009).

Methods of data collection

This study uses both qualitative and quantitative approaches. As per Kothari (1990), for this study the quantitative approach was used for the analysis of household data collected through survey questionnaire; whereas, the qualitative approach is concerned with subjective assessment of attitudes, opinions and behaviors of
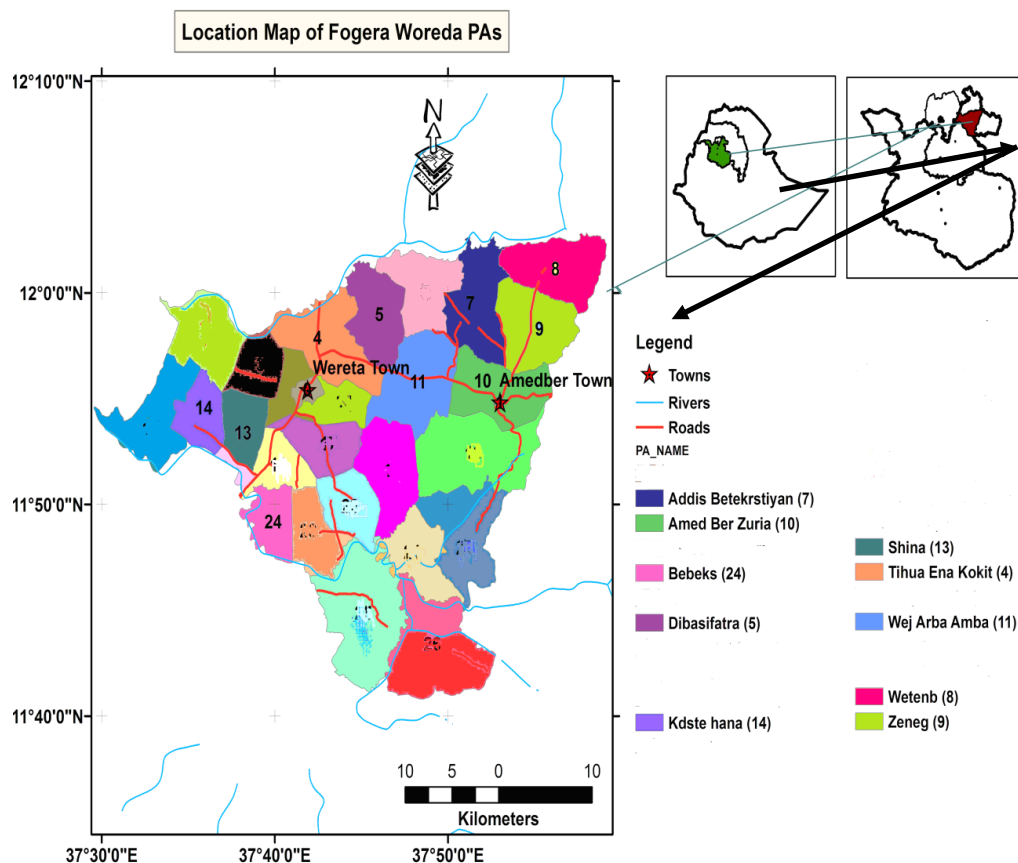
Figure 1. Map of the study area. Source: Fogera district Anti-Malaria Association Office, 2011.

biogas user households. Since the target population was manageable, by considering these parameters, this study used census study design. The data collection instruments were household survey questionnaire.

The biogas energy on which the study was conducted was selected purposefully and all the biogas user households were sampled. In addition to biogas users who work on biogas energy dissemination, the municipality sanitation and beatification process owners in the study area, agricultural and rural development officials were included purposively.

Primary data sources

Household data: Household data were collected through semi structured questionnaire. This survey was intended to gather information on demographic characteristics of households (household size, land size, education level and livestock number), household fuel consumption before and after biogas plant installation (consumption of charcoal, dung cake, fuel wood and kerosene).

Key informants interview: In addition to the household survey data, the interview was carried out on government and non-government partners and stakeholders who work on biogas energy technology dissemination. The key informants were NGO representatives from SNV-Netherlands/Ethiopia Field Office, government officials from the municipality, agriculture and rural development (department of alternative energy technology and animal science process owners).

Self-observation: The actual biogas plant status, toilet availabilities/toilet attached biogas plant/ and usage conditions, market value of household fuel at the local market (charcoal, fuel wood, kerosene and dung cake), state of waste management, utilization of spare time due to reduction of workload as a result of biogas plant were observed and snapped by camera, and voice of the users when they explained about the benefits of biogas were recorded in video to have evidenced data to the findings at their respective peasant associations (PAs).

Secondary data sources

Secondary data sources such as books, policy and published and unpublished documents, journals, and websites that were relevant and strengthened the study were reviewed and studied. Moreover, to have a deeper insight about biogas energy benefits and constraints of Fogera district, different organizations were visited and related documents about biogas energy were extensively used.

RESULTS AND DISCUSIION

Demographic data

The demographic characteristics of the biogas user households are presented in data presenting tools such as Figures and tables. The average household size of the surveyed biogas user households was 6.9 (Figure 2).

Table 1. Possession of animals by biogas user households.

Types of animals	Average holding size /household	Remark
Cattle	12	
Sheep	2	
Goats	5	
Poultry	5	
Horses	1-2	28 Households have no horse
Donkeys	2	8 Households have no donkey

Source: Field survey, 2011.

	Response	Percent
1-4	6	20
5-8	20	67
9-12	4	13
Av. Household size = 6.9	30	100
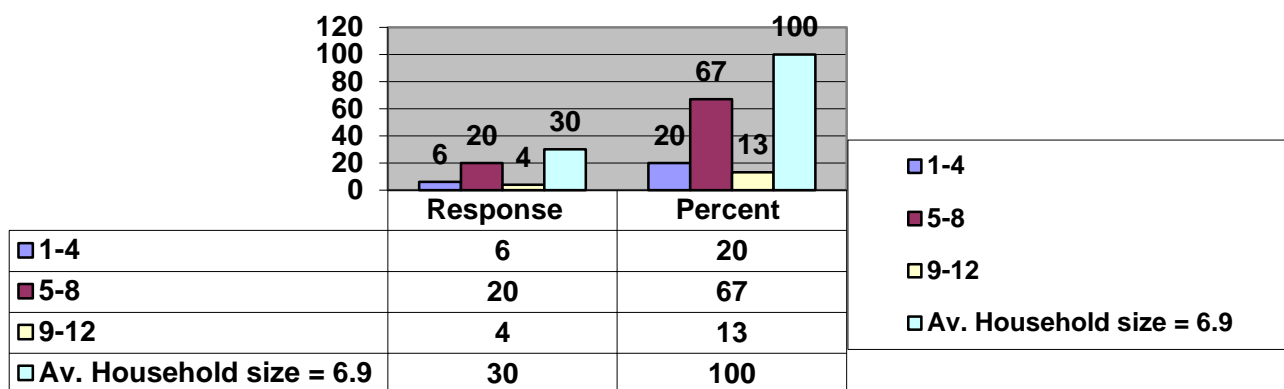
Figure 2. Average household size of the biogas household. Source*:* Field Survey, 2011.
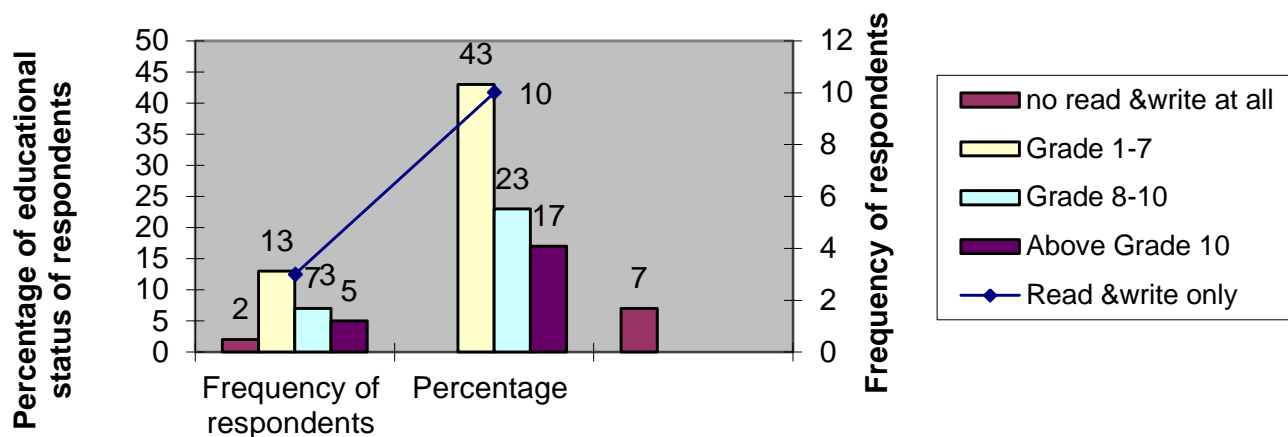
Figure 3. Educational status of biogas households. Source: Field Survey, 2011.

The surveyed biogas user households possess on average 12 cattle per household which is more than the minimum requirement of 4 cows for establishing biogas plant. The details are shown in Table 1.

From the total respondents, majority (83%) are well educated which are from grade 1 to 7, 8 to 10 and from 11 to 12 complete (Figure 3)

Environmental benefits of household biogas investment in the study area

Perception of households on impacts of traditional fuel on forest

All the respondents were asked whether using of Trade-
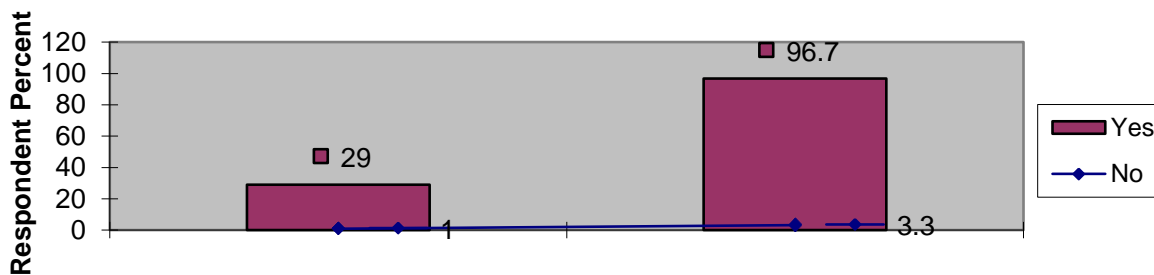
Figure 4. Respondents by knowledge of the impacts of traditional fuel on forest. Source: Field Survey, 2011.
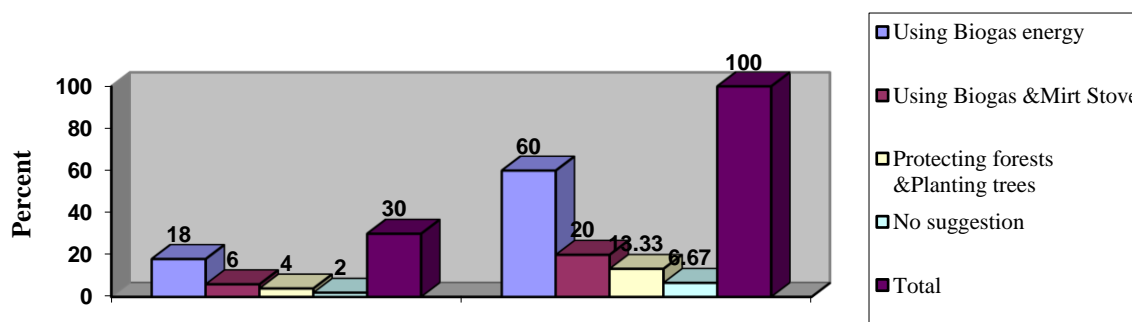
Figure 5. Mitigation measures of respondents' suggestion to minimize the problem of traditional fuel. Source: Field Survey, 2011.

tional fuel have direct impact on forest or not. Accordingly, the majority of the respondents (96.7%) perceived the negative impact of traditional fuel for the existing forest destruction and the rest (3.3%) did not perceive the impacts of traditional fuel for deforestation (Figure 4).

Regarding the solutions for deforestation, (60%) respondents suggested the use of biogas energy (20%) the use of biogas and Mirt stove, (13.3%) protecting forests and planting trees as a solution to control forest depletion and the rest (6.67%) did not show suggestion to minimize loss of forest due to use of traditional fuel (Figure 5).

It can be concluded that majority (96.7%) of the respondents perceived the negative impact of traditional household fuel on deforestation, and this could be attributed to their relatively better educational background. Even, all the solutions suggested by respondents are true, the researcher recommended the households to use biogas energy due to its clean and smokeless technology and ability to replace and reduce the use of firewood, charcoal, dung cake and other imported household energy sources such as kerosene.

Contribution of biogas as cleaner production mechanism

Biogas potential in the study area of Fogera district is in

favorable condition in respect of the climatic and availability of raw material for biogas production. The potentials are: Municipal waste, livestock and human population. Thus, potentials needs to be recycled as cleaner production such as biogas energy, to get dual benefits from getting energy and making the environment clean.

Livestock population in Fogera district: Documents gained from Fogera district Agriculture and rural development office, out of 302,800 livestock; 182,699 are cattle, 15,575 sheep, 25,956 goats, 64,227 poultry, 571 horses and 13,772 donkeys found in the district. Moreover, the annual dung production is about 666, 851,350 - 1,000,277,025 kg, which has a potential production from 24,006,648.6 to 36,009,972.9 m^3 of biogas annually. However, it is estimated that only 90% of the theoretical potential, that is, 21,605,983.74 to 32,408,975.6 m^3 (Av.27, 0074, 79.67 m^3) of biogas would be practically available since the number of animals also include the households with only one cattle or goat. This has a potential for saving fuel wood from 118,832,910.6 to 178,249,365.8 kg, charcoal from 34569573.98 to 51854360.96 kg, kerosene from 16226, 093.79 L to 24339,140.68 L and electricity from 34569,573.98 to 51854360.96 Kwh annually (Table 3).

Human population in Fogera district: In Fogera district, 228,449 people reside there (CSA, 2007), which have a

potential to produce 228449*0.3*365 = 2,501,5165.5 kg of human waste annually (Nijaguna, 2002). Assuming that all people have pit latrines and if they properly utilized their excreta, this would have a potential of producing 25,015165.5 kg x 0.046 m^3 = 1,150,697.613 m^3 of biogas, which saves 6,328,836.872 kg of firewood,1,841,116.181 kg of charcoal, 864,173.9 L of kerosene and 1,726,046.42 to 1956,185.942 Kwh annually (Filed survey, 2011; Nijaguna, 2002).

Municipal waste of the town administration: Fogera district town administration generates approximately 34,500 kg wastes (34.5 tons) of solid waste and 40,000 L (40tons) liquid waste was generated per day. Among these, the municipality collects and disposed only on average 32,000 kg of solid waste and 20,365 L of liquid waste per day, which is 92.5 and 50.91% of the total solid and liquid waste, respectively. The main sources of waste are from residential and commercial activities in the town. These wastes are collected and disposed in open space except small amount of liquid waste used for urban agriculture as fertilizer. Due to this small amount of utilization, the disposed waste creates bad smell to town and its surroundings that will create health problems.

COMEC (2006) stated that, in Brazil the biggest part of municipal waste generation is deposited without any methodology/without technological aid like Fogera district municipality, but Brazil uses high amount of waste for biogas energy production as energy source and waste treatment mechanism. This is also contended by UNESCO (1992), biogas technology have attracted considerable attention in waste recycling, pollution control and improvement of sanitary condition in addition to fuel and fertilizer.

On the contrary, the municipality of Fogera district have no future plan to use the potential waste as energy source officially except personal motivation and promise of experts after interview. As can be seen from Table 4, the town administration was collected and disposed 52.365 tons of waste per day and 19,113.225 tons of waste annually.

Assuming that all wastes are properly utilized, this has a potential of 19,113,225 kg × 0.03 m^3 = 573,396.75 m^3 of biogas, which saves 105,122,737.5 kg of firewood, 30,581,160 kg of charcoal,14,354,031.98 L of kerosene and 28,669,837.5 to 32,492,482.5 Kwh electricity annually. Besides, all this potentiality presented above such as wastes from livestock population, human population and municipal are dangerous unless it is recycled as cleaner production such as biogas to have dual purpose, killing two birds with one stone principle like Brazil (as source of energy and as environmental sanitation).

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*Pair of oxen ploughs, 1 hectare per day: this is called "Temad", which is the name of local measurement.

Social benefits of household biogas investment in the study area

Benefits from replacement of traditional household fuel

As the household traditional fuel consumption decrease, the contact hour of the family member to the traditional stove also decreased. As a result, the type of adverse effects of biomass combustion on human health stated by WHO (1991) could be decreased.

Household fuel wood consumption: The study showed that in the surveyed area, the biogas user households used Cordia Africana (Wanza) and acacia for cooking among others, *Injera*[1]; Sauce (Wot), porridge and coffee/tea, before and after installation of biogas plant. However, after biogas plant installation, the traditional household fuel consumption was limited to baking *Injera*. As can be seen in Table 7, before installation of biogas plant, households used 3,596.4 kg of fuel wood/HH annually, but after installation of biogas plant each household uses on average 1062 kg of fuel wood/HH/year which is reduction of 2,534.4 kg (70.47%)/HH/ annually.

Household charcoal consumption: The average charcoal consumption in the surveyed households used 1 sack of quintal (27 kg) per month and 12 sack of quintal (324 kg) per year. As can be seen from Table 8, in the study area of biogas households, all of them used charcoal in different amount before installation of biogas plant. However, after installation of biogas plant, all the biogas households have been fully replaced with biogas energy.

Household dung cake consumption: All the surveyed households, before installation of biogas, the majority (43.3%), used 6-10 sacks of quintal (138-230 kg), 36.67%, used 1-5 sacks of quintal dung cake (23-115 kg), 13.3% used 11-15 sacks of quintal (253-345 kg), 6.67% used above 15 sacks of quintal (460 kg) per month with on an average consumption of 8 sack of quintal(184 kg)/HH per month and 96 sacks of quintal (2208 kg) used annually. After installation of biogas plant, as presented in Table 9, majority (60%) used 0.5 to 2 sacks of quintal (11.5-46 kg), 33% used 3-5 sacks of quintal(69-115kg), and the rest 7% used 6-8 sacks of quintal dung cake(138-184 kg) and on average of 3 sacks of quintal (63kg)/HH per month which is reduction of 5 sacks (115 kg)/HH per month, and 60 sacks (1380 kg) dung cake annually which is 62.5% from the total. This traditional household fuel consumption could contribute in

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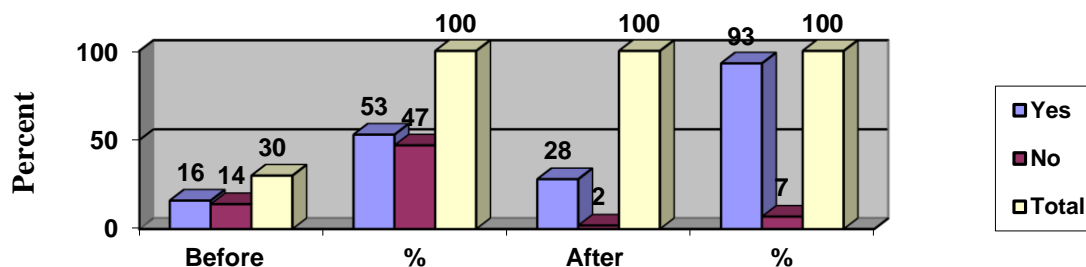[1] Injera is Ethiopian Traditional food made from Teff (crop).

Figure 6. Possession of toilet before and after biogas installation. Source: Field Survey, 2011.

reducing the health impacts of households that appeared due to indoor smoke. Bajgain and Shakya (2005) stated that, the burning of fire wood, dung cake and agricultural residue creates many hazardous particles. Cooking is usually done indoors; this can lead to severe health problems. The particles from the smoke can give rise to acute respiratory infections among the people who are in contact with the smoke.

Benefits of biogas on health and sanitation of biogas user households

The study showed that in the surveyed area, after installation of biogas plant, the construction of toilet is increased which can be compared to IEIA (2002), study that was carried out by SNV/BSP of Nepal, showing that the record of toilet construction is higher among biogas users. Before installation of biogas plant, toilet possession of the surveyed HHs were 53%, while after installation of biogas, the possession of toilet reached 93% (Figure 6). From these toilet owners, 13% of them have attached their toilet to their biogas plant and the majority (80%) of respondents ready to attached their toilet to the biogas and the system is already installed which shows promising to use the integrated biogas plant for the near future. Only few (6.65%) respondents have no toilet at all. As data gained from the household survey, these two respondents cannot read and write at all. It seems that education has its own impact on dissemination of technology.

The biogas user households were asked to express their opinion about the difference in using traditional fuel and biogas energy use in relation to health impact. They replied by remembering what the local nurses and doctors recommend about negative impacts of traditional fuel on health and by adding their indigenous knowledge gained from experience. A comparison of the status of household in terms of frequently complained health problems, from the total of respondents, 21 (70%) were complain in eye illness, respiratory disease (such as common cold) and headache which accounts for 56.6, 6.6 and 6.6% respectively (Table 5).

Bajgain and Shakya (2005) stated that, the particles

from the smoke can give rise to acute respiratory infections and eye ailments among the people who are in contact with smoke. These peoples are mainly women, children and infants, while in this study, the major victims were women, children and old people due to access to kitchen activities frequently and stay at home during food preparation. It has the same connotation with the study of Bajgain and Shakya (2005).

After biogas plant installation, the households reduce the use of traditional fuel such as firewood and dung cake, and limited these fuel only for *Injera* baking purpose which replaces the use of traditional fuel for cooking sauce (Wot), porridge, tea/coffee and at the same time the households replace kerosene and charcoal by lighting biogas lamp, and by using biogas stove for cooking sauce (Wot), porridge, tea/coffee etc. Due to this reduction of traditional fuel, after installation of biogas only 8 (26.6%) respondents complained about eye illness and head ache. The major victims were females due to baking of *Injera* by using firewood and dung cake but the frequency is less when compared with previous (before use of biogas energy). The direct effects of biogas plant on health and sanitation were found to be more visible than indirect ones; since, the study revealed that smokeless biogas had greatly benefited the plant owners by contributing to a significant reduction in eye related problems and respiratory diseases.

Biogas technology reduces contact hours to open stove fire, that is, after biogas installation the contact time is on average twice a week only for baking *Injera* and the rest activities are accomplished by biogas energy which is clean and smokeless.

Time saving and workload reduction

In the study area of the surveyed households, biogas installation makes each biogas household to save on average 144 min per day from fuel wood collection, cooking, cleaning utensils/kitchen materials, and the reduction in the physical stress was also remarkable. Women and children are the groups that collect fire wood traditionally. Table 6 depicts the time comparison that has been estimated to save up to 51 min on average every

day due to installation of biogas energy. Gautam et al. (2005) stated that today's use of biomass in list developed countries does not provide any use of sufficient lighting during the dark hours. The time consumed in collecting fire wood and other bio fuel carried out by women and children results in less time available for education. This means, as the study revealed that, children have time to go to school and they could use the biogas light for studying overnight unlike the previous time that they were used to kerosene for lighting purpose only from 2 to 3 h, and it has dangerous smoke that could affect respiratory organ and cannot be afforded by the poor. On the other hand, biogas gains equity of work among family members in accomplishing works such as slurry mixing which was accomplished by household members. Biogas households use their spare time/saved time in better care of family, in keeping household sanitation, education and other social affair. Due to absence of managing firewood and charcoal during cooking of sauce, porridge and tea/coffee, women could accomplish additional works at the same time.

Economic benefits of household biogas energy investment

Saving from fire wood purchasing expenditure

Due to the installation of biogas plant, there is an annual reduction of fuel wood consumption approximately 79 bundle of fire wood (2528 kg) per year per household and provides each biogas households an equivalent saving of 3833.28 Birr per year at the local rate of Birr 48.40 per 32 kg of fire wood (Table 7).

Saving from charcoal purchasing expenditure

In the surveyed area, after household biogas investment, purchasing of 12 sacks of quintal (324 kg) of charcoal is fully replaced by biogas stove. This amount of charcoal provides each biogas household an equivalent saving of 1,243.20 Birr per year at the local rate of Birr 103.60 per 27 kg of charcoal (Table 8).

Saving from dung cake purchasing expenditure

Due to household biogas investment, 60 sacks of quintal (1,380 kg) of dung cake are saved. This has an equivalent saving of Birr 1,542 annually at local rate of Birr 25.70/sack of quintal dung cake.

Saving from kerosene purchasing expenditure

Besides the above household fuel, all the surveyed households used kerosene for lighting on average of 1.78 L per month per household and 21.36 L per year. Each household spent Birr 22.1789 and Birr 266.1456 per

month and per year, respectively. After installation of biogas plant, all the surveyed HHs substituted their kerosene consumption fully by biogas lamp. This shows that Birr 266.1456 was saved annually at the local rate of Birr 12.46/L of kerosene per household (Table 10).

Savings from chemical fertilizer purchasing expenditure

Further, reducing chemical fertilizer has an effect on households' expense, from the total surveyed households, in the demographic characteristics of respondents, 27 of them have an average 1.453 ha/HH agricultural land and the rest have no agricultural land rather they have backyard farm used for managing the biogas slurry and cropping of cash crops such as khat (Chat). Before installation of biogas plant, the surveyed households used an average of 153.26 kg of chemical fertilizer per household annually/crop season/ in an equal proportion of dap and urea in their agricultural land to grow well the crop and increase the production but with an annual expenditure of Birr 1065.16/HH. After installation of biogas, due to use of bio-slurry fertilizer, the average household chemical fertilizer consumption in the crop season was reduced to 50 kg/HH which is saving of 103.26 kg of chemical fertilizer per household per crop season. This has an equivalent saving of Birr 717.657/HH/ crop season with an average local rate of Birr 695/100 kg of chemical fertilizer (Table 2).

Besides the above listed economic benefits of biogas, improving the hygiene and thereby reducing diseases also has an economic value. If people can avoid diseases it also means their working time will not be reduced as a result. The study also revealed that, household family illness due to use of traditional fuel also have an implication on health expense for treatment (Table 11).

In Fogera district, the cost of investment per plant varies due to personal contribution made by the respondents during construction work in the form of labor, variation in the year of construction, size of plants and access to the delivery of construction materials such as stone and sand/gravel. The total investment cost of the plant was an average of Birr 8,762.48 and Birr 9,813.46 for 6 and 8 m^3 respectively and Birr 8,832.55 for an average plant size of 6.14 m^3 for ease to calculate the approximate payback period of the plant. For a plant with total investment cost of Birr 8,832.55, the payback period was 5.77 years to recover investment of biogas plant per household without subsidy, whereas with subsidy of Birr 4,199.25, it could take only 2.7 years, which seem affordable as compared to study conducted by Li et al. (2005) and Woods et al. (2006). The calculation was based on saving from fuel wood, charcoal, dung cake, kerosene and chemical fertilizer (Table 12).

The shorter payback period makes biogas plant affordable for most peri-urban and rural households, even in poor areas (Li et al., 2005). The payback period for

Table 2. Land holdings of the surveyed households.

Land holding type	Average land holding /household in *Temad and ha	Number of respondents who have	Percentage of land holder respondent
Agriculture land	5.8 Temad = 1.453 ha	27	90
Grazing land	1.56 Temad = 0.39ha	16	53
	Common grazing land	14	47
Forest land	1.2 Temad = 0.3ha	5	17

Total land holding: 187.86 Temad = 46.971ha; Av. landholding/HH: 3.91 Temad = 0.978ha. Source: Field Survey, 2011.

Table 3. Total number of livestock and biogas produced per kg of animal dung.

Type of animals	Total number of animals	Daily produced dung/animal in kg	Total dung available per day in /kg/	Gas produced per day/ m³/
Cattle	182,699	10-15	1,826,990-2,740,485	65,771.6-98,657.5
Sheep	15,575	0.75-1	11,681.25-15,575	420.525-560.7
Goats	25,956	0.75-1	19,467-25,956	408.807-545.076
Poultry	64,227	0.06-0.2	3853.62-12845.4	1,965.35-6,551.15
Horses	571	14-16	7,994-9,136	7,274.54-8313.76
Donkeys	13,772	12-15	165,246-206,580	134,675.49-168,362.7
Total	302,800		2035231.87-3010577.4	210,516.312-282,990.886

Source: Fogera District Agricultural and Rural Development Office, 2011 and Nijaguna, 2002.

Table 4. The annual collected and disposed waste in the town administration.

Type of waste	Unit	Daily generated	Daily collected and disposed waste	Remark
Solid	kg	34,500	32,000	
Liquid	Liter	40,000	20365	
Total		74,500	52,365	

Source: Fogera district municipality Office, 2011. NB: 1 kg of solid waste equal to 1 L of liquid waste (Nijaguna, 2002

Table 5. Analysis of health benefits before and after installation of biogas.

Health problems	Before			After		
	Number of respondent	Percent	Major victim	Number of respondent	Percent	Major victim
Eye illness	17	56.7	Females, child and old	6	20	Females
Respiratory disease	2	6.6	Females and child	-	-	-
Headache	2	6.6	Females and old	2	6.6	Females
No complain	9	30	-	22	73	-
Total	30	100		8	100	

Source: Field Survey, 2011

Table 6. Analysis of average time for daily works before and after biogas installation.

Daily works	Average time in minutes per day		Av. time saved per day in min/HH	Implementers
	Before	After		
Fuel wood collection	76	25	+51	Women and Children
Cooking	240	164	+77	Women and Children
Fetching water	30	56	-26	Women and Children
Cleaning utensils	54	35	+19	Women and Children
Livestock caring	35	35	-	Men and children
Dung cake collection and moulding	57	19	+38	Women and Children
Slurry mixing	-	15	-15	All Family members
Total	**492**	**349**	**+144**	

Source: Field Survey, 2011. +shows saved time due to household biogas investment.

Table 7. The amount of fuel wood consumption before and after installation of biogas plant.

Before installation of biogas plant			After installation of biogas plant		
Amount of fuel wood /HH/month in bundle/	Number of respondent	percent	Amount of fuel wood /HH/month in bundle/	Number of respondent	Percent
4-7	10	33	1-2	16	53
8-11	12	40	3-4	12	40
12-20	8	27	5-6	2	7
Total	30	100		30	100
Av. Bundle/HH/Month = 9.366(299.7kg)			Av. Bundle/HH/Month = 2.766(88.5kg) Difference = 6.6bundle (211.2kg)		

1 Bundle of fuel wood weighs on average 32 kg; price of 1 bundle of wood = on average Birr 48.40 (local market, February 14, 2011); 1 US$ = Birr 16.66 (National Bank of Ethiopia) (NBE, March 10, 2011) Source: Field Survey, 2011.

Table 8: Amount of charcoal consumption per household per month before Installation of Biogas Plant

Amount of charcoal in sack of quintal/HH	Number of Respondent	Percent	Remark
0.5	13	43	1 Sack of quintal Charcoal weighs on average 27 kg
1	7	6.67	
1.5	10	34	
Total	30	100	

Average used /HH/month/ in sack of quintal = 1; Price of 1sack of quintal of charcoal at local market = Birr 103.60 Average used/HH/year in sack of quintal = 12, that is, 324 kg; 1 US$ = Birr 16.66 (National Bank of Ethiopia) (NBE, March 10, 2011) Source: Field Survey, 2011.

Table 9. Amount of dung cake consumption per household per month before and after installation of biogas plant.

Before installation of biogas plant			After installation of biogas plant		
Amount of dung cake /HH/month in kg	Number of respondent	Percent	Amount of dung cake /HH/month in kg	Number of respondent	Percent
1-5	11	36.67	.5 -2	18	60
6-10	13	43.3	3-5	10	33
11-15	4	13.3	6-8	2	7
≥ 16	2	6.67	-	-	-
Total	30	100	Total	30	100

Average sack of quintal dung cake /HH/Month = 8; Average sack of quintal dung cake /HH/Month = 3 (5 sack of quintal saved). 1 quintal sack of dung cake weighs on Average 23 kg. Price of 1 quintal sack of dung cake = on Average Birr 25.70 (Local market, February 14,2011). 1 US$ = Birr 16.66 (National Bank of Ethiopia) (NBE, March 10, 2011). Source: Field Survey, 2011.

Table 10. Amount of kerosene consumption per HH before installation of biogas plant.

Amount of kerosene in liter/HH/ month	Number of respondent	Saving of kerosene after installation of the plant/ in liter
1 to 2	26	
>2	4	
Average household consumption in liter		
Per month 1.78	30	1.78
Per year 21.4	30	21.4

Price of 1 liter of kerosene = on average Birr 12.46 (Trade transport Office of town Adm., February 1, 2011); 1 US$ = Birr 16.66 (National Bank of Ethiopia) (NBE, March 10, 2011); Source: Field Survey, 2011.

Table 11. Fertilizer consumption before and after biogas Installation.

Particulars	Fertilizer used	Number of respondent	Percent
Before biogas installation	Farmyard Manure and Chemical fertilizer	26	100
Total		26	100
After biogas installation	Farmyard Manure and Bio-slurry	23	88.46
	Farmyard Manure, Chemical fertilizer, Bio-slurry	3	11.54
Total		26	100

Source: Field Survey, 2011.

Table 12. Saving of chemical fertilizer due to household biogas investment.

Amount of Average chemical fertilizer used before installation of biogas/HH/crop season in kg	Amount of chemical fertilizer before installation of biogas/HH/crop season in kg	Difference/saved due to installation of biogas plant	Percent
153.26	50	103.26	67.37

100 kg of chemical fertilizer on Average = Birr 695 (Fogera District Agricultural and Rural Development (2011), 1US$ = Birr 16.66 (National Bank of Ethiopia) (NBE, March 10, 2011). Source: Field Survey, 2011.

Table 13. Households' level of satisfaction.

Particulars	Number of respondent	Percent
Fully Satisfied	26	87
Moderately Satisfied	4	13
Not Satisfied	-	-
Total	30	100

Source: *Field Survey, 2011.*

Chinese type fixed dome biogas digester depends on how the biogas digester is used, what substrates, size, price on fuel wood, etc and without any subsidies would be around 3.6 to 5.8 years of payback period (Woods et al., 2006). The regional biogas coordination office and SNV/Ethiopia, estimated the cost of annual maintenance and miscellaneous expenses to be Birr 200 and 100 per plant, respectively. These costs are reserved in bank in the name of the plant owners dedicated from the subsidy.

Perception of users on benefits of household biogas energy

All the surveyed biogas plants were operational except temporary problems of lamp and other accessories. Due to this, the responses were quite satisfactory (Table 13, plate 1 and 2, box 1). There was significant satisfaction in terms of reduction of household fuel consumption, cease to expend for chemical fertilizer and HH traditional fuel, improvement in health and sanitation, time saving and studying for students among others.

Plate 1. User while lights biogas stove

Plate 2. User while cooking with biogas stove.
Source: *Field Survey, 2011*

Mrs. Debre Tsega one of biogas user, lights her stove, emitting a full blue clean fire. *"Did you see how fast it sets fire?" This is one of the main benefits".* It used to take a long time to get an appropriate fire with charcoal, fuel wood and dung cake. *"It makes life a lot easy".*

With full Charm, Waga Alem leads us to her kitchen, which is equipped with a stove and a lamp that both run on biogas plant. With a big smile she speaks about the changes this new technology brought to her daily life. *"Look at my kitchen it has never been so clean and see the time to cook Shero (local Sauce) it's a matter of less than 5minutes. Before I got biogas, I used to cook with charcoal, wood, dung cake and agricultural residue which produced a lot of smoke and takes time to give fire and it brought a bad smell. This now belongs to the past and its history".*

Box 1. Opinion of the users.

Conclusions

The use of biogas has a potential to reduce the demand for wood and charcoal use, hence reducing greenhouse gas emissions. In addition, the slurry and waste from the biogas plants provides a high quality fertiliser that can be used to improve the soil fertility and increase productivity in agriculture dependent rural communities of the study area.

In the study area, the biogas user households benefit from reduced indoor smoke, improved sanitation and better lighting. The biogas installation make each household to save on average 144 min per day from fuel wood collection, cooking, cleaning utensils/kitchen materials),and there is also reduction in the physical stress and health improvement.

The economy of a biogas plant is characterized by initial high investments costs, some operation and maintenance costs, mostly free raw materials (animal dung, weeds, plants, sewage sludge, human wastes, municipal wastes, etc.) and income from replacement of purchasing trade-

tional fuels. In addition, the slurry and waste from the biogas plants provides a high quality fertilizer that can be used to improve the soil fertility and increase productivity in agriculture dependent rural communities in the study area. Use of biogas provide an annual saving of 3833.28 Birr from fuel wood, Birr 1243.20 from charcoal, Birr 128.50 from dung cake and Birr 266 and Birr 717.65 from kerosene and chemical fertilizer, respectively with Net cash flow of Birr 1530 per HH/year.

There are some challenges that must be tackled in order to ensure sustainable future of biogas technology. These challenges were seen from two angles: from the users' side and on the disseminators' side.

Attitudinal problems

According to the field survey, due to unavailability of demonstration areas for biogas plant in the nearby peasant associations (PAs), from the total surveyed users of biogas, 4 of them did not believe on gaining of light and cooking fuel from dung and human excreta until they saw it on the due date.

Lack of awareness on lamp care

Due to awareness problems on the technology, and lack of responsible technology disseminator technician, from the total respondent, in the majority (40%) their biogas

lamp was broken due to improper lamp care (4) and feeding amount (4).

Standard problems in feeding amount of the raw material to biogas digester

The users complained about fixed standards of the raw material amount of the digester that were recommended by the disseminator to feed the biogas digester. Since the cellulose content of the grass that the cow eats is not equal throughout the year, the chemical content of the grass makes the biogas lamp to break. From 40% stated above, (4) respondents complained the constant standard of feeding amount recommended by technicians of biogas disseminators, Surprisingly, 4 respondents stated that, "the power/cellulose/content of dung that we add per day throughout the year is not equal, due to this, the power (in their expression) of the grass that the cows eat in the summer season makes the lamp to break". Currently, these households use their own indigenous knowledge and make correction about the feeding amount without any externality advice on the side of the responsible bodies.

Bio-slurry management problems

Due to awareness problems, 2 respondents have not reserved bio slurry storage tank. As a result, they faced problems in using efficiently the bio slurry for their farm.

Missed application of liquid bio-slurry in their back yard farm

Unknowingly, 4 respondents' cash crop such as Khat (Chat) had got dry due to missed application of liquid bio-slurry. After the problem appeared, one user uses his indigenous knowledge by understanding the cause through experience without external technical assistance about liquid bio-slurry application. As stated by this respondent, "the chemical content of the liquid bio-slurry is dangerous unless it mix with water during application".

Fear of the future due to unavailability of accessories /appliances

The biogas accessories are lamp, stove, connecters, gas pipes, pressure meter. Not less than 3 users have no slurry mixture and this doubles the time to add dung to the digester. Such problems make the user to fear the future about getting these appliances due to absence of the appliances in the local market as they need. Currently, 12 respondents have no lamp either one of the two (8 m^3 owners) or from one of the one (6 m^3 owners) but some of the user uses local materials to gain light from biogas and 1 user encounters problems of stove, 3

users problems of connectors and 1 user problems of pressure meter. Even lamps are guarantee of up to two years by the disseminator to be replaced when broken, for sustainability of the technology; users fear the cost of lamp which is Birr 85 per lamp.

The challenges encountered by biogas disseminator organizations, non-governmental organizations (SNV/Ethiopia) and the local government organizations raised their problems for not disseminated as expected.

Variation of market price and cost of installation

The criteria for disseminating the biogas plant to the community in the study area was; purchasing power and willingness of the user, having at least 4 cows, accessibility of water and construction material, area for slurry management. However, according to regional biogas coordination office and SNV/Ethiopia regional branch office, "due to construction material cost variation (such as cement) by not less than 50% in 2010/11, cost are born by the user and absence of loan to the poor inhibits the dissemination of household biogas investment as planned and or expected".

Lack of users' promotion

Even the promotion and awareness of users were the responsibility of the local government bodies such as district agricultural and rural development, higher government bodies and energy officials, the higher government bodies are not aware of biogas energy benefits and there is no sufficient experts at district level, and in the PAs there is no expert at all that follows biogas energy affairs.

Recommendations

Mainstreaming and promotion of biogas technology in different development activities

Government commitments to the development and promotion of renewable energy sources are advisable. It could be helpful to learn from the experiences gained in the developed world but should adapt to the needs and situation in the study area and in Ethiopia in general.

Develop training programs

Develop training programs for engineers, artesian, users, and all professionals involved in biogas dissemination.

Good understanding of the relation between capital costs and plant size

It can provide useful information in assessing economic viability of biogas plants, and providing means whereby

decisions are taken on developmental of a new project.

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Full Length Research Paper

Climate variation based on temperature and solar radiation data over a 29 year period in Lilongwe City, Malawi

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Economies that mainly depend on agriculture are to a large extent being negatively impacted by climate change. In this study, temperature and solar radiation data from Chitedze Weather Station, Lilongwe City, Malawi for a 29-year period (1985 to 2013) were assessed for the possibility of climate variation. In addition, the concentration of carbon dioxide over Malawi within the same period as temperature and solar radiation data was assessed for inferences. The highest mean minimum temperature (15.7°C) was recorded in 2010. The highest mean maximum temperature (27.9°C) and solar radiation (21.5 MJm^{-2}day^{-1}) were recorded in 2005. The mean minimum temperature showed an increasing pattern but both mean maximum temperature and solar radiation data showed a lot of variation. There were significant differences ($p < 0.05$) among mean minimum and maximum temperature and solar radiation. The carbon dioxide concentration over Malawi has been increasing over the years which is one of the contributors to rising mean minimum temperatures.

Key words: Climate variation, solar radiation, temperature, weather.

INTRODUCTION

The world's climate is changing and will continue to change into the coming century at rates projected to be unprecedented in recent human history (Adger et al., 2003). There is now ample evidence of the ecological impacts of recent climate change, from polar terrestrial to tropical marine environments (Walther et al., 2002). The impact of climate change on agriculture may add significantly to the development challenges of ensuring food security and reducing poverty (Jones and Thornton, 2003). Climate is generally one of the main determinants

of agricultural production. Its shift alters the distribution of plant diseases and pests which may have adverse effects on agriculture (Wani et al., 2013). Additionally, temperature increases especially in spring leads to a decrease in net primary production of some native grass species making them more vulnerable to invasion by exotic species (Alward et al., 1999). Grain yields also decline by 10% for each 1°C increase in growing-season minimum temperature (Peng et al., 2004). In a study by Sorenson et al. (1998), it was found that increase in

temperature leads to declining numbers in both wetlands and birds such as ducks due to drought. Climate change therefore impacts negatively on communities who depend on natural resources for their livelihood (Nuorteva et al., 2010). These mostly include those from developing countries who heavily depend on agriculture (Mendelsohn and Dinar, 1999) for their livelihood.

According to US-EPA (2014), the changing climate impacts society and ecosystems in a broad variety of ways. For example, climate change can increase or decrease rainfall, influence agricultural crop yields, affect human health, cause changes to forests and other ecosystems, or even impact energy supply. Climate change also creates new challenges for biodiversity conservation (Heller and Zavaleta, 2009). In the geologic past, natural climate changes have caused large-scale geographical shifts in species' ranges, changes in the species composition of biological communities, and species extinctions. It is predicted that the effects of anthropogenic climate change will be more severe because of the extremely rapid rate of the projected change (Peters, 1990). Third world countries particularly in Africa are threatened by the effects of these changes because of their economic dependence on climate for development whose backbone is agriculture (Ngaira, 2007). In Africa among several examples, over the 20th century, the areal extent of Kilimanjaro's ice fields has decreased by approximately 80%, and if current climatological conditions persist, the remaining ice fields are likely to disappear between 2015 and 2020 (Thompson et al., 2002). Also, the increased frequency and intensity of storms in Africa are related to climate change (Douglas et al., 2008).

One of the most important climate factors is temperature. The ambient temperature is of most interest to humanity (Hansen et al., 2013). Temperature is affected by the amount of solar radiation and concentration of greenhouse gases among several other factors. The earth`s surface behaves like a blackbody (an object that absorbs and emits radiation). According to Stefan-Boltzman law, the emitted radiation is proportional to the fourth power of the absolute temperature of an object. The earth's atmosphere is heated from below since the sun radiates shortwave radiation which is emitted back as long wave radiation (infrared radiation) by the earth (NASA, 2013). This means that if there is more radiation from the sun reaching the earth, then the earth will radiate more and hence high temperature of the earth's atmosphere. The increase in temperature of the earth's atmosphere is compounded by the presence of greenhouse gases. Greenhouse gases absorb infrared radiation causing warming of the atmosphere. Therefore, the amount of greenhouse gases in the atmosphere is directly related to the atmospheric temperature. Increased concentrations of greenhouse gases increase the temperature of the atmosphere leading to warming of the earth's surface (Takle and Hofstrand, 2013).

In this study, temperature and solar radiation data for Chitedze Weather Station in Lilongwe City, Malawi was analyzed for possibilities of climate variation. In addition, carbon dioxide data for Malawi was used to make further inferences. In Malawi, research linking climate change based on factors like temperature is very rare hence the need for this research. The research also adds further information to literature on climate variation for least industrialized countries.

METHODOLOGY

The ambient air temperature and solar radiation data was obtained from Malawi Department of Meteorological Services (MET). The data was from Chitedze Weather Station, Lilongwe, Malawi. Chitedze Weather Station is located at some 16 km west of Lilongwe City (Capital of Malawi) with 13° 59`S longitude and 33° 38`E latitude. The elevation is 1097 m above sea level (Luhanga, 1996). Figure 1 shows the position of Lilongwe in Malawi. Lilongwe has a population of about 700,000 people. It is an urban and industrial center in Malawi. Additional data used in this research was sourced from literature.

The data was analyzed using Microsoft Excel and Statistical Package for the Social Sciences (SPSS) version 18. Using Microsoft Excel, box plots and graphs were plotted and used in the comparisons of trends over the years. In SPSS, T-tests were used to check for significant differences while hierarchical cluster analysis (HCA) was used to further examine the distribution of the data sets and linkages as reported by Mapoma et al. (2014).

RESULTS AND DISCUSSION

Minimum and maximum temperatures and solar radiation variations

Figure 2 shows box plots of minimum and maximum temperature and solar radiation in Lilongwe City. The values showed a narrow range over the years. This is attributed to the fact that Malawi has a sub-tropical climate (MET, 2006) where temperatures are both seasonal and show a narrow range within a specific period of the year. Figure 3 shows trend in mean minimum and maximum temperatures and solar radiation. The highest mean minimum temperature (15.7°C) was recorded in 2010 while lowest (13.2°C) was in 1985. The highest mean maximum temperature (27.9°C) was recorded in 2005 while the lowest (26.2°C) was in 1986. The amount of solar radiation received is dependent on both the month and time of the year. The highest mean solar radiation (21.5 $MJm^{-2}day^{-1}$) was recorded in 2005 while the lowest (18.9 $MJm^{-2}day^{-1}$) in 1989. The trend of mean minimum temperature shows an increasing pattern. The trend in mean maximum temperature indicates a fluctuating pattern over the years. The mean maximum temperature pattern was related to solar radiation more than the minimum temperature. The increasing pattern in mean minimum temperatures in the study area indicates a possibility of sequential warming. A study in Malawi
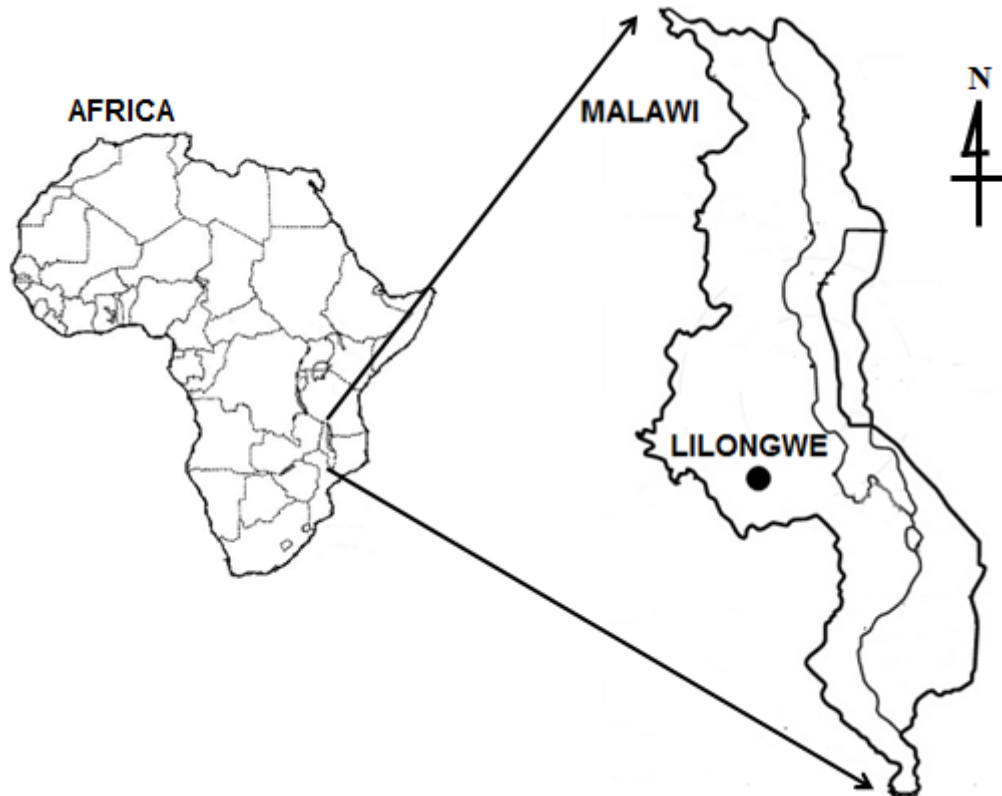
Figure 1. Map of Malawi showing the position of Lilongwe City.
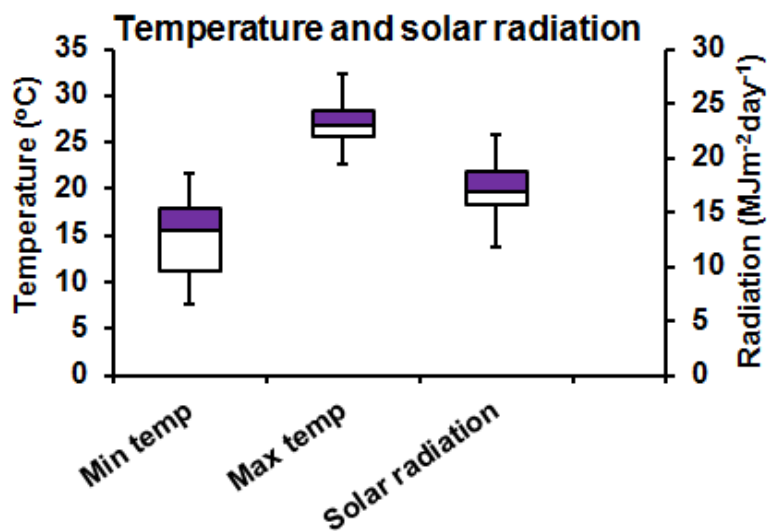

Figure 2. Box plots of minimum and maximum temperature and solar radiation in the study area (1985-2013).

over Chichiri weather station (A distance of about 365 km from the current study location) by Kaonga et al. (2012), also showed that in 2005, the temperature was higher than the preceeding years. The mean maximum and minimum temperatures recorded in that study were 26.8 and 15.8°C, respectively which are consistent with trends in the current study.
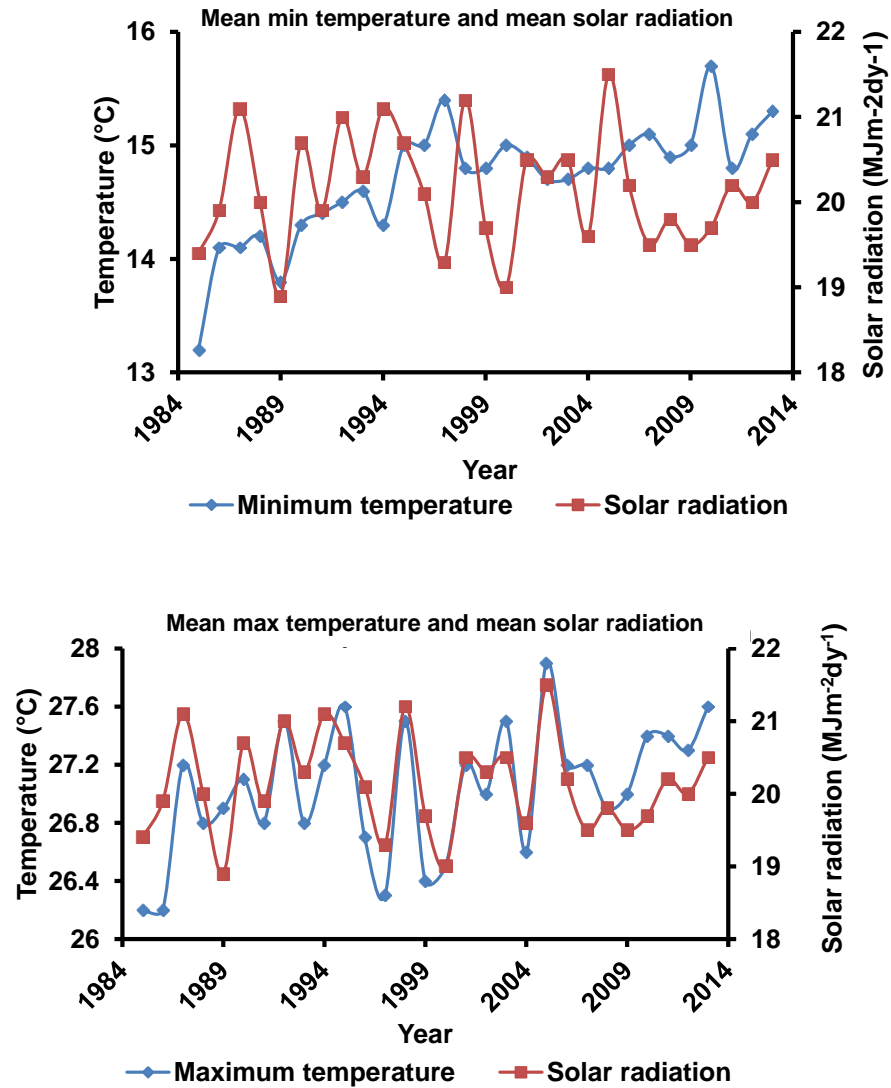
Figure 4 shows the observed and simulated net

Figure 3. Trend in mean minimum and maximum temperature and solar radiation over Lilongwe city.
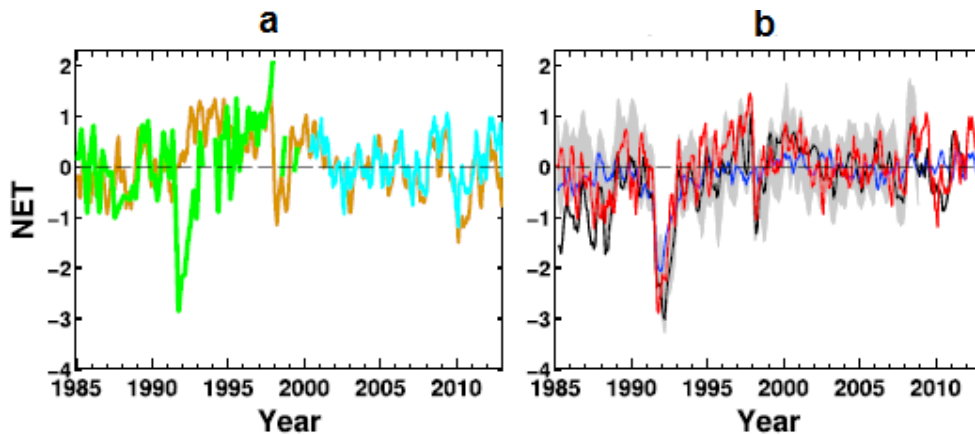

Figure 4. Changes in observed (a) and simulated (b) net downward radiation at the top of the earth's atmosphere (Adapted from Allan et al., 2014).

downward radiation at the top of the earth's atmosphere (Allan et al., 2014). The figure shows that there were no differences between the observed and simulated data. When these figures were compared with the current study, it was noted that the sudden drop and increase in temperature in 1992 and 1998 correlated with the mean maximum temperature trend. The mean minimum temperature agreed with the 1998 pattern only, that is, when there was a sudden increase in net solar radiation.

Relationship among minimum and maximum temperatures and solar radiation

Figure 5 shows that the correlations between mean minimum and maximum temperatures were weak. Statistical tests showed that there were significant differences ($p < 0.05$) between the mean minimum and maximum temperatures. This indicates that within the same year, the minimum temperature is independent of the maximum temperature. This is supported by the fact that the years when the minimum temperatures were highest, it was not the case with maximum temperature as indicated above. There were also significant differences ($p < 0.05$) between mean solar radiation as compared to both maximum and minimum temperatures. The correlations of solar radiation and both mean minimum and maximum temperatures were weak. This was further confirmed by cluster analysis. The frequencies (when the mean values were grouped into three clusters) were 7, 8 and 14 for clusters 1 to 3, respectively (comparison on mean maximum temperature and solar radiation using Ward method). Under the same conditions, the frequencies were 5, 16 and 8 when minimum temperature was compared with solar radiation. This means that the link among these factors was strong in the first cluster only with a bigger percentage of the values being dissimilar. This is an indication that other factors are responsible for warming in the studied area since temperature seem not to be dependent on the amount of solar radiation. According to Lashof and Ahuja (1990) and Paterson (2011), warming is largely caused by greenhouse gases, primarily carbon dioxide accruing in the atmosphere. In Malawi, carbon dioxide is an important greenhouse gas. This is mainly due to the fact that intensive use of firewood for energy purposes had reduced forest reserves to 28% by the year 2009 (UNEP, 2013). Forests are an important carbon dioxide sink since through photosynthesis, vegetation removes the gas from the atmosphere (FAO, 2013). In the absence of vegetation, most of the carbon dioxide remains in the atmosphere which causes warming. Figure 6 shows carbon dioxide emissions in Malawi from a number of sources. Mean solar radiation (as indicated in Figure 3) showed a lot of variation from 1985 to 2010 while during the same period, total carbon dioxide concentration showed an increasing pattern. The increase in total carbon

dioxide emissions over the years could be contributed to warming as seen by the rise in mean minimum temperatures. This is a concern for both Malawi and global climate because increasing greenhouse gas concentrations are expected to have significant impacts not only locally but also to the world's climate on a timescale of decades to centuries (Hughes, 2000; Mendelsohn et al., 1994). The increase in total carbon dioxide was correlated to the increase in the same gas from liquids. These liquids include fuels like petrol and diesel. In Malawi, the number of vehicles (use petrol and diesel as fuels) has increased over the years.   For example, from 1990 to 1999, the average registration of new vehicles was 5,282 per annum (GoM, 2002).

Already, the negative effects of climate change in Malawi are being felt especially in agriculture. According to Christian Aid (2015), in Malawi, farmers are no longer able to rely on the weather. The rains have become unpredictable since they can come too heavy and all at once. This is in addition to the fact that dry spells which have become common end up ruining crops or stunt the growth of young plants. This is further supported by Action Aid (2015) who postulates that Malawi is one of the most vulnerable countries to climate change and this has affected agriculture production which is the backbone of the country. The impacts in Malawi are being manifested in various ways such as intense rainfall, changing rainfall patterns, floods, droughts and prolonged dry spells.

Climate change is also having a negative impact on Malawi`s biodiversity and ecosystems. According to GoM (2012), it is on record that a high population of nyala antelopes died due to excessive heat and inadequate food. Also in 1995, one of the most important lakes (Lake Chilwa) in Malawi dried up with catastrophic consequences on fish species and fisheries. Therefore, the ecological problems that climate change is causing in Malawi cannot be underestimated.

Conclusion

This study assessed temperature and solar radiation data from Chitedze Research Station in Lilongwe, Malawi for the possibility of climate variation over a 29 year period. The results indicated that mean maximum temperatures have been fluctuating over the years. The mean minimum temperatures have been gradually increasing, indicating a possibility of warming. The mean maximum tempe-ratures correlated with net solar radiation at the boundary of the earth's atmosphere. However, there were weak correlations among minimum and maximum tempera-tures with solar radiation from the study area an indication that other factors like carbon dioxide are responsible for warming. This is because the rise especially in minimum temperature was related to the increase in carbon dioxide concentration over the years.
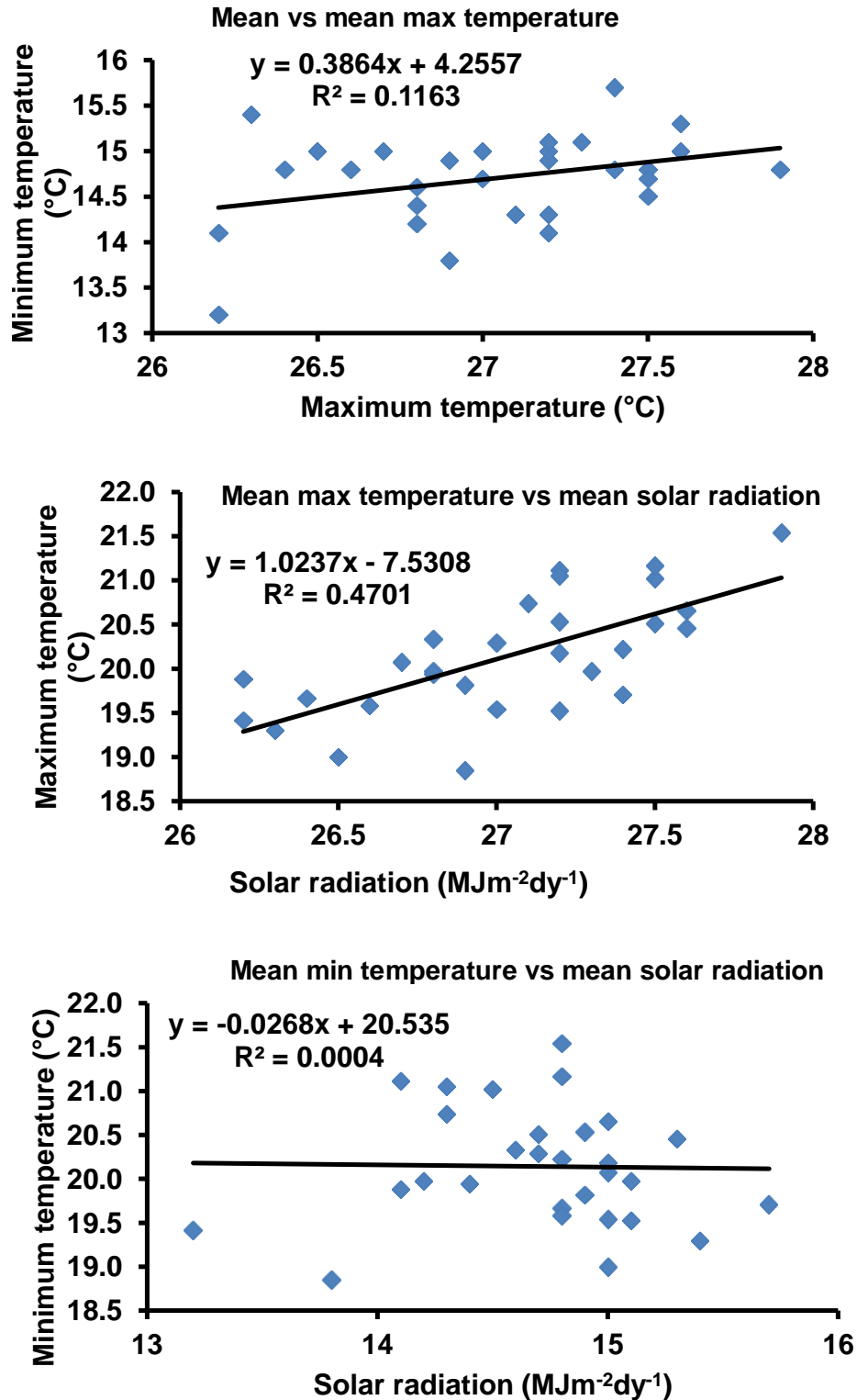
Mean vs mean max temperature

$y = 0.3864x + 4.2557$
$R^2 = 0.1163$

Mean max temperature vs mean solar radiation

$y = 1.0237x - 7.5308$
$R^2 = 0.4701$

Mean min temperature vs mean solar radiation

$y = -0.0268x + 20.535$
$R^2 = 0.0004$

Figure 5. Correlation among minimum and maximum temperatures and solar radiation.

Conflict of interests

The authors did not declare any conflict of interest.
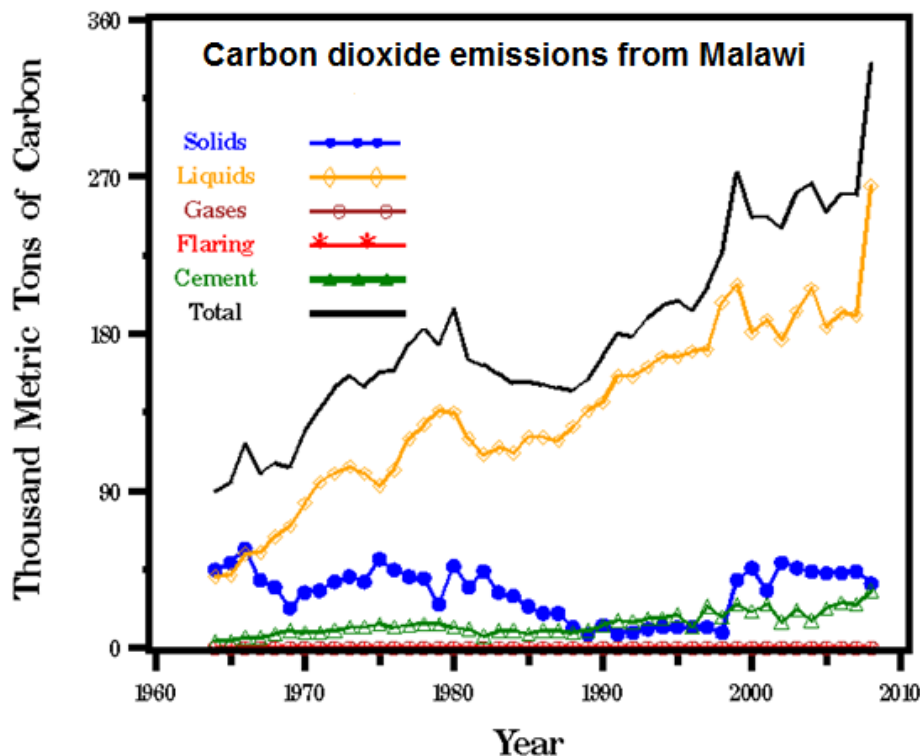
Figure 6. Carbon dioxide emissions for Malawi (Source; CDIAC, 2012).

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Full Length Research Paper

Study of the physico-chemical conditions and evaluation of the changes in eutrophication-related problems in El- Mex Bay

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El- Mex Bay is a relatively large coastal embayment west of Alexandria. The bay is an important fishery ground as well as recreation area. It includes both the Western Harbor and Dekhaila Harbor. It is one of heavily polluted areas on the Egyptian Mediterranean coast, receiving huge amount of agricultural, industrial, and sewage wastes from the adjacent Lake Mariut through El- Umoum Drain. According to different estimations in literatures the volume of the wastewaters varied between 7×10^6 and 8×10^6 m^3day^{-1}, which is supposed to increase with the growing population density of Alexandria city. These conditions cause pronounced eutrophication and drastic changes. Eutrophication-related problems in El- Mex Bay of Alexandria were studied seasonally from autumn 2011 to autumn 2012. Geographical information system (GIS) and remote sensing techniques were used together with the ground-based surveys to assess the vulnerability of the most important physical and eutrophication parameters along El- Mex Bay coast. As a result of increasing population and industrial development, poorly untreated industrial waste, domestic sewage, shipping industry and agricultural runoff are being released to the bay. With the rapid increase in the industries and population, changes in water quality would have potential consequences for the large rapidly growing population of the Alexandria region. Recommendations for environmental recovery and restoration are proposed for preservation of El- Mex Bay and harbors in order to facilitate development of environmental and tourist activities.

Key words: El- Mex Bay, recreation area, El- Umoum drain, geographical information system (GIS, remote sensing, eutrophication, and restoration.

INTRODUCTION

The Egyptian Mediterranean coast receives huge volumes of wastewaters every year through the coastal lagoons and from other land-based effluents. These wastes are loaded by variable amounts and types of pollutants, in addition to great amount of nitrogenous and phosphorous compounds, which in turn cause high level of eutrophication along a significant part of the Mediterranean coast, particularly of both the Nile Delta region and Alexandria coast.

Eutrophication is an important problem to the Egyptian

Mediterranean coast, resulting in fundamental changes in the structure of the planktonic and benthic communities as well as fish mortality. Eutrophication was accompanied by the appearance of several harmful algal species at several hot spots along the coast. The level of eutrophic-cation demonstrated wide variation along the Egyptian coast relative to the variations in the volume and contents of discharged wastes. High nutrient levels and chlorophyll concentration are indication of Alexandria sea coast, like Mex Bay, Western Harbor, Abu Qir Bay, and others (Dorgham, 2011).

Eutrophication has become a persistent problem in El-Mex Bay of Alexandria and was recorded for the first time in 1985 (Dorgham, 2011). These problems came about as a result of the continuous enrichment of nutrients from different sources, including maritime activities, several land-based effluents consisting of mixed industrial, domestic and agricultural wastes as well as stored chemical fertilizers. Nutrient loads are directly dependent on human activities, which in turn depend on the growth of the world's human population. Consequently, human-induced eutrophication is in a way related to the increase in human population (De Jonge et al., 2002). In Alexandria City, the human population has just about doubled since the first record of eutrophication in El- Mex Bay in 1985 (Dorgham, 2011). This population increase has been associated with the intensive development of human activities, which directly or indirectly have led to the increase in nutrient enrichment in the bay and the consequent increase in the level of eutrophication during the past two decades.

Numerous studies have been conducted on the physical, chemical and biological characteristics of El-Mex Bay (Abuldahab et al., 1990; Soliman and Gharib, 1998; Gharib, 1998; El- Sherif, 2006; Dorgham et al., 2004; Hussein and Gharib, 2012; Hendy, 2013) and showed that, the continuous discharge of polluted water into the bay caused massive development of algal blooms and a gradual deterioration of water quality created (Zakaria et al., 2007; Mahmoud et al., 2009) identified four types of water in El-Mex Bay based on the salinity values: the mixed land drainage (L) of salinity < 10 ppt, mixed water (M) of salinity range 10 to 30 ppt, diluted sea water (D) of salinity range 30 to 38.5 ppt and Mediterranean Sea water (S) of salinity > 38.5. Youssef (2001) recorded the maximum average ratios of specific alkalinity at regions affected by the drainage water (El- Rayis, 1984; Abuldahab et al., 1986) and studied the levels of heavy metals in El-Mex Bay ecosystem including marine organisms of different trophic levels (Tayel and Shiradah, 1996; Halim et al., 1986) and also concentrations of

heavy metals in fish tissues were studied. The majority of these studies were based on seasonal or bimonthly sampling. However, the rapid changes in water quality and biotic components require frequent follow-up at shorter time intervals. In the present work, the aim was to study the physico-chemical conditions and evaluate the changes in eutrophication-related problems in El- Mex Bay. Recommendations are presented to facilitate imple-mentation of a coastal zone management program.

MATERIALS AND METHODS

Study area

El- Mex Bay is relatively large coastal embayment west of Alexandria, at longitude 29° 45′ and 29° 54′ E and latitude 31° 07′ and 31° 15′ N, from Agami headland (west) to the Western Harbor (east), with an average depth of about 10 m and surface area of about 19.4 km^2 (El- Sherif, 2006). The bay is an important fishery ground as well as recreation area. It includes both the Western and Dekhaila harbors. The bay is one of the heavily polluted areas on the Egyptian Mediterranean coast, receiving huge amount of agricultural, industrial, and sewage wastes from the adjacent Lake Mariut through El- Umoum drain. Accordingly to different estima-tions in literatures the volume of the wastewaters varied between 7 × 10^6 and 8 × 10^6 m^3 day^{-1} (Dorgham, 2011), which is supposed to increase with the growing population density of Alexandria city. In addition to El- Umoum Drain discharge, industrial wastes from several industries in the surrounding area, like chemical, chloro-alkali, tanneries, cement, and petroleum, are also discharged to the bay. These conditions cause pronounced eutrophication and drastic environmental changes.

Sampling design

Samples were collected seasonally during a year (from autumn 2011 to autumn 2012) at the selected stations. The stations were selected to cover all possible climatic and environmental charac-teristics of the different parts of the study area. Eight stations were chosen in the El- Mex Bay for the present study, the locations of the sampling stations are shown in Figure 1.

The samples for hydrographic measurements and nutrient analysis were collected. The water temperature was measured with an ordinary thermometer graduated to 0.1ºC, the limit of visibility of water was measured by using a white enameled Secchi disc, the salinity measured by using Salinometer and the measurements were done by electrode (range 0-199.9 µm, 2-19.99 ms) model (Oyster, inspected 82738, Extech instruments, Germany). The pH values by using a pocket digital pH meter, and nutrients (phosphate, nitrate, nitrite, ammonia and silicate) were determined according to the methods mentioned in Grasshoff (1976). Chlorophyll a and dissolved oxygen content in the water was carried out according to Strickland and Parsons (1972).

The remotely sensed satellite imagery (LAND SAT 3) was found to be the most appropriate one for this study, as with its regional
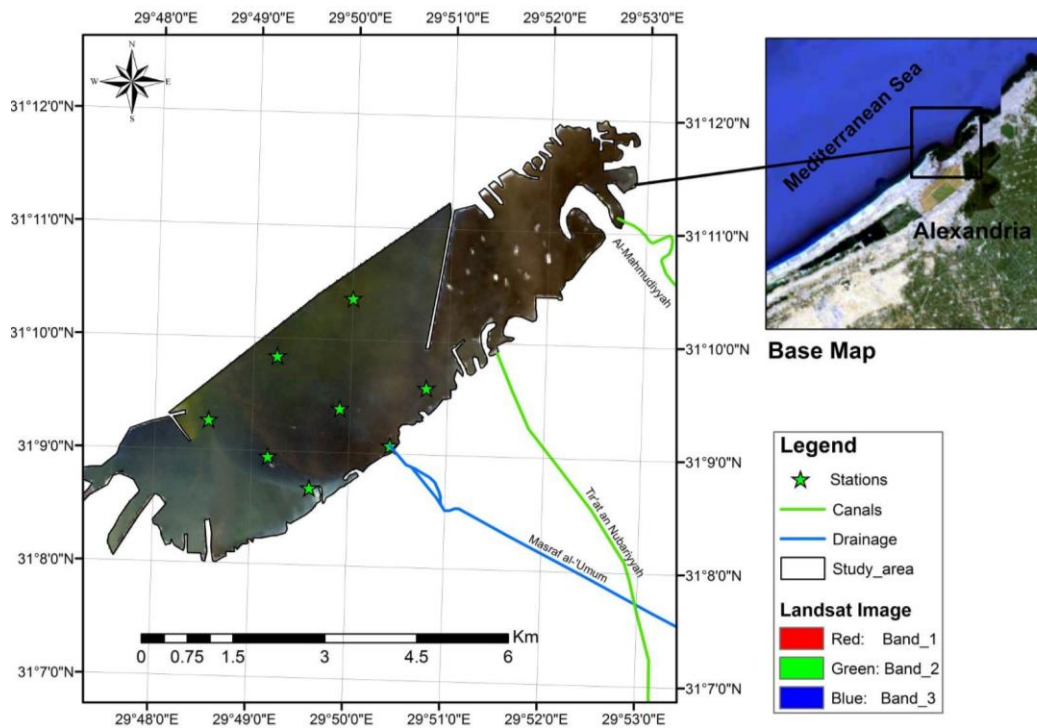
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Figure 1. Base map showing the study sites.

coverage, all necessary map features were obviously clear and interpreted. A raster depending software was used for the purpose of digitizing the map features. ARC-GIS 10 and Envi software was used for this purpose for its high digitization capabilities, also in finalizing and visualizing data. The analysis and interpretation of physico-chemical parameters were done by ARC-GIS 10.

RESULTS

The hydrographic conditions and the eutrophication parameters varied widely during the study period. However, the water temperature did not deviate from the seasonal fluctuations normal on Egypt's Mediterranean coast (15-34°C) (El- Sherif, 2006). Although the bay is a shallow basin subject to vigorous mixing during much of the year, the largest value was reported in summer 2012 (32 °C) and the smallest one in winter 2012 (14.2°C) as shown in Figure 2.

Salinity is considered as a sensitive parameter for measuring the rate of dilution of seawater caused by land-based sources discharge and subsequently it reflects the degree of contamination in aquatic environment. Water salinity at El- Mex Bay showed wide variations from a minimum of 6.20 ‰ in front of El- Umoum Drain during winter 2012 to a maximum of 33.50 ‰ during autumn 2012 inside the sea (Figure 3), which directly reflects the changes in the volume and dispersion of the discharged wastewater through El-Umoum drain. This

observation agrees with those found by several authors at the same area (Mahmoud et al., 2009). The seasonal values of salinity at El- Mex Bay water reflects the mixing of the bay water with fresh water. The salinity of the drain water, on the other hand, did not exceed 7‰. Generally the water salinity in the recent period decreased which insure the effects of land drainage.

The transparency of the bay water was relatively low for almost the whole year, with Secchi disc readings varying from 0.4 to 0.6 m. The water was more turbid (0.3- 0.4 m) in summer and autumn 2012, but relatively clear (1- 3 m) during winter and spring 2012 (Figure 4).

The pH values of water samples varied over rather a wider range (4.51- 8.01) with negligible differences between stations so, it was considered to range between slight alkaline and acidic (Figure 5).

Dissolved oxygen is considered as one of the most important and useful parameters in identification of different water masses and in assessing the degree of pollution especially with organic pollutants which affects fish and other marine life through oxygen reduction or depletion. The distribution pattern of DO at El- Mex Bay showed a wide variation and fluctuated between 2.52 to9.11 mg/L (Figure 6). The maximum value of DO recorded at station I during autumn 2012 can be attributed to lower water temperature (16.0°C) as well as agitation of water by strong winds (Nessim, 1994; Hendy, 2013). Drain water is characterized by relative lower
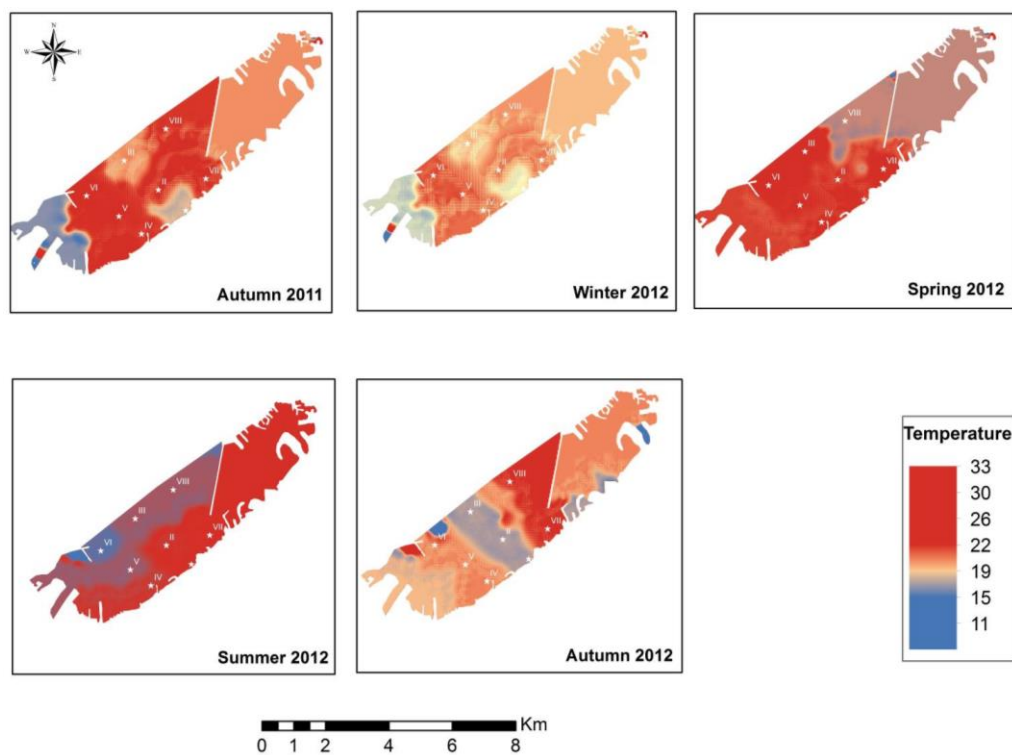
Figure 2. Variations of water temperature (°C) at different stations during study period.
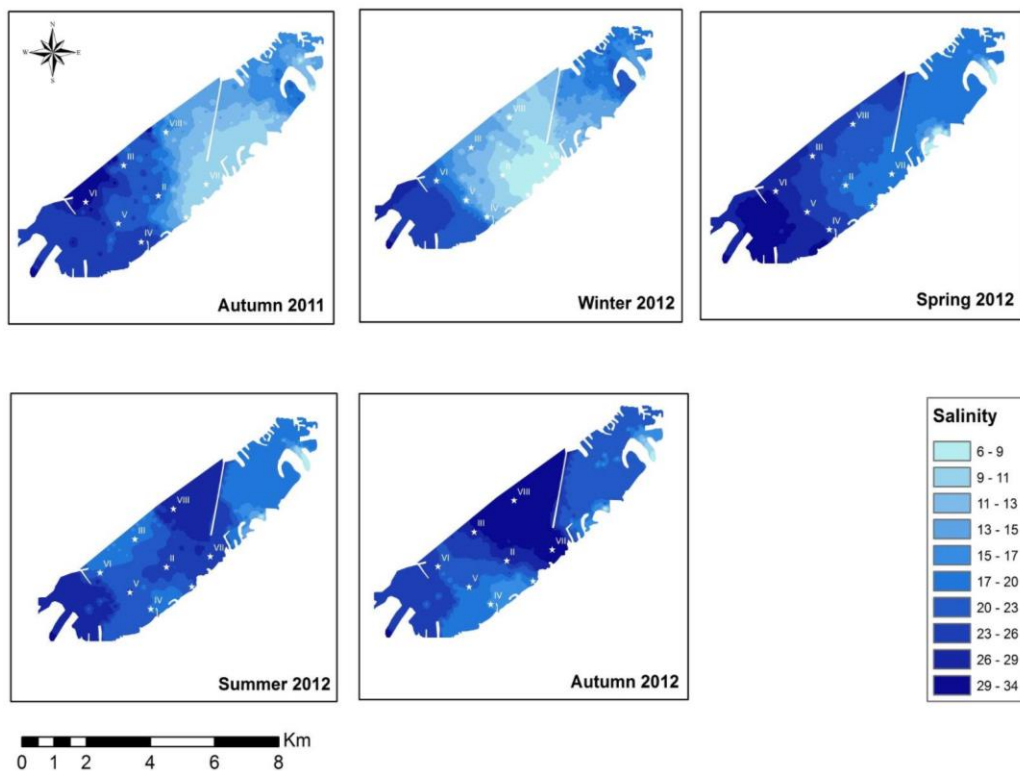

Figure 3. The seasonal distribution of salinity (‰) during study period at El- Mex Bay.
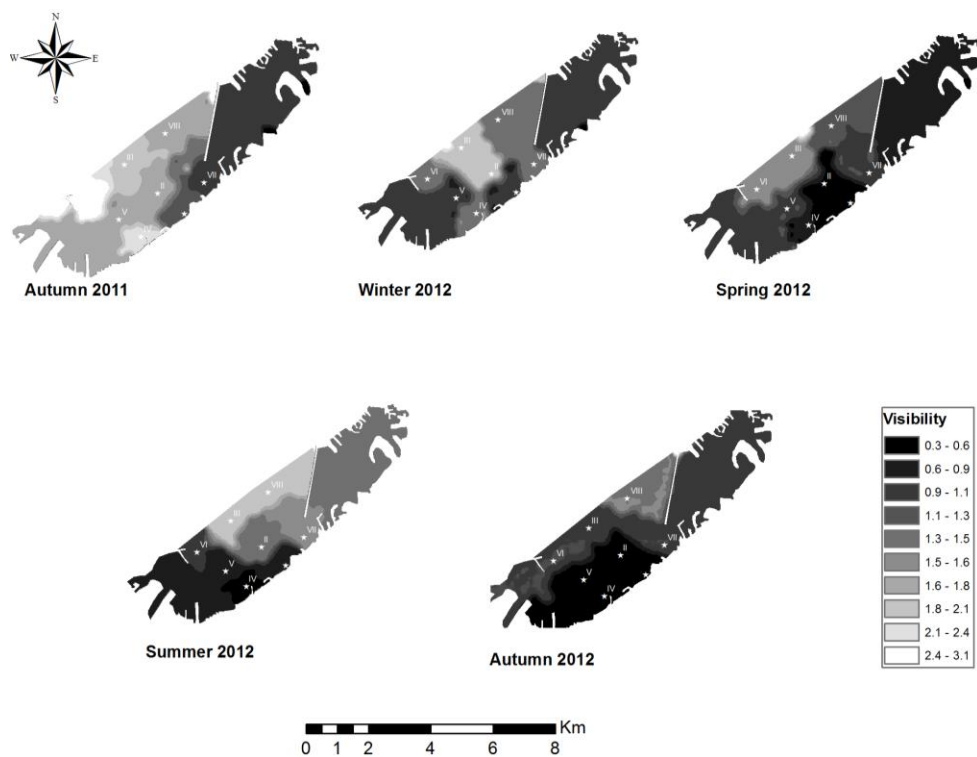
Figure 4. The seasonal distribution of transparency (m) during study period at El- Mex Bay.
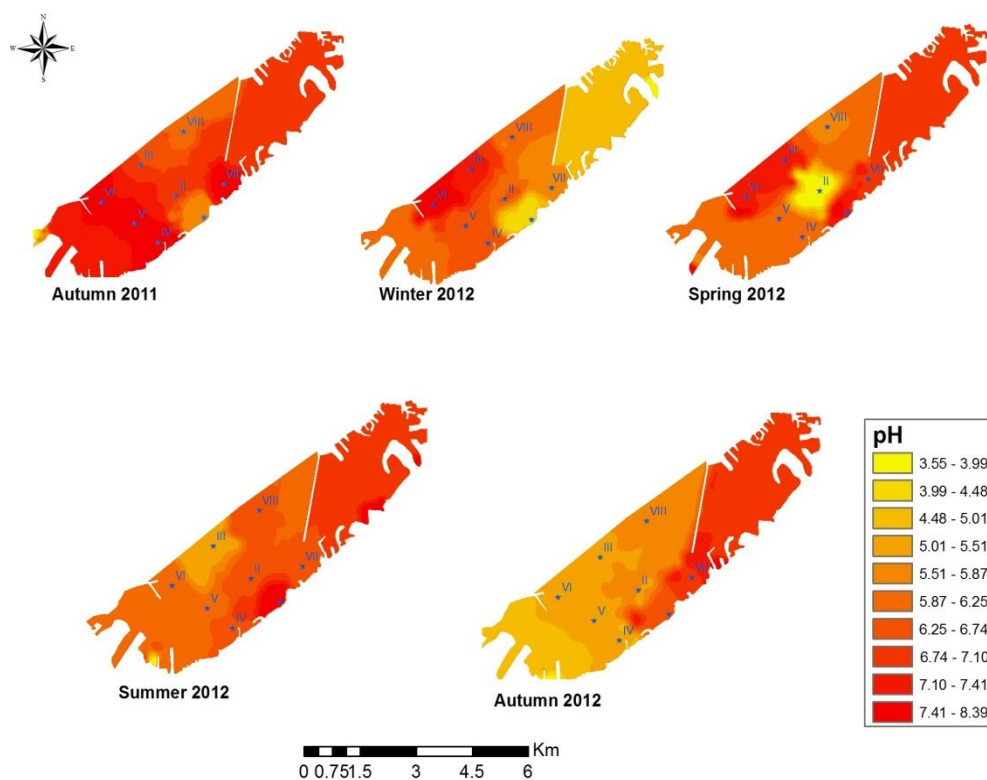

Figure 5. The seasonal distribution of pH during study period at El- Mex Bay.
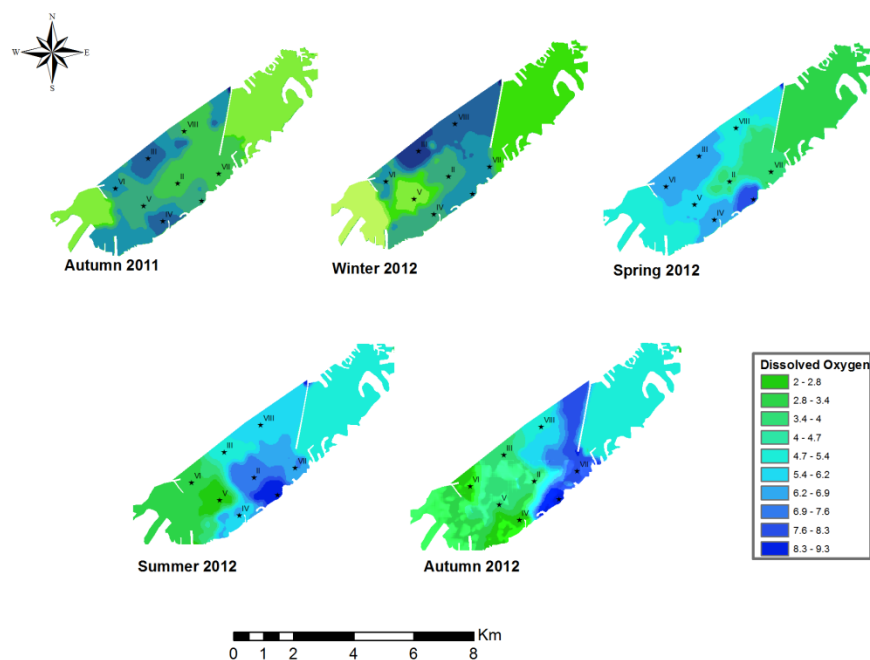
Figure 6. The seasonal distribution of DO (mg/l) during study period at El- Mex Bay.

oxygen content (5.8 mg/L), and complete depletion of oxygen was not observed among all samples but the values were found in under saturated conditions. The data showed sharp decrease in oxygen content of El-Mex Bay water during the study period that revealed the undesirable conditions.

The continuous nutrient enrichment resulting from the discharged wastes and other human activities raised the fertility in El- Mex Bay to a high level. However, the concentrations of nutrient salts displayed different ranges of variations relative to those occurring in the supplying sources.

Nitrite that appears in water results mainly from bio-chemical oxidation of ammonia (nitrification) or the reduc-tion of nitrate (denitrification). During the period of study, station I during spring 2012 and autumn 2012 recoded higher contents of nitrite than those recorded in sea water (14.57 and 15.17 µg/l respectively), consequently, the discharged of El- Umoum drain water affected directly the in front area. The seasonal distribution of nitrite content was represented graphically in Figure 7. Due to the mixing of drainage water with seawater at El- Mex Bay, the values of NO_2 dropped to less than 0.23 µg/l during winter and spring 2012.

Nitrate is the most stable form of inorganic nitrogen in oxygenated water. It is the end product of nitrification process in natural water. Figure 8 illustrates that El-Umoum drain (station I) attained higher value of nitrate than most of the studied stations during survey with value of 20.09 µg/l, which means that El- Umoum drain

possesses twice as much nitrate content as that of surrounding area. Several factors may affect the distri-bution of nitrate content in the investigated area, such as, the drainage water (the main factor), decom-position of organic matter, regeneration from suspended matter and bottom sediment as well as phytoplankton assimilation. The minimum values of NO_3 were observed during winter and spring 2012 (0.21 µg/l to 0.11 µg/l, respectively).

The environmental significance of phosphorus arises out of its role as a major nutrient for both plants and micro-organisms (Vanloon and Duffy, 2000). The mean concentration had a higher range and fluctuated between 0.84 (Okbah et al., 1999) and 3.34 µM (Said et al., 1991). Stations I and II (El-Umoum drain) attained higher values of reactive phosphate than all stations during the period of study with values 9.09 and 10.14 µg/l respectively (Figure 9).

The continuous discharging of polluted water into El-Mex Bay caused massive development of algal blooms and a gradual deterioration of water quality was created (Hussein and Gharib, 2012).

The land-runoff discharges from human settlements, certain industries and agricultural activities are largely the cause of man-made eutrophication in the Egyptian Mediterranean coastal waters of Alexandria. Controlled fertilization, mainly by nitrogen and phosphorous of infertile marine systems increases primary production, which can have consequence for fishery yield. Conver-sely, uncontrolled eutrophication of productive systems can lead to undesirable consequences (Hussein and
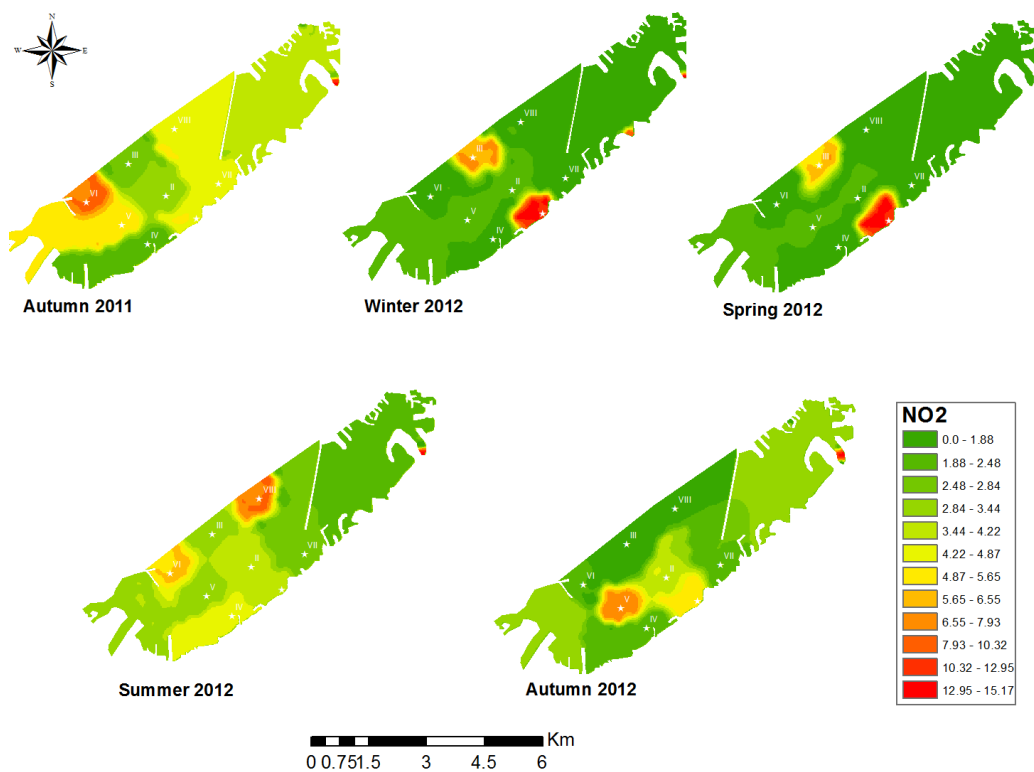
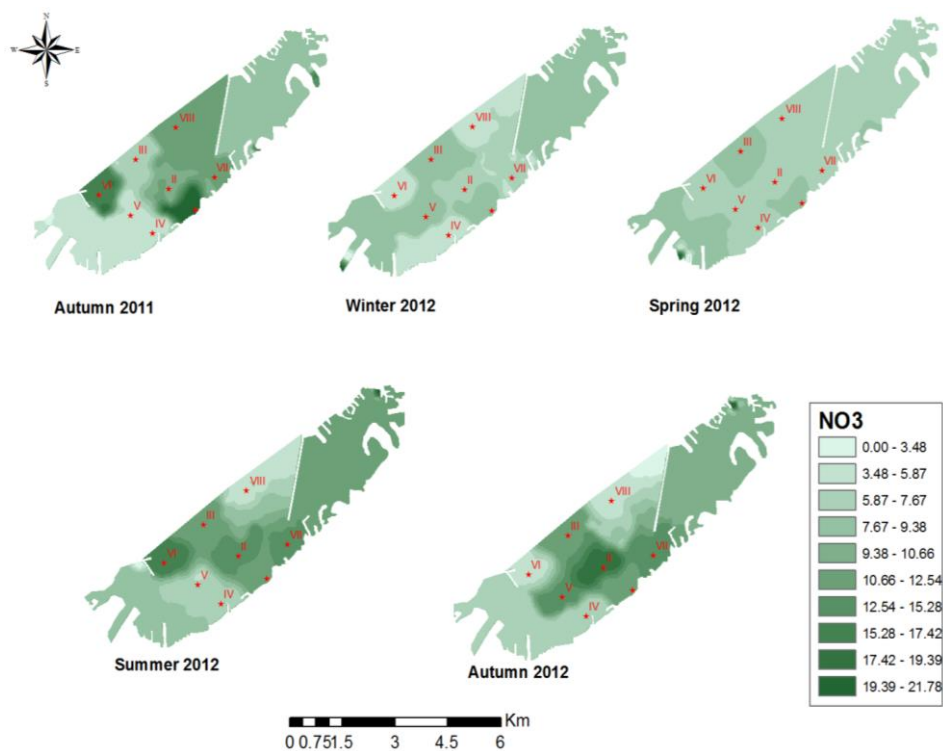**Figure 7.** The seasonal distribution of NO$_2$ (µg/l) during study period at El- Mex Bay.

Figure 8. The seasonal distribution of NO$_3$ (µg/l) during study period at El- Mex Bay.
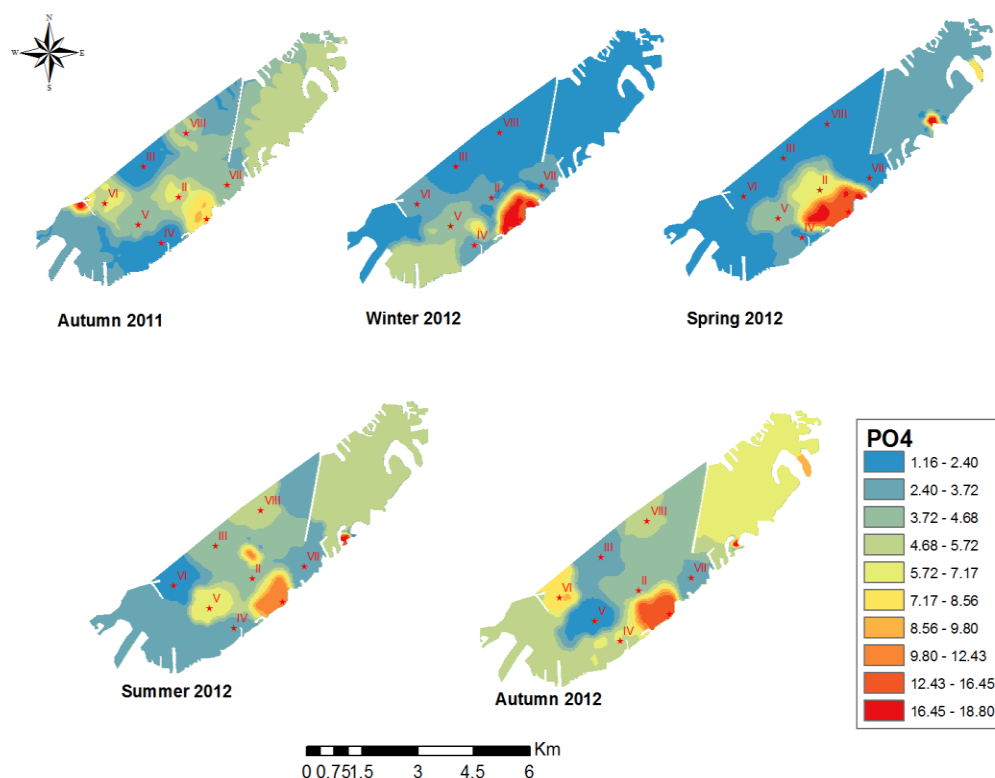
Figure 9. The seasonal distribution of PO$_4$ (µg/l) during study period at El- Mex Bay.

Gharib, 2012).

The maximum value of chlorophyll-a has recorded during 2 seasons summer and autumn 2012 with an annual average (34.38 and 29.92 µg/l, respectively). The high concentration of Chl-a content recorded in the water coincided with low salinity and high values of nutrient salts, which reflects such eutrophication condition caused by drainage effluents (Figure 10).

DISCUSSION

El-Mex Bay area has been and still being subjected to continuous major and drastic changes as a result of human activities; consequences of growing heavy industries (chloro-alkali plant, petrochemicals, pulp, metal plating, industrial dyes, and textiles) and uncontrolled disposal of resulting wastes, in addition coastal water of El- Mex Bay received huge amounts of untreated industrial wastes. The different human activities that bring large amounts of nutrient salts and harmful substances to the bay appear to have a pronounced impact on the physico-chemical characteristics.

The current regime there effectively controls the temporal and spatial variations of the ecological parameters. The predominant current directions were directed north-

eastward under the influence of the north-westerly wind and sometimes directed south-eastward when the wind has southwesterly component in December 2012 and January 2012. The current and wind directions interpret that directions in 2012 and 2013 were not different from that in 1996 and 1997 whereas, the wind speed in winter 2012 was 27.36 knots and in January 2013 was 29.8 knots that exceed that which occurred in December 1996 which was 26 knots. Also, the current speed increased in winter 2013 and became 86.21 cm/s whereas winter in 1996 was 49.94 cm/s. El- Mex Bay and the two surrounding harbors (Western and El- Dekhela) are subjected to two main problems. Storm surges in association with spring tides which cause considerable trouble to coastal roads. Storm surges raise the sea level by 40 cm, causing overtopping of adjacent of beaches and structures. Storm waves in winter attack El- Mex Bay from the NW direction (Hendy, 2013). Moreover, the water exchange between the harbor and the sea exerts a considerable influence on the environmental and biological characteristics of the harbor, since one such cycle takes about 30 days to complete (El-Gindy, 1986; Hassan and Saad, 1996).

The spatial distribution of salinity was in fact a better reflection of the effect of El- Umoum Drain discharge into El- Mex Bay. In the long term, salinity decreased gradually from 39.6 ‰ in 1997 (Dorgham, 1997) to 33.50‰ during
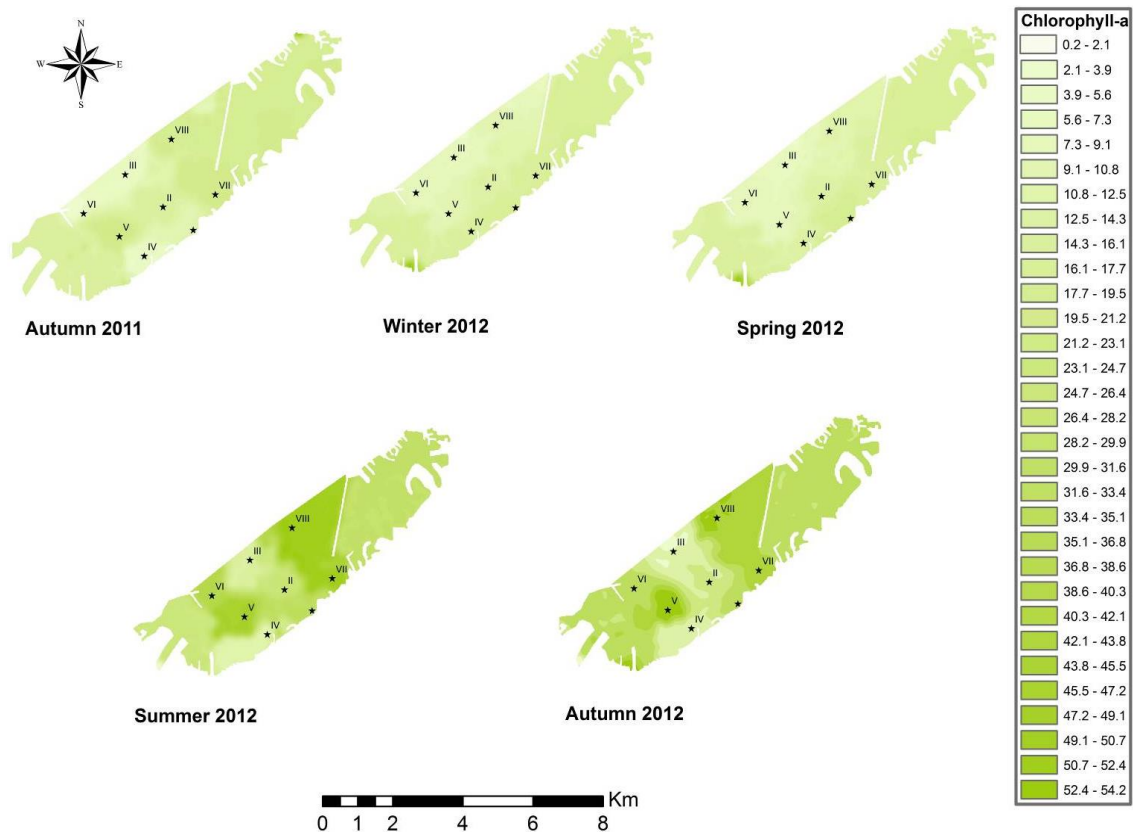
Figure 10. The seasonal distribution of chlorophyll- *a* (µg/l) during study period at El- Mex Bay.

the present study, indicating the chronic impact of the land-based effluents.

Although mixing processes caused by ship traffic and land-based runoff are the major cause of water turbidity in the bay, abnormally intensive phytoplankton blooms also substantially reduced water transparency; the two variables showed an inverse relationship all the year round.

The physico-chemical variables revealed that water temperature did not deviate from the normal seasonal fluctuations on the southeastern coast of the Mediterranean sea (15- 30°C). The pH values were always on the slight alkaline side and lower than that of the open sea. The decrease in the pH value coincided with the drop in oxygen content due to the effect of accumulating organic pollutants as well as the discharge of brackish water. El-Mex Bay demonstrated wide range of variations in its salinity on the spatial scale relative to the dispersal pattern of the discharged waste waters. The salinity of the near-shore waters sustained usually low values, increasing seaward to exceed 26.1 ‰ in the open part of the sea which reflects the effect of land drainage.

The water column of El- Mex Bay suffers from pronounced turbidity, particularly in front of the land runoff, whereas

the Secchi disc readings were mostly < 1 m. Such turbidity is attributed to the strong mixing caused by discharged wastes, heavy traffic of fishing boats, and high count of plankton organisms. However, the open area of the bay shows comparatively high transparency (up to 5 m). These observations agreed with those of other studies (Mahmoud et al., 2009; Dorgham, 2011; Hendy, 2013).

In spite of the extremely high primary production in El-Mex Bay, dissolved oxygen was generally low along the water with a relatively small vertical gradient. The decrease in dissolved oxygen with depth is attributed to its consumption in oxidation of organic matter and the stagnation conditions prevailing in summer (Nessim and Tadros, 1986). The inter-annual records of dissolved oxygen testify to the continuing deterioration of water quality during the past two decades: its concentration fell from 1.6- 10.9 mg l^{-1} in 1997 (Labib, 1997) to <9.11 mg l^{-1} during the present study. It is therefore important to notice that the oxygen concentrations in the water of the study area was comparable to the threshold level of well oxygenation (<9.11 mg l^{-1}) proposed by Huet (1973) and near the bottom it resembled the hypoxia condition stated by Stachowitsch and Avcin (1988). Accordingly, El- Mex

Bay is categorized as an area with critical limits of dissolved oxygen (3.5-4.2 mg l^{-1}) necessary for healthy growth of biota in both cold and warm waters (Grundy, 1971; Arin 1974).

The seasonal distribution of nitrate in the water dropped in spring and summer owing to its intensive uptake by the abnormal phytoplankton blooms. Although the difference in nitrate between stations may be related to the effect of discharged wastes at the surface, it is probable that nitrification and mineralization of nitrate take place at different rates in the two layers. This concurs with the seasonally distribution of nitrate at all the stations, which reflects the ecological conditions prevailing at each one in different seasons. At stations I and II, nitrate attained its maximum concentration during summer and autumn 2012, when salinity dropped to its lowest value during the year; meanwhile, station I sustained the highest value for several seasons, possibly as a result of the dissolution of stored chemical fertilizers.

Nitrite levels in sea water can be regarded as a measure of the rate of nitrification and denitrification processes, which are also related to salinity variation. In the study area, the difference in nitrite between stations indicates that in the low salinity area, these processes occurred at the surface and the bottom at two different rates, while in the higher salinity area they took place at approximately similar rates. This suggests that nitrification occurred more rapidly in the former area, while denitrification was the faster process in the latter.

The value of the phosphate decreased gradually along the remaining stations due to detergents and decomposition of organic matter which is a general component of urban sewage may be the important source of reactive phosphate. The relative decrease of phosphate content in stations (III, V, VI, VII and VIII) may be attributed to several factors that lead to removal of phosphorus from the water, the consumption of phosphate by algae and aquatic plant phosphate adsorption on the clay mineral and suspended matter or precipitation by iron, calcium and aluminum.

The long-term observations of the nutritional conditions demonstrated wide variability in the spatial distribution in the bay, but the levels of all nutrient salts reflect high eutrophication. The markedly high nutrients reported during 1995 and 1996 (Soliman and Gharib, 1998; Gharib, 1998; Dorgham, 1997) reflect the large amount of nutrients reaching the bay through the discharged wastewaters, since the maximum values were reported in front of the land runoff. In contrast, the comparatively low concentrations during 2003- 2005 represented the amount of nutrients in area especially the locations far from entrance of El- Umoum Drain. It is clear that El- Mex Bay is characterized by great load of organic matter on the long-term scale. The phytoplankton demonstrated pronouncedly intensive growth in El- Mex Bay, maximizing the level of eutrophication condition, since the inter-annual records over the past three decades indicate

pronouncedly high chlorophyll- a concentration in the bay (Dorgham, 2011).

Chlorophyll- a is considered as essential component responsible for photosynthesis process. It was primary photosynthesis pigment in all oxygen evolving photo-synthetic plants. In the present study, we used chlorophyll-a concentration as an indicator of phytoplankton abundance and biomass in coastal waters. In the present study, the maximum chlorophyll- a concentrations was recorded at station (I) as 52.65 µg/l. The high concentration of Chl-a content recorded in the water coincided with low salinity, high temperature and high values of nutrient salts, which reflects such eutrophication condition caused by drainage effluents. These data agreed with that obtained by El-Sherif (2006) and Hendy (2013) where Chl-a ranged from 9.4 to 21.3 µg/l. Gharib (1998) observed that the phyto-plankton abundance and the number of species increased consistently towards the outer region of El-Mex Bay, where the salinity was high.

Conclusion and recommendations

El-Mex Bay is located under stress condition due to the discharge of untreated domestic, industrial and agricultural effluents, beside the effect of ships movements from and to the harbors. Therefore, the condition at this bay is eutrophic and completely different from the open sea water. These are expected to continue and add to climatic influence of increasing temperature and rising sea level in the future.

As a consequence of rapid population growth, industrial development, untreated or poorly treated industrial waste, domestic sewage, industrial waste and agricultural runoff have moved to and through Mariut Lake south of the city and then released into The sea. This lake has also received a large loading of agricultural runoff through canals and drains. El- Mex Bay is subjected to severe environmental conditions.

Some recommendations includes:

1. the control of the discharge of drainage and sewage water into El- Umoum Drain, Mariut Lake and El- Mex Bay.
2. Water quality will continue deteriorating due to salt water intrusion; soil transport is still in progress. Water treatment plants and sewage systems are necessary for soil conservation, archeological sites protection and upgrading of health conditions.
3. Unplanned urbanization without consideration for the needed infrastructure is still progressing. This may lead to increased risk of extreme events and water pollution. A strong institutional capability in monitoring and assessment is necessary for law enforcement.
4. Low income, shortage of awareness and high unemployment rates are the main driving forces leading to low water quality due to careless behavior of coastal

area inhabitants. Planned industrial and tourism development, building a Marina and revival of fishing industries may be possible relief for upgrading conditions.

5. Pollution recovery and restoration by offshore extension of sewage pipelines.

6. Coastal management for future projects at Alexandria requires an environmental impact assessment study (EIA). This has to be enforced by monitoring and law enforcement and upgrading of awareness.

7. Establishment of management information system that stores all previous information and data which will help in future development, management and restoration of the Alexandria coastal zone.

Conflict of interest

The authors did not declare any conflict of interest.

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Full Length Research Paper

The effects of heavy metals concentration on some commercial fish in Ogun River, Opeji, Ogun State, Nigeria

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A study was conducted on commercially important fish species of heavy metals in water bodies. The primary objectives were to find out the amount of heavy metals concentration in the fish species, sediments and water samples at the deep and shallow part of the river, to determine the toxicity and relationship between the collected samples and the rate at which it pollutes the water. Atomic absorption spectrophotometer (AAS) evaluates their wholesomeness for human consumption. Four heavy metals (lead, cadmium, copper and zinc) were analyzed and only copper and zinc were found to be present in the digested samples. The concentration of copper in the fish (flesh) was 0.09 mg/l and that of zinc was 0.25 mg/l. In the bone samples, copper was found to have 0.17 mg/l and zinc 0.22 mg/l. In the water samples analyzed, the concentration of copper is 0.035 mg/l while that of zinc is 0.047 mg/l. In the sediment sample, the amount of copper is 310.0 mg/kg while that of zinc is 2050.0 mg/kg. This however signifies that the fish species in the Ogun River as well as the water is suitable for consumption which was found to be less than the World Health Organization (WHO) maximum recommended acceptable limits in the food.

Key words: Heavy metals, fish species, water samples, toxicity.

INTRODUCTION

Metals are solids materials that are opaque, lustrous elements that are good conductors of heat and electricity. A study by Skeat (2005) showed that the heavy metals are members of a loosely defined subset of elements that exhibit metallic properties which include solubility in water, non- degradability and strongly attachment of polypeptides and protein. Over seventy five percent (75%) of everything on the planet Earth are directly or indirectly associated with metals. The recent activities of nature and that of human beings on most water bodies

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have led to a mass deposition of these minerals called metals.

Heavy metals occur naturally in the ecosystem with large variations in concentrations. Most metals in the streams and rivers come from industrial, municipal and urban run-offs which can be harmful to life (Tolcin, 2011). Increased urbanization of industrialization could be the cause for an increased level of trace metals, especially the heavy metals in our waterways (Njar and Al-Doush, 2012). The presence of toxic materials in ecosystems is presently related with increased concentrations of heavy metals ions, which enter water sources with sewage waters.

In recent years, world consumption of fish has increased simultaneously with the growing concern of their nutritional and therapeutic benefits. In addition to its important source of protein, fish typically have rich contents of essential minerals, vitamins and unsaturated fatty acids (Medeiros et al., 2012). The American Heart Association recommended eating fish at least twice per week in order to reach the daily intake of omega-3 fatty acids (Kris-Etherton et al., 2002).

However, fish are relatively situated at the top of the aquatic food chain; therefore, they can accumulate heavy metals from food, water and sediments (Yilmaz et al., 2007; Zhao et al., 2012). The content of toxic heavy metals in fish can counteract their beneficial effects; several adverse effects of heavy metals to human health have been known for long time (Castro-Gonzalez et al., 2008). This may include serious threats like renal failure, liver damage, cardiovascular diseases and even death (Al-Busaidi et al. 2011; Rahman et al., 2012). Therefore, many international monitoring programs have been established in order to assess the quality of fish for human consumption and to monitor the health of the aquatic ecosystem (Meche et al., 2010).

Heavy metals have various levels of toxicity as the surrounding environment affects it through certain factors. Even when it comes to fish, the toxicity of these heavy metals (lead, mercury, copper and zinc) plays certain roles that may even be hazardous. Sometimes, these heavy metals combine with soil organic matter and clay (WHO, 2007). As a result of drinking water and eating fish contaminated with heavy metals, diseases occur due to the bioaccumulation of these heavy metals in the body system of human being, thus leading to serious health problems and eventual death. Also, a lot of these metals are carcinogens and cannot be destroyed by heat.

Studies have been done to detect the presence of the heavy metal pollutants in water bodies in Nigeria (Olaifa et al., 2004; Omoregie et al., 2002; Oguzie, 2000). Ogun River with its tributaries is the main river that traverses the length and breadth of Opeji and Abeokuta metropolis in Ogun State where it serves as the source of domestic, agricultural and water consumption. It is the major source of freshwater fish for the inhabitants of Opeji, and is highly exploited by artisanal fishermen. It is also the final drain discharge for all waste-water from domestic and agricultural source within and around Opeji and environs.

The problem facing any living organisms will be related to measurable chemical or biological parameters such as a flow rate turbulence, inter and intra- specific competition, feeding behavior, disease, parasitism, commensalism and symbiosis. This work is evidence to ascertain the metallic concentration in most fish species at the River Ogun (Opeji). Some of these elements are actually necessary for humans in minutes or lower amounts (cobalt, copper, chromium, manganese, nickel) while others are carcinogenic or very toxic, affecting among others, the central nervous system (mercury, lead, cadmium, copper). In view of the strategic and important role of Ogun River to Opeji people and environs as a source of freshwater fisheries for the inhabitants, hence this study determine the amount of heavy metals (lead, cadmium, copper and zinc) concen-tration in the body parts of some commercial fish species, the water environment and the sediments (soil) samples of the River Ogun (Opeji village) and to evaluate the toxicity and relationship between the heavy metals concentration in the fish, water and sediments (soil).

MATERIALS AND METHODS

Description of the study area

Lower Ogun River is located in Abeokuta North Local Government of Ogun state. It lies between Longitude 3° 28′E to 3° 40′E and Latitude 7° 14′N to 7° 20′N of Abeokuta (Ogun State Bureau of Lands and Survey).

The study was carried out at lower Ogun River, Akomoje in Abeokuta, Ogun State. The river is located in Abeokuta North Local Government of Ogun State and lies between longitude 3°21'S and latitude 7°21'E North of Abeokuta with a size of 1000 hectares. Ogun River (Figure 1) as a perennial river in Nigeria has a coordinate of 3°28'E and 8°41'N from its source in Oyo State to 3°25'E and 6°35'N in Lagos State where it enters Lagos Lagoon. The dry season lasts from November to March while the wet season lasts from April to October. The annual rainfall ranges from 900 mm in the North of the River to 200 mm towards the South. Total annual potential evapotranspiration is 1600 and 190 mm. The Ogun River catchment is located in South West Nigeria, bordered geographically by latitude 6°26'N and 9°10'N and longitude 2°28'E and 4°4'E. The land is about 230 km^2. The relief is generally low, with the gradient in the North-south direction. The water source is from the Igaran hills at an elevation of about 540 m above the sea level and flows directly southward over a distance of 480 km before it discharge into the Lagos Lagoon. The major tributaries of the river are Ofiki and Opeki River.

Collection of samples

The study was carried out for 10 weeks between January and March 2011 by collecting water samples once in a month. The Fish samples and water parameters were determined according to APHA (1985) and Adeosun et al. (2011).

Fish samples were collected from Ogun River, Opeji village three times a week. The samples were collected for 10 weeks. Samples
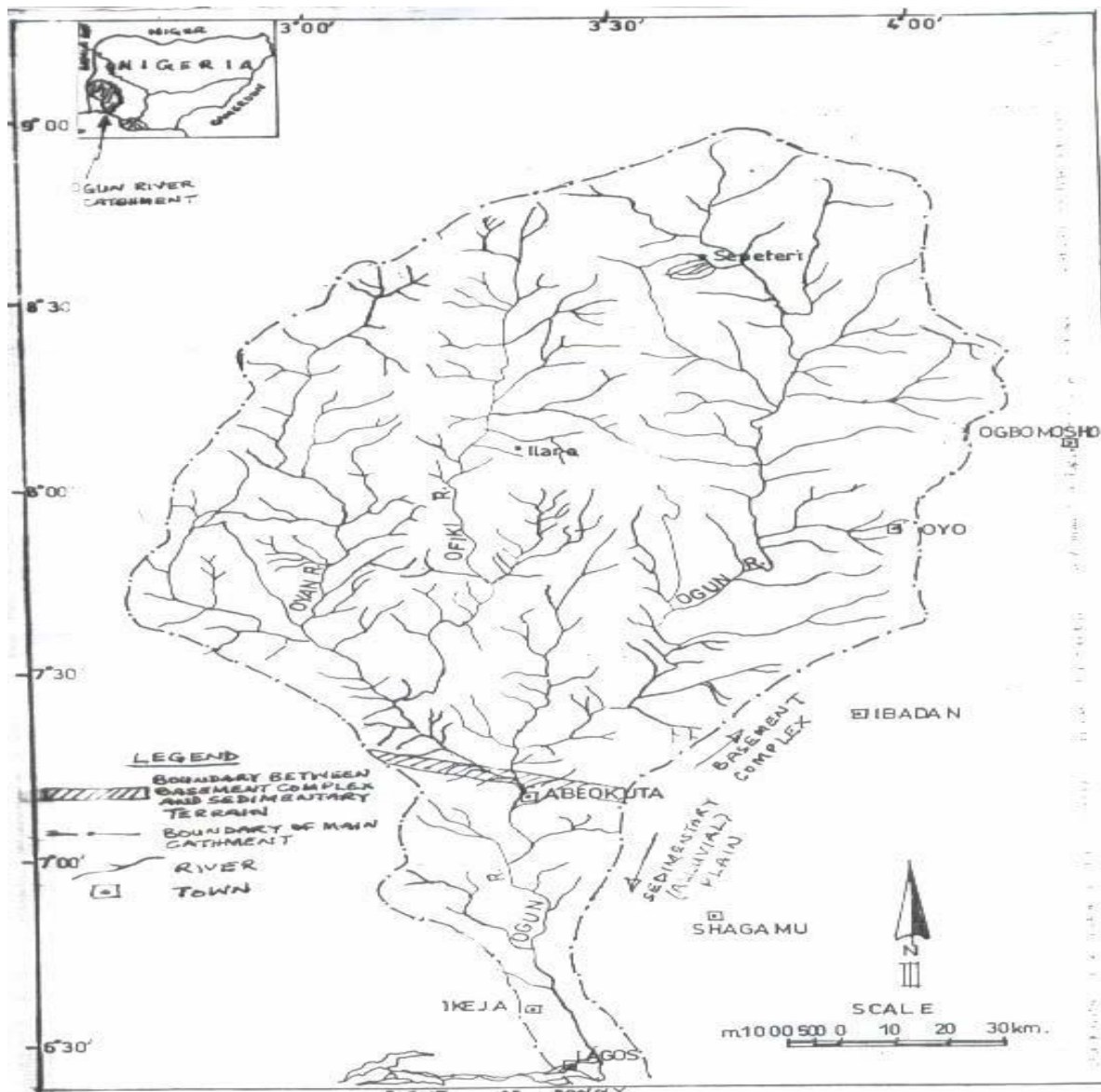
Figure 1. A map showing River Ogun.

of fish species were taken with the use of set gill nets and cast nets of three different mesh sizes of 1, 2 and 4 mm. Soil and water samples were collected from the deep and shallow parts of the water.

Ten (10) different fish species were harvested and brought to the laboratory and dissected with clean stainless steel instruments over a ten week period. One gram of each wet fresh tissue of fish, water sample and soil samples were weighed out and digested. The digests were allowed to cool, filtered, transferred to 100 ml volumetric flasks and made up to mark with 1% nitric acid (FAO, 1983). The digests were kept in plastic bottles and later, the heavy metal concentrations were determined using an atomic absorption spectrophotometer (AAS). This analysis were validated by diluting the salt solutions of the metals in various concentrations of 0.2, 0.4, 0.6, 0.8 and 1.0 ppm to enable the spectrophotometer to measure the metals from the samples of fish, water and soil. The following formula is used to calculate the concentration of heavy metals in the samples:

$$\mu/g = \frac{ppm \times v}{W \times 10^3}$$

Where ppm is mg/l (AAS reading), v is the volume of the digested sample and W is the weight of the sample used for digestion. The four different metals analyzed were lead (Pb), cadmium (Cd), copper (Cu) and zinc (Zn). The amounts of heavy metals concentration in the samples were then measured and recorded.

RESULTS

Table 1 shows that lead and cadmium are absent in the samples of fish while copper and zinc appear to be present in the flesh of the samples. From the result, it was observed that the average concentration of copper is

Table 1. Concentration of heavy metals in the flesh (tissue) of fish species.

Species	Pb (mg/l)	Cd (mg/l)	Cu (mg/l)	Zn (mg/l)
Hepsetus odoe	0.000	0.000	0.025	0.104
Chrysichthys nigrodigitatus	0.000	0.000	0.000	0.563
Tilapia mariae	0.000	0.000	0.020	0.145
Malapterurus electricus	0.000	0.000	0.069	0.340
Heterobranchus bidorsalis	0.000	0.000	0.054	0.203
Parachanna obscura	0.000	0.000	0.030	0.145
Tilapia zilli	0.000	0.000	0.045	0.202
Brycinus nurse	0.000	0.000	0.593	0.126
Heterotis niloticus	0.000	0.000	0.000	0.103
Oreochromis niloticus	0.000	0.000	0.015	0.520

Source: Field survey.

Table 2. Concentration of heavy metals in the bone of fish species.

Species	Pb (mg/l)	Cd (mg/l)	Cu (mg/l)	Zn (mg/l)
Hepsetus odoe	0.000	0.000	0.068	0.232
Chrysichthys nigrodigitatus	0.000	0.000	0.022	0.168
Tilapia mariae	0.000	0.000	0.058	0.271
Malapterurus electricus	0.000	0.000	0.058	0.100
Heterobranchus bidorsalis	0.000	0.000	0.031	0.249
Parachanna obscura	0.000	0.000	1.058	0.607
Tilapia zilli	0.000	0.000	0.054	0.213
Brycinus nurse	0.000	0.000	0.272	0.128
Heterotis niloticus	0.000	0.000	0.117	0.111
Oreochromis niloticus	0.000	0.000	0.000	0.129

Source: Field survey.

Table 3. Analysis of variance of heavy metals concentrations in the flesh and bone of the fish samples.

Source	Df	Sum of squares	Variance	F	F5%
Factors (flesh and bone)	1	0.336	0.336	7.23*	2.320
Treatment (metals)	3	2.960	0.987	21.44**	
Interaction (metals x factors)	3	2.624	0.875		
Residual (error)	57	1.973	0.035		
Total	64	7.893			

Lead (Pb) and cadmium (Cd) are absent because they were not observed.

found to be the highest in the flesh of *Brycinus nurse* amounting to 0.593 mg/l and is very minute or rather absent in the flesh of *Chrysichthys nigrodigitatus* while the average concentration of zinc was also found to be highest in the flesh of *Chrysichthys* spp. with an amount of 0.563 mg/l and lowest in the flesh of *Hepsetus odoe* containing about 0.104 mg/l.

In Table 2, lead and cadmium are absent as well while copper and zinc were observed to be present. The average concentration of copper is found to be highest in bone of *Parachanna obscura* with an amount of 1.058 mg/l and lowest or perhaps absent in the bone of *Oreochromis niloticus* while for zinc, it was observed to be highest in the bone of *P. obscura* having an amount of 0.607 mg/l and found to be lowest in the bone of *Malapterurus electricus* with an amount of 0.100 mg/l

Table 3 shows that at 50% significant level, it is clear that the interaction effect is significant. This effect was

Table 4. Distribution of average concentration of heavy metals in the flesh and bone of the fish species samples

	Flesh		Bone	
Treatment	Cu	Zn	Cu	Zn
Metals (mg/l)	0.09	0.25	0.17	0.22
95% CI	0.09±0.05	0.25 ± 0.05	0.17 ± 0.05	0.22 ± 0.05

95% CI means 95% confidence interval.

used to find out the average concentration of heavy metals in the fish samples (flesh and bone). From the analysis of the variance table, the independent effects of the factors and treatment are significant at the 5% level.

Table 4 shows that the average concentration of the metals in the flesh and bone of the ten fish species samples are 0.09, 0.25 and 0.17 and 0.22 mg/l, respectively. Also included are the confidence intervals of the average concentration of the metals in the flesh and bone of the fish samples.

DISCUSSION

The toxicity and accumulation of heavy metals in River Ogun (Opeji village) is very low and the villagers solely depend on it for their livelihood. The heavy metal concentration in the water body shows that it is within a safe limitation as it meets the recommended maximum acceptable limits of the World Health Organization (WHO, 2007).

The concentration of zinc was found to be the highest in the river followed by copper; this may be as a result of the fishing and agricultural activities and biological breakdown of rocks in the river (weathering). Based on the analysis ran on the concentration of heavy metals in the fish species, it should be a thing of note that the fishes at River Ogun (Opeji) are safe for consumption.

Due to the various activities such as dredging and clothes washing, the fish species in the River Ogun might go into extinction unless proper regulatory measures and action are taken by the state and federal government, the law makers of the country and IFSERAR (Institute of Food Security, Environmental Resources and Agricultural Research, FUNAAB) by passing out the information to the villagers, that their activities around the river can increase the concentration of heavy metals which can cause harmful effects on the fish species and the inhabitants when it exceeds the World Health Organization recommended maximum acceptable limits.

Conclusion

From the data presented, it can be concluded that the values of these heavy metals were found to be below the acceptable limit in fish food. However, these fish can be said to be wholesome for human consumption, there is need for caution as they have the potential to bio-concentrate some of these heavy metals in food chain over time.

Conflict of interest

The authors did not declare any conflict of interest.

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Full Length Research Paper

Trace metals in intertidal sediment of mangrove-sheltered creeks in Niger Delta, Nigeria: Variability before and after crude oil spillage

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Trace metals (Zn, Cu and Pb) fluxes were studied in five intertidal flats at Bodo Creek, Eastern Niger Delta, Nigeria in 2006, and re-evaluated in 2010 following two major oil spills that occurred in the creek. This study is the first to look at trace metal loads in the interstitial sediments of Bodo creek. Standard methods were employed in the sampling campaign and analysis. The concentration of all metals under study were higher than stipulated limit by WHO (2006) during post spill analysis. Concentration of Zn did not vary between stations and months pre-spill but did in post-spill, having values slightly higher than WHO (2006) stipulated limit. During the pre-spill sediment analysis, Pb concentrations ranged from no detection to 0.0012 mg/kg in 2006, increasing to 0.169 mg/kg post spill in 2010. Cu content ranged from 0.1312 - 0.1858 and 0.3374 - 0.4504 mg/kg pre- and post-spill, respectively. In addition to oil-induced metal loadings, the metals concentration dynamics show strong correlation with season. Metals had higher concentrations during the dry season due to reduced water volume in the creek and consequently less dilution. Implication for uptake, bioaccumulation and biotransformation by food species in the creek catchment above biosafety limits for user population is stressed and measures to avert public health consequences are advocated.

Key words: Trace metals, inter-tidal sediment, Niger Delta, oil pollution.

INTRODUCTION

The Niger Delta is the hub of oil and gas production in Nigeria. It is also Africa's largest wetland and the continent's mangrove dominant region. Oil pollution substantially degrades the delta network of alluvial swamps and lands, creeks and rivers. Apparently, there is no consensus on the number of oil spills and volume of oil spilling into the delta environment, as the operating companies and government of Nigeria keep conflicting data (Amnesty International, 2009). However, a recent report by UNEP (2011) put the annual average number of oil spills and volume spilled into the delta environment at 273 and 115,000 barrels, respectively, making the delta

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one of the most oil spill vulnerable areas in the world (Steiner, 2008).

The exploration and exploitation of oil interfere with ecological and biodiversity integrity of ecosystems arising from flaring of associated gases, oil spills, use of drilling chemicals, etc. These processes can release trace metals into coastal waters. Pollution studies have revealed elevated levels of zinc (Zn), copper (Cu), lead (Pb), chromium (Cr), nikel (Ni), cadmium (Cd) and vanadium (V) in Niger Delta sediments and some species of fauna, suggesting inputs from petroleum exploration and exploitation (Kakulu and Osibanjo, 1992; Horsfall and Spiff, 2002; Howard et al., 2006). The direct impact of petroleum exploitation on the environment was illustrated in a study where trace metal levels of the Warri River were assessed before and after dredging a canal leading to an oil well (Ohimain et al., 2008). They noted that percentage increase was several folds for lead, zinc, copper, iron, chromium, manganese and cadmium. Trace metals are associated with crude oil in variable con-centrations depending on the geologic background of the oil (Onojake and Okonkwo, 2011). For Nigeria's 'sweet' and dominant crude petroleum, Bonny Light, the associated metals occur in the order Ni>V>Cd>Cu>Pb (Osuji and Adesiyan, 2005). The concentration profile of trace metals (Zn, Cu and Pb) in soft-bottom sediments was assessed by the lead author as part of a 2-year (April 2006 to May 2008) baseline ecological survey of the 'Dor Nwezor' section of Bodo Creek. Information on other physico-chemistry, macrozoobenthos (tree, epifauna and infauna) of the study area (Dor Nwezor section of the creek) have been documented (Zabbey et al., 2010; Zabbey, 2012; Zabbey and Hart, 2011; Zabbey and Malaquias 2013). Shortly after the above study, 2 major crude oil spills hit Bodo creek from August 2008 to February 2009 from a Trans-Niger pipeline traversing the creek to Bonny export terminal (CEHRD, 2008; Amnesty International and CEHRD, 2011). Information on the spills and livelihood implication for the locals are reported by Pegg and Zabbey (2013). In this study, we compared the pre-spill and post spill concentrations of Zn, Cu and Pb in the intertidal flats to highlight changes in metal loads in time and space.

MATERIALS AND METHODS

Study area

Occupying approximately 9,230 ha, Bodo Creek is a network of brackish water creeks flanking Bodo community on the upper reaches of the Andoni-Bonny estuarine system in Rivers State, Nigeria (Pegg and Zabbey, 2013). Four major channels conduct saline waters in and out of Bodo Creek: Dor Nwezor, Kpador, Koola Tobsoi and Koola Seato. These major waterways are intercon-nected by myriad of feeder channels, some of which terminate blindly in mangrove swamps (Onwugbuta-Enyi et al., 2008). This study was conducted at a protected mangrove swamp (Sivibilagbara) and four open and unvegetated low inter-tidal flats along the Dor Nwezor channel of Bodo Creek; approximately bet-

ween latitude 04° 36' 29.7''N to 04° 35' 26.3''N and longitude 7° 15' 30.2''E to 7° 16' 50.9''E (Figure 1). Detailed information on some physico-chemical parameters in the creek had been documented (Onwugbuta-Enyi et al., 2008; Zabbey, 2012; Zabbey and Malaquias, 2013). Salinity of the creek interstitial water fluctuates between mesohaline (5 psu) and polyhaline (28 psu), while surface water values range from 6.2 - 22.7 psu. Surface and interstitial water temperature varied from 26.7 to 30.1 and 25 - 34°C, respectively.

Sampling locations

Station 1

This was the most upstream station and was located in the Sivibilagbara protected mangrove swamp (approximately latitude 4° 36' 29.7''N and longitude 7° 15' 30.2''E (Figure 1). The vegetation of Sivibilagbara was homogenously red mangrove (*Rhizophora racemosa*) with knitted structural architecture of prop roots and thick intertwined crowns. The swamp dimension is approximately 105 x 42 m (4,410 m^2). The sediment type was peaty clay (dominated by silt and clay) (Zabbey and Hart, 2014).

Station 2

This was located approximately 1,280 m downstream from station 1 (Figure 1) on an open, unvegetated tidal flat locally called Si Eeva. Facing downstream, the station lay to the left of Dor Nwezor main channel (latitude 4° 36' 12.7'' N and longitude 7° 16' 08.1'' E). The riparian vegetation of this station was mainly stunted red mangrove, and dwarf, aged and unproductive coconut trees at the edges of the supralittoral shores. The substratum was sandy mud.

Station 3

This was located approximately 956 m downstream from Station 2, on a right-flanked tidal platform. The station was sited opposite a sprawling fishing settlement called Kozo (lat. 4° 35' 55.3'' N and longitude 7° 16' 33.8'' E). The marginal vegetation was dominated by red mangrove (*R. racemosa*), with few stands of the white mangrove (*Avicennia germinas*) and mangrove sedge (*Paspalum vaginatum*) at the high intertidal zone. The date palm (*Phoenix reclinata*) and mango are amongst the mosaic admixture of plants at the supralittorial zone. The bottom was muddy sand.

Station 4

This was located 994 m downstream from station 3, having expansive unvegetated intertidal flat (latitude 4° 35' 32.4'' N and longitude 7°16' 56.6'' E). The sediment was sandy mud. Predominantly black mangrove and few stands of red mangrove and Nypa palm characterise the marginal vegetation.

Station 5

It is located on an expansive tidal mudflat (sandy mud) parallel to station 4. The marginal vegetation is dominantly black mangrove. The distance between stations 5 and 4 is approximately 256 and they are separated by the main creek channel. Station 5 was geo-located at latitude 4° 35' 26.3'' N and longitude 7° 16' 50.9'' E).

Field and laboratory procedures

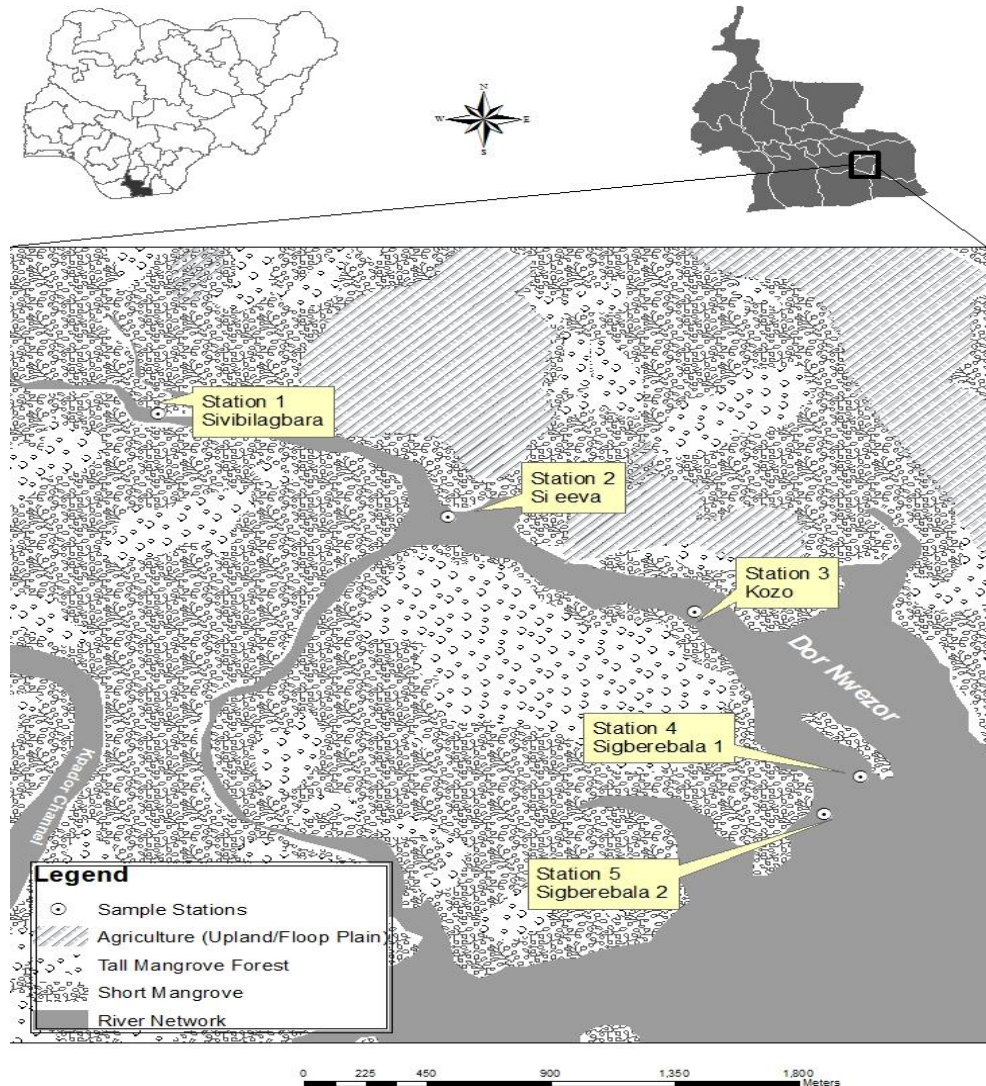Sediment samples were collected every month at low tide from 5

Figure 1. Map of Bodo creek in Rivers State, Nigeria.

intertidal flat locations along Dor Nwezor channels at Bodo Creek for 2 years (January – December 2006 and 2010), representing baseline and post spill respectively (Figure 1). Three replicate samples of the top 2 cm of sediment were collected with hand trowel and homogenised to form a composite sample per site during the sampling campaign. The sampling trowel was washed with the site water between replicates and with alcohol between stations (Chapman et al., 1996). The pooled sample of each location was covered in clean aluminium foil and transported in an ice-chest. In the laboratory, the sediment samples were analysed for Zn, Cu and Pb according to (APHA, 1995). Five grams of finely ground soil samples were weighed into 250 ml pyrex beakers and 10 ml of hydrogen peroxide (H_2O_2) added to it and allowed to warm for about 1 h during which most organic matter was destroyed. The content was transferred to savillex digestion bombs and concentrated hydrochloric (HCl) acid and nitric acid (HNO_3) were added in the ratio 5:10. The mixture was heated in a steam bath to a thick yellow liquid and the procedure repeated two times to get a clear solution indicating complete digestion of samples. Digested samples were cooled at room temperature, and filtered through a 0.45 μm membrane filter and diluted to 50 ml in volumetric flasks with double distilled water (Jin et al., 1999; Sastre et al., 2002). Following acid digestion, all samples were analyzed for the required metals (Zn, Pb and Cu) by flame atomic absorption spectrophotometer (Perkin Elmer Analyst AA 200 equipped with a high sensitivity nebulizer) calibrated by successive dilution of a 1000 mg/l multi - element instrument calibration standard solution.

All acid used were of analytical grade quality and control was assured by the use of procedural blanks and spikes. The spike recovery for each element was greater than 94%. All samples were run in triplicates and the relative standard deviation for the triplicate analysis was less than 10%. The instrument was calibrated with standard solutions prepared from Merck. The analytical blanks were run in the same way as the samples and concentrations were determined using standard solutions prepared in the same matrix. Doubled distilled water was used as solvent throughout the study. All glassware and other containers were thoroughly cleaned with 10% (w/v) nitric acid solution and finally rinsed with double distilled water several times and air dried prior to use. One-way analysis of variance (ANOVA) and Duncan's test (p=0.05) were used in order to assess whether trace metal concentrations varied significantly between sites and months.
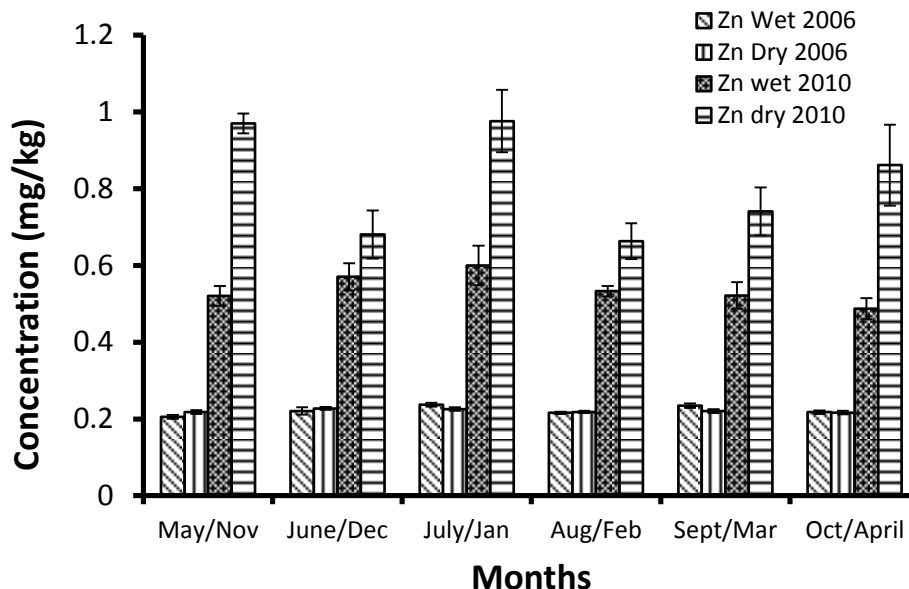
Figure 2. Mean monthly Zn concentrations in sediments of Bodo creek pre-spill and post spill (n = 5 for SE).

RESULTS AND DISCUSSION

Sediment characteristics at Station 1 had particles in the sand fraction (very coarse to fine sand) constituted 13% of the sediment, while clay represented 82.7%. The silt and clay proportions at Stations 2-5 ranged from 14.3 to 49.2%. Gravelly particles constituted 4 and 0.7% of sediments at Stations 1 and 5, respectively, whereas this class fraction was apparently lacking at Stations 2–4. The sand fraction ranged from 13.3% at Station 1 to 85.7% at Station 3. Particle size variation may influence trace metal loads at different stations studied. Silt and clay may retain and lock away metals preventing re-suspension while sand particles may readily release metals into solution during re-suspension. Generally, the levels of metal load in the present study may not be conclusive as low levels may simply mean more metal is locked away in silt and clay and not available during this survey. However, such contaminants may be re-suspended during dredging activities which are frequent at the study area.

The highest and lowest concentration values of Zn were recorded in the months of July and May (0.237 and 0.205 mg/kg, respectively) (Figure 2). The 2006 zinc monthly concentrations were not statistically different (P = 0.105; P >0.05). There was also no statistical variation in the concentration of Zn at all stations between the weighted averages of the wet and dry seasons in 2006 (P = 0.113) (Figure 5). Zinc concentrations were higher in 2010 than 2006 at all stations and in all the months at statistically significant levels (P = 0.0244) (Figure 5). This variation may have been due to the oil spill incidents in Bodo creek in 2008 and 2009 (Pegg and Zabbey, 2013).

Concentration of Zn at all stations in both years was also higher than stipulated limit (0.01 mg/kg) by WHO (2006). In 2010, Zn concentration values were highest and lowest in the months of January and October, respectively. Significant variation in contents were recorded between the wet and dry seasons in 2010 (P = 0.0227), with dry season values being higher at all stations (Figure 5). Seasonal variation may be attributed to less dilution of Zn in dry season leading to higher concentration and spatial variation may be due to varying impact from incidental inwelling sources at various stations. Lead concentrations did not vary significantly across the wet season months in 2006 (P = 0.222) ranging from below detection limit in August, September and October to 0.0012 mg/kg in May (Figure 3). During the wet season months in 2006, Pb was only detected at stations 2 and 3 in May, station 5 in June and stations 2, 3 and 4 in July. During the dry season months (November – April, 2006), Pd was detected only in November, March and April at all stations with the highest and lowest levels in March and April (0.0016 and 0.001 mg/kg), respectively. The concentration varied only numerically across the three months (P = 0.104; P > 0.05). Lead concentrations also did not vary significantly between the wet and dry seasons at all stations (P = 1.00). This result is similar to that reported for Pb (Onojake and Okonkwo, 2011) in surface and sub-surface soils in Bodo near the creek and lower than the limit of 0.01 mg/kg stipulated by WHO (2006). In 2010 however, Pb was detected at all stations and in all the months. Its concentration ranged between 0.074 mg/kg in October to 0.1206 mg/kg in July (wet season) and 0.066 to 0.169 mg/kg in March (dry season). The highest Pb concentration was recorded at station 2 in
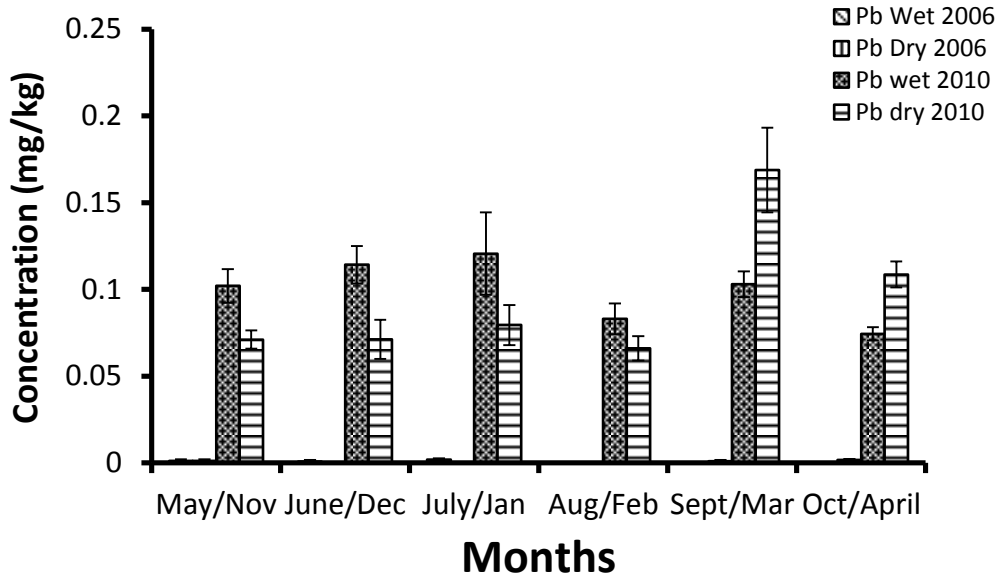
Figure 3. Mean monthly Pb concentrations in sediments of Bodo creek pre-spill and post spill sampling eras (n = 5 for SE).
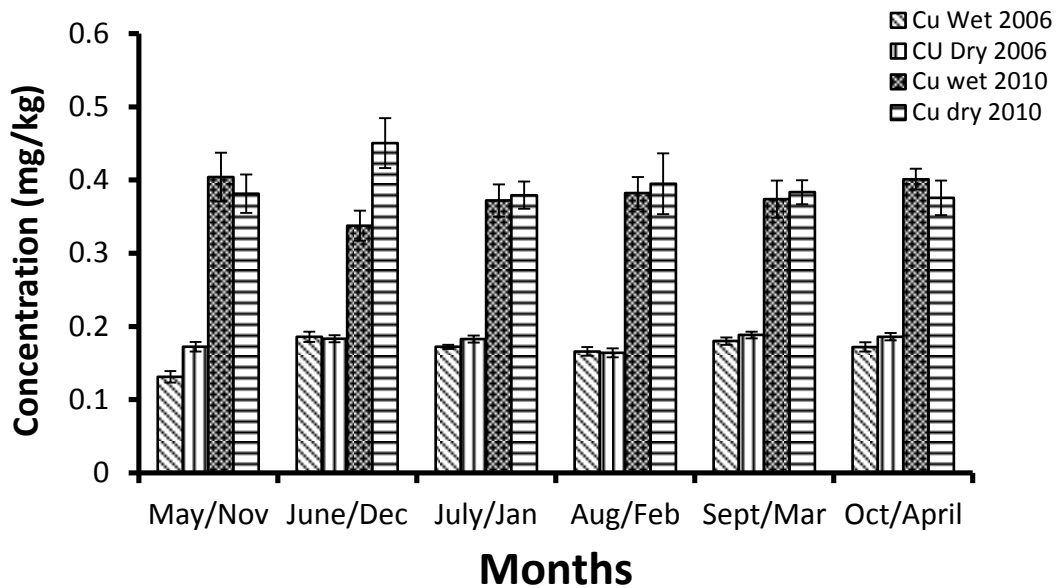

Figure 4. Mean monthly Cu concentrations in sediments of Bodo creek pre-spill and post spill sampling eras (n = 5 for SE).

wet season and station 1 in dry season in 2010 (Figure 6). Lead values varied significantly between wet and dry seasons in 2010 (P = 0.003). Lead values in 2010 were higher than those recorded in 2006 and higher than those reported by Onojake and Okonkwo (2011) and stipulated limit of 0.01 mg/kg by WHO (2006). This variation may have been due to the oil spill incidents in 2008 and 2009 (Pegg and Zabbey, 2013).

The concentration of Cu in all the stations investigated in 2006 ranged between 0.1312 and 0.1858 mg/kg with no statistical variation between the months (Figure 4). The highest and lowest values were recorded in March and May, respectively. There was no statistical variation in the concentration of Cu between the wet and dry seasons in 2006 (P =0.052). However, dry season recorded the highest value of Cu at station 2 while the
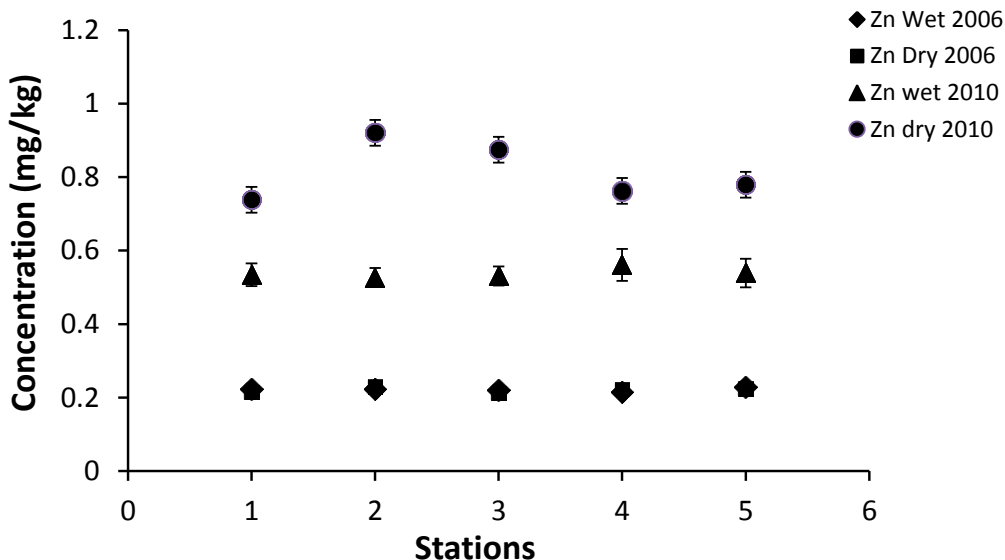
Figure 5. Mean Zn concentrations for wet and dry seasons in sediments of Bodo creek pre-spill and post-spill sampling eras (n = 5 for SE).
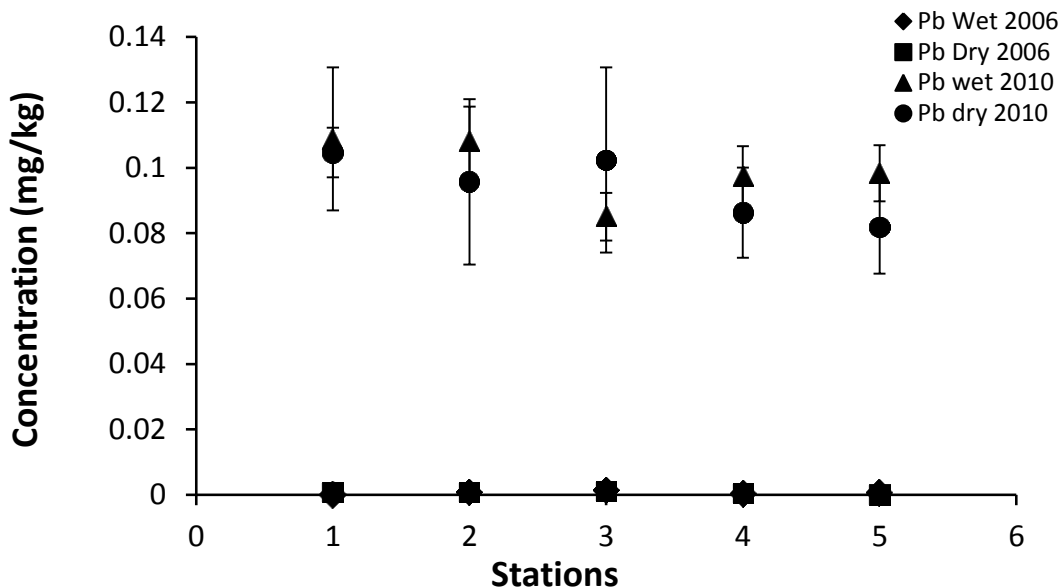

Figure 6. Mean Pb concentrations for wet and dry seasons in sediments of Bodo creek pre-spill and post-spill sampling eras (n = 5 for SE).

lowest value was recorded in wet season at station 3. In 2010, however, Cu concentrations ranged from 0.3374 mg/kg in June to 0.4504 mg/kg in December. Its concentration varied statistically between the wet and dry seasons (P = 0.001). The highest and lowest values were recorded at stations 5 and 1 in dry season and stations 3 and 2 in wet season, respectively; overall, dry season had higher values. Elevated concentration of metals in the dry season may be attributable to evaporation which

leaves behind less water and thus more concentrated solution-dilution in the wet season was as a result of increased volume of exogenous water. Cu values in 2010 were higher than those in 2006 at all stations in all the months (Figure 7), increment was possibly due to the oil spill contamination. However, Cu values were below stipulated limit of 2 mg/kg by WHO (2006).

Seasonal variations in the concentrations of the metals investigated may be due to the effect of dilution during
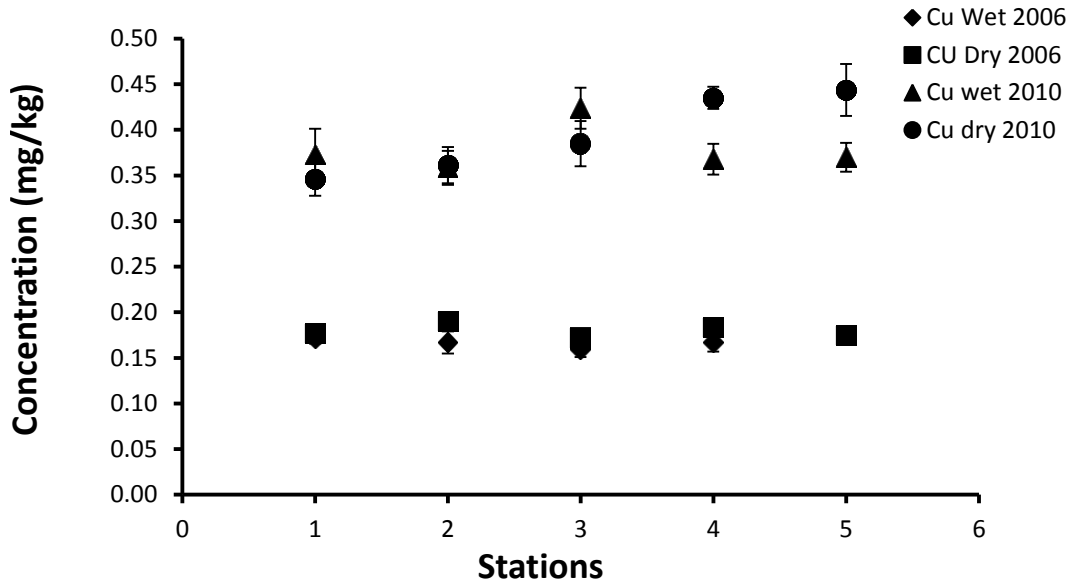
Figure 7. Mean of Cu concentrations for wet and dry seasons in sediments of Bodo creek pre-spill and post-spill sampling eras (n = 5 for SE).

the rains and evaporation during the dry season and this agrees with the report of Chindah et al. (2004). Spatial variation in trace metal load was not statistically significant (P>0.05), suggesting that common and anthropogenic sources contributed to the metal loading especially from the oil spills in Bodo creek in 2008 and 2009 (Pegg and Zabbey, 2013). Results of trace metals under study compares well with other reports on sediments in creeks and rivers in the Niger Delta that have been impacted by oil (Horsefall and Spiff, 2002; Obire et al., 2003; Chindah et al., 2004; Hart et al., 2005; Davies et al., 2006; Ubalua et al., 2007; Gideon and Chidiebere, 2008). However, some of the studies reported higher trace metal loads in similar oil contaminated environment in the Niger Delta, even much higher in organisms analysed for the same environment suggesting bioaccumulation of these metals (Chindah et al., 2004). In a similarly polluted river system in the Niger Delta, Horsefall and Spiff (2002) reported trace metal load in sediment and biota of the New Calabar river to be higher than those in the present study.

Conclusions

Results of trace metals compared between 2006 (pre-spill) and 2010 (post-spill) showed clearly that metal loads increased significantly after the oil spills in Bodo creek in 2008 and 2009. The present result shows that there are possibilities of high human exposure to trace metals in study area given that inhabitants of the study area consume biota from the studied creek. Further studies on trace metals in biota, particularly food species, and assessment of bioaccumulation factors are imperative to determine human exposure to trace metal loads detected in the present study following major oil spills. Some aquatic organisms have been reported to have capacity to concentrate trace metals such as Fe, Cu, Zn up to 10^5 times the concentration present in the water, making potential human health hazards associated with the consumption of contaminated sea food 20 to 40 times higher than the ingestion of contaminated water (WHO, 2011). Health effects of these trace metals (Pb, Zn and Cu) in humans have been demonstrated in acute toxicity, neurotoxicity and nephrotoxicity (Katz and Salem, 1993; ATSDR, 2000; Stift et al., 2000). Pb in particular is a confirmed carcinogen (Martin and Griswold, 2009; WHO, 2011).

Conflict of interests

The authors did not declare any conflict of interest.

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