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African Journal of Environmental Science and Technology

ARTICLES

Review

Land degradation in Northern Nigeria: The impacts and implications of human-related and climatic factors

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Northern Nigeria despite its promising agricultural potential, is currently not enjoying economic bloom like its Southern counterpart as a result of political, religious, ethnic and socio-economic factors. The degradation of land and its resulting impact on other agricultural resources may have further exacerbated the economic and social conditions of the region. The perceived encroachment of Nigeria's Savannah into its rainforest zone indicated possible land degradation. Some authors attributed this degradation to anthropogenic sources whilst others reported climatic variability (which is nature-driven) as the singular culprit. Therefore, this study reviews the impacts and implications of both human-related and climatic factors on land degradation in Northern Nigeria. Human-related activities such as agricultural/pastoral expansion, agricultural intensification and fuel-wood extraction as well as climatic/physical factors such as rainfall variability and land-atmosphere feedback mechanisms were suggested by various authors as agents of land degradation in Northern Nigeria. The remediation strategies to reduce the impacts of anthropogenic factors include the practice of agroforestry, rainwater harvesting, local irrigation techniques, utilization of wetter sites, contour ridging and terracing to conserve nutrient and water run-off, cautionary expansion of cultivated sites, and the maintenance of a viable seed stock well-suited to variable climatic conditions. The recommendations made on the resulting conflict between crop farmers and pastoralists include a federal government-assisted water project to build more waterpoints at strategic areas in the region and the practice of agropastoralism. However, the controversy over the cause of land degradation in Africa has led to a number of research questions itemised in this paper on the main cause of land degradation, the elements of climate inducing the dryness and wetness of the region, and the extent of land recovery when wet seasons return.

Key words: Land degradation, impacts and implications, human-related factors, climatic factors, northern Nigeria,

INTRODUCTION

Nigeria, a West African country located in the tropical zone of the world has a land area of about 923,769 km^2 with the Northern region covering about 79% of the entire land mass (FOS, 1989; Salako, 2003; Aregheore, 2005). The country comprises about five broad ecological zones: Swamp forest, Tropical rainforest, Guinea Savannah,

Sudan Savannah and Sahel (Okpara et al., 2013). Of the five zones, Northern region is made up of three: Guinea Savannah, Sudan Savannah and the Sahel. Northern Nigeria is composed of 19 of the country's 36 states. It is inhabited by over 50% of the country's 167 million people (Pate and Dauda, 2013) sparsely distributed across 79% of the country's total land mass. It is home to over two-third of the country's 250 ethnic groups (Pate and Dauda, 2013).

According to Cleaver and Shreiber (1994), the surface area of Nigeria is about 91.07 million hectares and 57% of this land surface is suggested to be used for crops and pasture production (commonly practiced in Northern Nigeria) whilst the remaining 43% is divided amongst forests, water bodies and other uses such as construction and human settlements (Aregheore, 2005). Iortim (2012) also reported that agriculture contributes about 42% of the country's GDP and the Northern part of the country is responsible for most of these; yet the region is suffering from both economic and infrastructural deficiency as indicted by the country's Human Development Index (UNDP, 2010).

There are six geo-political zones in Nigeria: the South-South, South-West, South-East, North Central, North-West and North-East. Of the six geopolitical zones in Nigeria, the most developed in the North, is the North Central, possessing economically-viable cities like Kano (the centre for commerce in the North) and Abuja (the Federal Capital Territory) whilst other northern geo-political zones appear to be economically less-attractive. The north-west and north-east, according to the 2012 National Bureau of Statistics (NBS) data, have the highest poverty rates of about 77.7 and 76.3% respectively (UNESCO, 2010); and alarming illiteracy levels of about 86% each in the country (UNESCO, 2010). The North also has the least annual per capita income, below the national average of twenty thousand naira (approximately $127). The industrial deficiency in the North has increased the unemployment levels and youth restiveness in the region (Pate and Dauda, 2013). The region thus, experiences more violence than other parts of the country as a result of the poor management of its diverse resources (Pate and Dauda, 2013). The violence could manifest in the form of religious, ethnic, economic, political or value-based crisis, which makes the region "increasingly stigmatised as a theatre of violent clashes and as a parasite that cannot survive without monthly federal allocations" (Pate and Dauda, 2013). As a result of the socio-economic structure of the region, most families practice subsistent farming and/or nomadic, pastoralism for economic sustenance.

Northern Nigeria (as one advances north-ward) is characterised by low rainfall and drought-like conditions (Xue and Shukla, 1993). Despite the perceived harsh weather conditions of this region, many plant species such as *Acacia* species, baobab tree, mango, orange and *Moringa* species, with soils suitable for the production of crops such as cereals (millet, rice, corn, sorghum and maize) and legumes (soybeans and cowpea) inhabit the area. The vast 'fertile' land of this region has the potential for agricultural revolution, however, most farming practices are not mechanised (Pate and Dauda, 2013) probably because the states in the north are not economically-fit to commercialise agriculture.

Human activities such as agricultural expansion/-intensification, pastoralism and fuel-wood extraction, and climatic/physical factors such as rainfall variability and land-atmospehere feedbacks have been reported by many authors to have a significant impact on land degradation. Therefore, this study intends to review the impact of the aforementioned human-related and climatic factors on land quality in northern Nigeria, including the underlying implications and possible misconceptions and debates. The knowledge would improve the understanding of how land and other agricultural resources can be properly managed so that the potential of the region to lead the 'green revolution' crusade in the country can be actualised.

HUMAN-RELATED IMPACTS AND IMPLICATIONS ON LAND DEGRADATION IN NORTHERN NIGERIA

According to the WRI (1992) and Barbier (1999), land degradation and conversion in Africa is mostly caused by agricultural activities. Land uses such as tree felling for fuel-wood and timber production, crop and pastoral land expansion and agricultural intensification have been suggested to be part of the causes of land degradation in Africa (including Nigeria). The possible loss of natural vegetation cover due to changes in land use, influenced by man, could expose the soil surface and render it vulnerable to the elements of weather such as rain and wind. Lanly (1982) and Skoupy (1987) reported that for the past 30 years, changes in human activities have resulted in the continuing loss of vegetation cover and soil fertility in West Africa. Land use change has been suggested to impact the northern ecosystems of the country over the years leading to a perceived creeping of the savannah into the tropical rain forest zone (Badejo, 1998). Changes in crop and livestock production methods and increasing demand for forest products (such as fuel-wood and timber) will accelerate the rate of land degradation which if not checked, would have a negative implication on food and livestock quality and yield.

The total annual rainfall in the ecological zones of Northern Nigeria is lowest in the Sahel and increases southward. This variation in rainfall distribution greatly affects the soil type and biodiversity in each ecological zone in the country. The Northern region is also characterised by high intensity solar radiation in the area (Hekstra, 1985). Evapo-transpiration is therefore, higher in the Northern part of the country than in the South. Despite the increased temperature and decreased precipitation in Northern Nigeria, many vegetation species (generalists with a broad ecological niche) have

Table 1. The soil types in the ecological zones of Nigeria.

Ecological zone	Major soil types (FAO classification)
Humid forest	Ferralsols, nitosols and gleysols.
Derived savannah	Ferralsols, luvisols, lithosols, arenosols, nitosols and acrisols.
Guinea savannah	Luvisols, acrisols, ferrasols and lithosols.
Sudan savannah	Luvisols, ferrasols.
Sahel	Ferralsols and nitosols

Source: Salako (2003).

been found to survive and thrive in the area as a result of their resilience and ability to grow on a variety of soil types. In spite of the low precipitation in the Northern region, the soil types mostly iron-rich (Table 1) are well-suited for crop production under the right application of fertiliser and soil management practices.

About 80% of the inhabitants of the Northern region are involved in crop production, pastoral farming and nomadic pastoralism (Schaefer, 1998). These agricultural activities require the use of land, which if not managed properly may lead to the over-exploitation of the natural resource and consequently, degradation. Barbier (2000) reported that many poor pastoralists and farmers in Africa (including Nigeria) often respond to declining land fertility by moving on to a new piece of land for cultivation and grazing. There are cases when farmers and pastoralists will seek new lands for the purpose of expansion and not as a result of declining soil fertility. This practice is known as agricultural/pastoral land expansion.

Agricultural expansion takes place when uncultivated or unused lands are utilized for crop production. The aggressive acquisition of unused or virgin lands could mean the indiscriminate destruction of forest lands. Therefore, land fallowing is suggested by some authors as a means of reducing the incessant need by farmers and pastoralists to occupy virgin lands. Taylor et al. (2002) reported that if used land is abandoned for a period of 20 years, the land will replenish itself. However, farmers in the North have started reducing the fallow periods of used lands due to the rising demand on food crops in order to meet natural population growth and this may affect crop quality and production rate over time. For example, the reduction of fallow period from 6 to 2 years led to a decline in cassava yield from 11 to 2 tonnes/ha whilst maize yield reduced from 3 to 0.7 tonnes/ha in sub-Saharan Africa (Sanginga et al., 1995). Honlonkou (1999) suggested the use of inorganic fertilisers to restore degraded farmlands, although noted that it might be too expensive for farmers in Northern Nigeria to afford. However, Mortimore and Adam (2001) discouraged the incessant application of chemical fertilisers for environmental and health reasons whilst Tiffen et al. (1994) suggested that the local farmers be encouraged to maximize agricultural output using the resources at their disposal.

Both agricultural and pastoral land expansion may lead to severe conflicts between farmers and pastoralists in Northern Nigeria. This is because two or more interdependent resource users, in this case, between crop farmers and pastoralists, are very likely to have a clash over common environmental resources such as land, pasture, crop-residue, livestock routes and water-points (Ime, 2013). Farm encroachment, that is, crop damage caused by animal belonging to herdsmen as a result of cattle routes or waterpoints on farmlands (Gefu and Gills, 1990) and even the straying of livestock into the grazing land of other pastoralists are possible sources of conflict (Traore, 1996). For example, Amzat (2013) reported the violent clashes between the Fulani herdsmen and the Berom natives of Jos in Plateau State, Northern Nigeria. Pastoralists engage in seasonal rotation; migrating to southern Nigeria (which is usually moist) during the dry season in search of pasture and waterpoints, and returning to their major base in the north during the wet season (Shettima and Tar, 2008). This means that a possible face-off with pastoralists is not confined to the North as cases of bloody clashes have been recorded in southern states such as Enugu, Osun and Delta (Amzat, 2013).

The Nigerian Senate discussed a bill in 2012 seeking for the establishment of a National Grazing Reserves Commission, which will possess the authority to cease or/and acquire land that will serve as grazing reserves and routes for herdsmen in any part of the country. However, the majority of the senators expressed their dissatisfaction with the bill, pointing out that it negates the Land Use Act and the concept of federalism. It was then decided that the matter be handled by the State House of Assembly in each of the 36 states of the country (Odebode et al., 2012). Currently, the matter is yet to be addressed by the State House of Assemblies.

Taylor et al. (2002) measured the percentage land use of areas in Northern Nigeria using the Sahelian Land use Model (SALU) and selecting three reperesentative years (1961, 1996 and 2015) which span through a 54 year period (Table 2). The result indicated a continuous decrease in the percentage of forest areas but showed a continuous increase in the percentages of land area used for pasture and cropland. This inverse relationship suggests the direct impact of agricultural/cropland

Table 2. The percentage land use of areas in Northern Nigeria using the SALU for 1961, 1996 and 2015.

Land	1961	1996	2015
Forest	72	40	35
Pasture	14	16	17
Cropland	5	14	22
Fallow	9	16	15
Unused	0	13	11

Source: Taylor et al. (2002).

expansion (and probably fuel-wood demand) on forest resources which may likely have grave environmental/climatic consequences over time. Forest components such as trees act as nutrient pumps in ecosystems (Kang, 1993); provide shade; and preserve the little soil water available in the case of a low rainfall.

Trees also make the soil less-susceptible to erosion. Therefore, the roles of forest resources in the presservation of land quality cannot be overemphasized. However, Mortimore and Adams (2001) presented a contrasting idea that indigenous intensification has the potential to promote the stability of high densities of multi-purpose trees on farmlands. They considered agricultural expansion into virgin forested land as an adaptive strategy of the local farmers and pastoralists to climate variation.

In the Sahel and Savannah, nutrient deficiency due to the absence of vegetation cover poses a more serious threat to crop/pastoral productivity than insufficient water supply (Badejo, 1998). An study by Bremen and De wit (1983) revealed that the problem of insufficient soil nutrients in the Sahel and Savannah is a serious limitation to crop productivity as compared to low rainfall. The application of fertiliser in the right proportion was observed to promote vegetation growth in the area. They also added that water is the limiting resource in the desert but in the semi-arid ecosystems (such as the Sahel and Savannahs found in northern Nigeria), nutrient is a more limiting resource. The need to increase fertiliser inputs has led to agricultural intensification.

Agricultural intensification refers to the application of very high amounts of fertilisers, pesticides and other agricultural products, even including labour inputs, with the sole aim of maximizing crop production. Krogh (1997) reported that agricultural intensification may improve soil performance in sites intensely cultivated, however, there may be a net loss of soil fertility and quality in the surrounding extensive land areas. A better approach of restoring soil fertility is to combine nutrient amendments with fertiliser application. Pieri (1989) reported that the use of fertilisers alone has often, in the long run, had negative impacts on soil productivity. The choice of nutrient amendment depends on soil organic matter, phosphorus availability and the pH of the soil (Breman et al., 2001).

Agricultural intensification may increase crop produc-tion to a break-even point where incessant nutrient addi-tions will have little or no impact on soil quality and fertility. This is because the soils in Northern Nigeria gene-rally comprise coarse-textured aggregates which bind loosely and therefore do not retain sufficient water and nutrients. This implies that even in the midst of sufficient nutrients, if the soil physical condition is not managed, soil productivity might still be low. Therefore, the addition of organic matter like animal dungs or crop residues may be required to safe-guard nutrient or water run-off/-leaching, thereby, restoring the soil's fertility and quality. According to Batterbury and Warren (2001) agricultural intensi-fication is an improvised means by which local farmers cope with the changing climatic conditions of the region as successfully practised in Northern Nigeria (precisely Kano), but stated that the underlying challenges can be managed effectively by adopting an environmentally-healthy indigenous land restoration methods such as rainwater harvesting, local irrigation techniques, utilization of wetter sites, contour ridging and terracing to conserve nutrient and water run-off, cau-tionary expansion of cultivated sites, and the main-tenance of a viable seed stock well-suited to variable climatic conditions.

CLIMATIC FACTORS INFLUENCING LAND DEGRADATION IN NORTHERN NIGERIA

A study in 1998 by Badejo (1998) showed that the savannah is creeping into the rainforest in Nigeria. Similarly, a study by Nobre et al. (1991) predicted that climate change due to deforestation may cause tropical savannahs to creep into tropical rainforests stretching 500 to 1000 km into the zone whilst the savannah will in turn be encroached by the sahara. Many authors termed this 'southward creep' as desertification.

Desertification has been identified to be one of the processes that degrades land, however, there has been an unending debate about the use of the concept to describe the environmental changes occurring in the African terrain. The process of desertification was described by the UN as human-induced with climatic factors increasing susceptibility (Nicholson, 2001). One of the definitions of desertification is 'the expansion of desert-like conditions and landscapes to areas where they should not occur climatically' (Graetz, 1991). The UN later modified their definition to 'land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variations and human activities' (Puigdefabregas, 1995; Warren, 1996). The concept of the 'advancement of the desert' was first proposed by Lamprey (1975) using maps of 1950s and aerial surveys of 1975. He concluded that between 1958 and 1975, the Sahara desert had advanced southward into Western Sudan by 90 to 100 km (a desert expansion of about 5.5 km per year). Similarly, in 1983, Skoupy

(1987) reported that about 4.125 million km^2 of land area in Africa's Savannah was affected by desertification. However, in 1984, a field study by Hellden (1984) at the same location found no proof to support Lamprey's claims.

A 10 year study by Tucker et al. (1991) from 1980 to 1990 using satellite-derived vegetation index to determine the annual variations in rainfall and the rate of expansion or retraction of the Saharan-Sahelian boundary, found that there was a progressive decrease in rainfall between 1980 and 1984. However, a steady improvement in rainfall was observed between 1985 and 1990, which led to the restoration of the native vegetation of the Saharan-Sahelian boundary. This variation in rainfall was found to determine the direction of movement of the boundary. Between 1980 and 1984 (during the drought), there was an overall southward movement of the Saharan-Sahelian boundary (the expansion of the desert) whilst between 1985 and 1990 (during the wet season), there was an overall northward movement of the boundary (the retreat of the desert). This study revealed that the average estimation of the overall direction of movement for the 10 year study period was southward (130 km) but most importantly, it should be noted that the movement is not progressive but fluctuating based on rainfall patterns in the region. This discovery rendered the desertification estimates problematic because Lamprey and Skoupy did not put into consideration the rainfall decline of about 50% that occurred during the period of assessment (Nicholson, 1990). Thus, while 'desertification' itself was defined as anthropogenic, evidence shows that such land degradations could have been a product of climatic variability.

In a similar vein, a group of scientists from the University of Lund, Sweden, carried out studies in Sudan in 2001 and revealed through a combination of satellite images and field work that there was neither a systematic advancement of the desert or other vegetation zones, nor a reduction or disappearance of vegetation cover, although the replacement of forage with woody species was observed which indicated declining soil quality (Nicholson, 2001). They reported no evidence of widespread removal of vegetation cover in the villages. However, the study revealed that vegetation changes was as a result of drought and noted that there was a full recovery of the land as soon as the drought ended. Therefore, the researchers added that the perceived 'advances of the desert' was as a result of fluctuations in rainfall pattern in the Sahelian region with no large-scale reduction or disappearance of biological entities in the region (Prince et al., 1998) which is in support of Tucker et al (1991) propositions. In other words, it might be technically wrong to refer to the environmental changes in the Sahelian as a product of desertification since these changes are not irreversible neither do they lead to the sterility of land. A better term could be 'land degradation' which explains the replacement of diverse and nutrient-

rich plant species by vegetation of poorer quality (Nicholson, 2001) due to reduced soil quality caused by drought.

Many studies (Bonan et al., 1992; Xue and Shukla, 1993; Zhang et al., 1996) have shown that the climate is altered when deforestation (mostly caused by human activities) occurs, due to land-atmosphere feedbacks. Charney (1975) and Garratt (1993) reported that rainfall over a semi-arid region may be affected if there is a change in the surface albedo (the reflectivity of solar radiation). Charney (1975) argued that bare soils have a higher albedo than vegetation surfaces, therefore, a decline in rainfall following increased deforestation is a possibility. This is because an increase in albedo can reduce the heat flux within the troposphere (atmosphere closest to the Earth's surface) thereby, weakening convection mechanisms and limiting cloud formation and precipitation (Hoffmann and Jackson, 2000). As a result, an increase in albedo may promote a positive feedback mechanism leading to a drier environment, unable to sustain natural vegetation recovery and may conesquently cause prolonged drought (Wang and Eltahir, 2000). Similarly, Woodward (1987), Zeng et al. (1999) and Taylor et al. (2002) reported that land-atmosphere interactions may cause inter-decadal climate variability in the semi-arid regions of the world.

Zheng and Eltahir (1997) reported that the West African monsoon which fed rain to the Sahel regions of Africa is sensitive to vegetation removal. They added that changes in land use such as the overgrazing, agricultural expansion and increased fuel-wood extraction may collectively alter the behaviour of the West African monsoon over time. Clark et al. (2001) pointed out that the climate in semi-arid regions is very sensitive to land degradation whilst Nicholson et al. (1998) referred to the region as the most "ecologically unstable" in the world. The ecological instability of the Sahel and Savannah regions was explained by Zeng and Neelin (2000) who revealed that these "grassland ecosystems" try to smoothen out the large climatic variability between the desert and the rainforest, thus creating a state of unsteadiness in-between. Nevertheless, human population in the region is doubling every 20 years which has caused a proportional increase in demand for agroforestry resources (Taylor et al., 2002), therefore an accelerated loss of vegetation cover from anthropogenic sources may increase the albedo of the area, thus exacerbate climatic conditions. However, Taylor et al. (2002) argued that rainfall conditions have been generally poor since the 1960s and this would have caused the loss of vegetation cover by biophysical feedbacks even without changes in land use which are not large enough to cause the persistently low rainfall observed in the region over the decades. Taylor et al. (2002) argument may not hold water because it was reported that there was persistent drought between the 1950s and 1970s (Nicholson, 2001) but rainfall improved in the late 1980s

(Tucker et al., 1991) restoring the native vegetation of the region. Therefore, there should not be a progressive loss of vegetation as a result of a temporary drought that occurred many decades ago.

CONCLUSION AND RECOMMENDATIONS

This study reviewed the human-related and climatic factors inducing land degradation in northern Nigeria. Some authors believe that the human-related activities such as agricultural/pastoral expansion and agricultural intensification are localised adaptation measures by the natives of northern Nigeria in response to the changing climatic condition of the area, an idea referred to as the 'optimists view'. Others believe that the so-called adaptation measures are further destroying the integrity of the ecosystem, an idea referred to as the 'pessimists view' (Batterbury and Warren, 2001). Various studies in literature show that neither the optimists view nor the pessimists view can be totally discarded. Only when the uncertainties in the arguments presented by both parties are well-clarified with supporting evidences, will a common ground be found.

Conflicts between pastoralists and crop farmers may be reduced by the siting of more boreholes or waterpoints in the region by granting Northern states experiencing such crisis, a special federal-supported water project fund as a result of the political structure of the country and the financial limitations of most Northern states. Ime (2013) recommended 'agro-pastoralism' (a form of farming that combines the growing of crops with the rearing of livestock) as a way of managing pasture lands more effectively, thereby, reducing pastoral expansion and face-off with crop farmers.

Owing to the various debates on the cause of land degradation in Africa, it would be imperative for further studies to be carried out. The following controversial questions are to be further researched for the purpose of clarity of knowledge and a better understanding of land degradation in Nigeria and West Africa:

1. Is the perceived creeping of the Savannah in Nigeria, a result of either climatic variations which could be reversed during better weather conditions or human-related activities which some authors claimed are insufficient to cause large-scale land degradation?
2. It has been suggested that the African Monsoon and the InterTropical Convergence Zone (ITCZ) may be responsibile for the rainfall variablility in West Africa (Nicholson, 2001), therefore, what are the elements in these meteorological entities forcing the dryness and wetness of the region?
3. What is the extent of land recovery (whether total or partial) of the West African region each time rain is restored?

It is important for the inter-decadal measurement of the current Savannah-Rainforest boundary as well as the current Saharan-Sahelian boundary to be carried out as this would help project a possible expansion or retreat of Nigeria's Savannah. The proper management of land and its resources including the full understanding of the climatic forces at work, may go a long way to help Northern Nigeria reach its full potential as a pace-setter for agricultural revolution in the country. The State Governments in Northern states are advised to utilize the potentials in agriculture as a reliable route to economic emancipation.

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Full Length Research Paper

The comparative insecticidal and residual efficacy of sniper and alpha cypermethrin in the control of *Blattella germanica* (L.) (Dictyoptera: Blattellidae) infestation

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Blattella germanica (German cockroach) is an urban insect pest in Nigeria due to an increase in strains that are resistant to the commonly used insecticides. The purpose of this study was to determine which of the insecticides used by pest control professionals are still effective. The insecticidal efficacies of dichlorvos (organophosphate-called sniper[©]) and alpha cypermethrin (a pyrethroid called alpha action [©]) were determined in laboratory bioassays against *B. germanica*. Efficacy and response were affected by application rate of insecticide and exposure period. Insecticides mixed with diesel were more effective than those mixed with water. Insects exposed to the insecticides in closed chambers gave higher mortalities than insects in open chambers. *B. germanica* was more susceptible to dichlorvos than to alphacypermethrin in both open and closed chambers. Mortality of *B. germanica* increased with increase in concentration of the insecticide used. Sniper mixed in diesel was fastest acting insecticide against *B. germanica* where 100% mortality was observed 5 min post exposure in closed and opened chambers. Both insecticides gave 100% mortality of all insects exposed within 4 h of the exposure period. Sniper mixed with diesel had the LT_{95} of 10 min while sniper mixed in water was 17 and 23 min, respectively in closed and opened chambers. The LT_{95} of alphacypermethrin (5% (v/v)) mixed with diesel and water in closed chambers were 10 and 125 min, respectively. The residual effect of sniper and alphacypermethrin was less than one week.

Key words: Resistance, commercial insecticide, susceptibility.

INTRODUCTION

German cockroaches live in close association with people. They are tropical in origin but in the temperate zone most species live in parts of house and other building where warmth, moisture and food are adequate. They usually live in groups and are mostly active at night. In the daytime they hide in cracks and crevices in walls, door frames, and furniture, and in secure places in bath-rooms, cupboards, steam tunnels, animal houses, base-ment, television, radio and other electronic devices, drains and sewer systems. If the light is turned on in an infested kitchen at night the cockroaches will run from dishes, utensil, working surface and the floor toward shelters (Rivault et al., 1993).

German cockroaches eat all food used for human

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consumption. They however prefer starchy and sugary materials. They sip milk and nibble at cheese, meats, pastry, grain product, sugar and sweet chocolate. They also feed on cardboard, book binding, ceiling boards containing starch, the sized inner lining of shoe sole, their own cast skin, dead and crippled cockroaches, fresh and dried blood, excrement, sputum, fingernails and toenails of babies and sleeping or sick persons (Rauh et al., 2002). More importantly, roaches are sometimes implicated as disease vectors, as carriers of intestinal diseases, such as diarrhea, dysentery, typhoid fever and cholera (Appel and Tucker, 1986; Gradcolas, 1996).

The females unlike most other cockroaches carry ootheca that protrude from their abdomen until the eggs are ready to hatch or may hatch from ootheca while female still carries it (often in rear cases). The ootheca is then dropped in a secluded location, where the nymphs emerge within 24 h. A female may produce four to eight cases during her lifetime, each containing 30 to 48 eggs. Eggs hatch in about one month and nymph develop in 1 to 4 months. Adult females live for about six to seven months and males live slightly less. The German cockroach produce more eggs and has more generation per year (three to four) than other cockroaches thus troublesome infestation can develop from a few individuals (Rust et al., 1995).

Chemical control is still the main approach for urban pest control (Castle et al., 1999; Rozendaal, 1997; Marrs, 1993; Lee and Yap, 2003; Tidwell et al., 1994). The use of insecticides is seen as the most effective tool in cockroach control program (WHO, 1996; Chavasse and Yap, 1997; Lee and Yap, 2003; Tidwell et al., 1994). The major insecticides used against cock-roaches in Nigerian households include pyrethroids (alpha cypermethrin) and organophosphates (dichlorvos).

Resistance has been reported amongst cockroaches to various groups of insecticides such as organophos-phates, carbamates and synthetic pyrethroids, when applied directly, as residual spray and or in topical application (Diaz et al., 1994; WHO, 1996, Wei et al., 2001). With the increase in the number of German cockroach resistance to insecticides lately, there is a need to re-evaluate/ re-ascertain the insecticides that are being used so as to know those that have become less effective or the efficacious ones, in order to sustain the control of this deleterious organism.

This study therefore seeks to investigate the comparative insecticidal and residual efficacies of sniper and alpha cypermethrin against *B. germanica* in laboratory during fumigation (closed) or disinfestation (opened) exercises.

MATERIALS AND METHODS

All the experiments were carried out at the laboratory of the Department of Zoology, University of Lagos, Nigeria. Temperature and relative humidity measurements were recorded daily using the Thermo-Hygro Analog Yenaco.

Insect collection

A number of German cockroaches identified at insectary of the department, were collected from some old cupboards in some hostels in New Hall Area of the University of Lagos. The cupboards have been locked for over four months. Several male and female nymphs and adults, including female carrying ootheca were found in the cupboards.

Insect culture

These insects were carefully removed, kept in vials and taken to the Zoological laboratory and transferred to another plastic vial measuring 25 cm in length and 17 cm in width. A wire gauze and net were used to cover the plastic vials. The cover and body of the vials were strapped together using rubber band to prevent escape or cross infestation of the cockroaches. The cockroaches were fed with bread, and the slices of bread were changed three times a week. The drinking water placed in each container was also renewed weekly. The culture was kept in the laboratory for over six months, until the roaches in each vial were more than hundred. Each vial contains nymphs, adult males and females.

Insecticides used

The insecticides used were alpha cypermethrin and dichlorvos called sniper by SaroAgroSciences

Experimental design

Four experimental groups (two groups and two formulations) were included in the design. The first two groups contained filter paper treated with diesel formulation of sniper and alpha cypermethrin while the other two groups contained filter paper treated with water formulation of sniper and alpha cypermethrin. Each group was exposed to closed environment (fumigation) and opened environment (disinfestation). There were two controls (treatment with water and diesel), that were each run parallel to the treatments. The controls consisted of filter papers treated with water and diesel for both closed and opened environments

Toxicity test

All life stages of German cockroach except the first, second nymphal stages and the gravid females were used for the toxicity tests. Sniper and alpha cypermethrin insecticide formulation were used in accordance to the instruction on the labels. Four concentrations 2.5% (v/v) and 5% (v/v) of water; and 2.5% (v/v) 2.5% (v/v) and 5% (v/v) of diesel were used. Each formulation was sprayed on filter paper to run off. Excess liquid was drained off. Thereafter ten (10) German cockroaches were confined into each jar.

The upper surfaces of the jar were lightly greased with petroleum jelly to prevent escape of the insects. Control jars had only water sprayed on the filter paper. Each treatment was replicated three times. Cockroaches' knockdown or mortality was recorded at 5, 10, 15, 20, 30 min to the 4th h after spraying. The number of cockroaches dead and alive was counted and noted. The cockroaches were removed from the jar and kept in the freezer for 30 min and thereafter discarded. The jars containing treated and untreated filter papers were kept aside on laboratory bench and used in subsequent experiments.

Table 1. Cockroach mortality upon exposure to water (control) in filter paper in open and closed chambers.

	Treatment	Time									
Percentage mortality (%)		5 min	10 min	15 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
	Open	0	0	0	0	0	0	0	0	0	0
	Closed	0	0	0	0	0	0	0	0	0	0

Number of insects per replicate was 10 and each experiment was replicated three times.

Table 2. Cockroach mortality upon exposure to diesel (control) soaked in filter paper in open and closed chambers.

	Treatment	Time									
Percentage mortality (%)		5 min	10 min	15 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
	Open	0	0	0	0	10	13	13	27	27	37
	Closed	0	0	0	10	10	20	20	27	43	43

Number of insects per replicate was 10 and each experiment was replicated three times.

Quantal response

On assumption of death, the German cockroach is pricked with the strands of hair from a camel hair brush to ascertain death. Responses of cockroaches were noted and the parameters considered include time of knock down and mortality rate per minute

Residual effect of the insecitides

The jars used in the experiments above containing treated filter paper were used for the residual test on weekly bases for two weeks, 10 cockroaches were confined to each jar and mortality and or knockdown noted as in toxicity test above.

Statistical analysis

Statistical analysis of the results was also done after the results have been ascertained and its corresponding mean and standard deviation were recorded against time. This was done using the equations:

Mean, $\bar{x} = \Sigma FX / \Sigma F$

Standard deviation $= \sqrt{\Sigma(x - \bar{x})}/n - 1$

The lethal time value (LT_{50}) and the regression slope for each treatment were obtained using probit analysis (SPSS 2000). Mean percentage of insect mortality value was subjected to arcsine transformation followed by comparison of mean using LSD test.

RESULTS

Mortality of *B. germanica* exposed to diesel and water

No insects died throughout the period of the experiment when exposed to water in both the closed and opened chambers (Table 1). No mortality was recorded in the insects exposed to diesel until after 20 and 30 min in closed (Io) and opened (Ic) chambers respectively with the highest mortality (43%) recorded in closed (I$_o$) chambers (Table 2).

Mortality in Insects exposed to sniper and alphacypermethrin mixed with water

Mortality of *B, germanica* increased with increase in concentration of the insecticide used. It was higher in closed than in opened chambers and higher in insecticide mixed with diesel than in water. Mortality of *B. germanica* was recorded from 5 min in the insects exposed to both 2.5% (v/v) and 5% (v/v) of aqueous sniper in both opened (Io) and closed (Ic) chambers. All insects placed in aqueous sniper (5% (v/v)) died within 20 min while 100% mortality was recorded in all concentration used in the closed and opened chambers within one hour (Table 3). On the other hand, no mortality was recorded until after 20 min (6 and 33%) in *B. germanica* exposed to 2.5% (v/v) and 5% (v/v) of aqueous alpha cypermethrin respectively. 100% mortality was recorded after 4 h of exposure in both open (Io) and closed (Ic) chambers (Table 4).

Mortality in insects exposed to sniper and alphacypermethrin mixed with diesel

100% mortality was recorded in less than 5 min in the insects exposed to sniper mixed with diesel in both concentrations (2.5% (v/v) and 5% (v/v)) used and in both open (Io) and closed (Ic) chambers (Table 5) On the

Table 3. Cockroach mortality upon exposure to sniper (mixed with water) in filter paper in an open(Lo) and closed (Lc) chambers.

Treatment	Time									
	5 min	10 min	15 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
2.5% (v/v) L_O (I)	27	27	50	70	93	100	-	-	-	-
2.5% (v/v) L_C (II)	13	27	33	37	73	86	100	-	-	-
5% (v/v) L_O (I)	40	70	76	96	100					
5% (v/v) L_C (II)	56	66	96	100	-	-	-	-	-	-

Number of insects per replicate was 10 and Each experiment was replicated three times.

Table 4. Cockroach mortality upon exposure to alpha cypermethrin (mixed with water) in filter paper in an open(Lo) and closed (Lc) chambers.

Treatment	Time									
	5 min	10 min	15 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
2.5% (v/v) L_O (I)	0	0	0	6	6	16	53	90	96	100
2.5% (v/v) L_C (II)	0	0	0	33	33	40	70	60	60	67
5% (v/v) L_O (I)	0	0	0	26	33	33	56	83	93	100
5% (v/v) L_C (II)	0	0	0	33	40	43	63	90	90	100

Number of insects per replicate was 10 and each experiment was replicated three times.

Table 5. Cockroach mortality upon exposure to sniper(mixed with Diesel) in filter paper in an open(Lo) and closed (Lc) chambers.

Treatment	Time									
	2 min	5 min	8 min	10 min	20 min	30 min	45 min	1 h	2 h	3 h
2.5% (v/v) L_O (I)	100	-	-	-	-	-	-	-	-	-
2.5% (v/v) L_C (II)	100	-	-	-	-	-	-	-	-	-
5% (v/v) L_O (I)	100	-	-	-	-	-	-	-	-	-
5% (v/v) L_C (II)	100	-	-	-	-	-	-	-	-	-

Number of insects per replicate was 10 and each experiment was replicated three times.

Table 6. Cockroach mortality upon exposure to alpha cypermethrin (mixed with diesel) in filter paper in an open (Lo) and closed (Lc) chambers.

Treatment	Time									
	2 min	5 min	10 min	15 min	30 min	45 min	1 h	2 h	3 h	4 h
2.5% (v/v) L_O (I)	56	100	-	-	-	-	-	-	-	-
2.5% (v/v) L_C (II)	46	93	100	-	-	-	-	-	-	-
5% (v/v) L_O (I)	40	93	100	-	-	-	-	-	-	-
5% (v/v) L_C (II)	46	100	-	-	-	-	-	-	-	-

Number of insects per replicate was 10 and each experiment was replicated three times.

other hand, 100% mortality was recorded after 10 min in insects exposed to Alpha cypermethrin mixed with diesel in both open and closed chambers (Table 6).

Residual effect of sniper and alpha cypermethrin on *B germanica* at *one week after treatment*

At one week after treatment 5% (v/v) of sniper mixed with

water gave 10 and 50% mortality of *B. germanica* at 15 min and 4 h respectively of exposure in the closed chambers (Table 7) while sniper diluted with diesel gave 26 and 46% mortality respectively in closed and opened chambers under the same conditions (Table 8). On the other hand under same concentrations, 0 and 23% mortality respectively of *B. germanica* was recorded for Alphacypermethrin mixed in water (Table 9) and 16 and 40% mortality recorded for Alphacypermethrin mixed in

Table 7. Residual effect of sniper (mixed with water) in filter paper on cockroach morality in an open(Lo) and closed (Lc) chambers (after one week).

	Treatment	Time									
		5 min	10 min	15 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
Percentage mortality (%)	2.5% (v/v)L$_O$ (I)	0	0	0	23	23	30	33	33	37	37
	2.5% (v/v)L$_C$ (II)	0	0	23	26	26	33	40	40	46	46
	5% (v/v)L$_O$ (I)	0	0	3	6	36	43	43	43	50	50
	5% (v/v)L$_C$ (II)	0	0	10	13	26	33	40	40	50	50

Number of insects per replicate was 10 and each experiment was replicated three times.

Table 8. Residual effect of sniper (mixed with diesel) in filter paper on cockroach morality in an open (Lo) and closed (Lc) chambers (after one week).

	Treatment	Time									
		2 min	5 min	10 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
Percentage mortality (%)	2.5% (v/v)L$_O$ (I)	0	10	16	16	20	23	26	26	26	26
	2.5% (v/v)L$_C$ (II)	0	13	16	16	16	30	36	36	36	36
	5% (v/v)L$_O$ (I)	0	16	23	23	26	33	43	43	43	43
	5% (v/v)L$_C$ (II)	0	20	26	26	30	36	46	46	46	46

Number of insects per replicate was 10 and each experiment was replicated three times.

Table 9. Residual effect of alpha cypermethrin (mixed with water in filter paper) on cockroach morality in an open (Lo) and closed (Lc) chambers (after one week).

	Treatment	Time									
		5 min	10 min	15 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
Percentage mortality (%)	2.5% (v/v)L$_O$ (I)	0	0	0	0	0	13	13	16	20	20
	2.5% (v/v)L$_C$ (II)	0	0	0	0	0	13	16	16	20	20
	5% (v/v)L$_O$ (I)	0	0	0	0	0	3	10	16	16	16
	5% (v/v)L$_C$ (II)	0	0	0	0	0	20	20	23	23	23

Number of insects per replicate was 10 and each experiment was replicated three times.

Table 10. Residual effect of alpha cypermethrin (mixed with diesel in filter paper) on cockroach morality in an open (Lo) and closed (Lc) chambers (After one week).

	Treatment	Time									
		2 min	5 min	10 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
Percentage mortality (%)	2.5% (v/v)L$_O$ (I)	0	0	0	6	10	10	16	26	26	26
	2.5% (v/v)L$_C$ (II)	0	0	0	13	13	13	23	30	30	30
	5% (v/v)L$_O$ (I)	0	0	0	6	10	23	23	33	33	33
	5% (v/v)L$_C$ (II)	0	0	0	16	16	26	26	40	40	40

Number of insects per replicate was 10 and Each experiment was replicated three times.

diesel (Table 10).

Residual effect of sniper and alpha cypermethrin on *B germanica* at *two weeks after treatment*

No mortality was recorded at two weeks of treatment until after 3 and 4 h in *B. germanica* exposed to sniper mixed with diesel and water respectively and the highest mortality of 16 and 10% were recorded after 4 h with 5% (v/v) sniper in closed chambers (Tables 11 and 12). Same trend of 3 and 4 h after exposure was found in *B. germanica* exposed to alphacypermethrin mixed with diesel and water. Highest mortality of 20% was recorded

Table 11. Residual Effect of sniper (mixed with water in filter paper) on cockroach morality in an open(Lo) and closed (Lc) chambers (After two weeks).

	Treatment	Time									
		5 min	10 min	15 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
Percentage mortality (%)	7.5ML/300ML $_O$ (I)	0	0	0	0	0	0	0	0	0	3
	7.5ML/30OML$_C$ (II)	0	0	0	0	0	0	0	0	0	3
	5% (v/v)L$_O$ (I)	0	0	0	0	0	0	0	0	0	3
	5% (v/v)L$_C$ (II)	0	0	0	0	0	0	0	0	0	10

Number of insects per replicate was 10 and each experiment was replicated three times.

Table 12. Residual effect of sniper (mixed with diesel in filter paper) on cockroach morality in an open(Lo) and closed (Lc) chambers (after two weeks).

	Treatment	Time									
		2 min	5 min	10 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
Percentage mortality (%)	2.5% (v/v)L $_O$ (I)	0	0	0	0	0	0	0	0	6	6
	2.5% (v/v)L$_C$ (II)	0	0	0	0	0	0	0	0	10	10
	5% (v/v)L$_O$ (I)	0	0	0	0	0	0	0	0	13	13
	5% (v/v)L$_C$ (II)	0	0	0	0	0	0	0	0	16	16

Number of insects per replicate was 10 and each experiment was replicated three times.

Table 13. Residual effect of alpha cypermethrin (mixed with water in filter paper) on cockroach morality in an open (Lo) and closed (Lc) chambers (after two weeks).

	Treatment	Time									
		5 min	10 min	15 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
Percentage mortality (%)	2.5% (v/v)L $_O$ (I)	0	0	0	0	0	0	0	0	0	0
	2.5% (v/v)L$_C$ (II)	0	0	0	0	0	0	0	0	0	3
	5% (v/v)L$_O$ (I)	0	0	0	0	0	0	0	0	0	3
	5% (v/v)L$_C$ (II)	0	0	0	0	0	0	0	0	0	6

Number of insects per replicate was 10 and each experiment was replicated three times.

Table 14. Residual effect of alpha cypermethrin (mixed with diesel in filter paper) on cockroach morality in an open(Lo) and closed (Lc) Chambers (After two week).

	Treatment	Time									
		2 min	5 min	10 min	20 min	30 min	45 min	1 h	2 h	3 h	4 h
Percentage mortality (%)	2.5% (v/v)L $_O$ (I)	0	0	0	0	0	0	0	0	6	6
	2.5% (v/v)L$_C$ (II)	0	0	0	0	0	0	0	0	13	13
	5% (v/v)L$_O$ (I)	0	0	0	0	0	0	0	0	16	16
	5% (v/v)L$_C$ (II)	0	0	0	0	0	0	0	0	20	20

Number of insects per replicate was 10 and each experiment was replicated three times.

after 4 h in 5% (v/v) alphacypermethrin in closed chambers (Tables 13 and 14).

Lethal time of sniper to *B. germanica*

Table 15 shows the LT_5, LT_{50} and LT_{95} of 2.5% (v/v) and 5% (v/v) of sniper mixed in diesel and water. LT decreases

with increase in the concentration of sniper. The LT_5 and LT_{50} could not be calculated because 95% mortality of *B. germanica* was recorded within 10 min of the experiment. Sniper mixed with diesel had the LT_{95} of 10 min in both closed and opened chambers while with sniper mixed in water was 17 and 23 min respectively in closed and opened chambers.

Table 15. Lethal time of sniper to mortality of *B. germanica.*

Lethal time (min)	Aqueous sniper				Sniper and diesel			
	2.5% (v/v)		5% (v/v)		2.5% (v/v)		5% (v/v)	
	I_O	I_C	I_O	I_C	I_O	I_C	I_O	I_C
LT_5 (min)	8	6	2	2	-	-	-	-
LT_{50} (min	**12**	**18**	**7**	**5**	**-**	**-**	**-**	**-**
LT_{95} (min)	45	72	23	17	10	10	10	10

Number of insects per replicate was 10 and each experiment was replicated three times

Table 16. Lethal time of alpha cypermethrin to mortality of *B. germanica.*

Lethal time	Aqueous alpha-cypermethrine				Alpha-cypermethrine mixed with diesel			
	2.5% (v/v)		5% (v/v)		2.5% (v/v)		5% (v/v)	
	I_O	I_C	I_O	I_C	I_O	I_C	I_O	I_C
LT_5(minutes)	25	12	13	11	2	-	3	-
LT_{50}(minutes)	62	40	44	30	5	-	6	-
LT_{95}(minutes)	183	175	161	124	10	10	10	10

Number of insects per replicate was 10 and each experiment was replicated three times

Lethal time of alphacypermetrin to *B. germanica*

Table 16 shows the LT_5, LT_{50} and LT_{95} of 2.5% (v/v) and 5% (v/v) of alpha cypermethrin mixed in diesel and water. LT also decreases as concentration of alphacypermethrin increases. The LT_5 and LT_{50} is unknown for alpha-cypermethrin and diesel solution in both 2.5% (v/v) and 15 ml/300 ml in closed (Ic) chambers because 95 mortality was recorded within 10 min. The LT_{95} of 5% (v/v) of Alphacypermethrin mixed with diesel and water closed chambers were 10 and 125 min respectively (Table 16).

Percentage mortality after four hours of exposure

At the onset of the experiment, both insecticides gave 100% mortality of all insects exposed within 4 h of the exposure period. However, the efficacy decreased with increase in residual time that by the second week after treatment, 17 and 20% mortality of *B. germanica* were recorded in sniper and alphacypermethrin respectively mixed in diesel in the closed chambers (Table 17).

DISCUSSION

For effective pest control of the German cockroach, closed (fumigation environment) and mixing the insecticide with diesel rather than water is being suggested. This is because *B. germanica* mortality was higher and time of death faster in closed chambers than in open

chambers. Moreover, mixing each of the two insecticides with diesel gave better results than mixing with water.

The study revealed the effectiveness of two groups of insecticides, sniper (organophosphate) and alpha-cypermethrin (Pyrethroid) in the control of German cockroaches. Label-recommended doses of sniper and alphacypermethrin (5% v/v), were effective by having 100% mortality after four hours of exposure to *B. germanica*.

However, the 100% mortality recorded in 2 min in the insects exposed to sniper (Table 5) mixed with diesel in both concentrations used (2.5% (v/v) and 5% (v/v)) and in both open (Io) and closed(Ic) chambers suggest sniper to be more effective in controlling *B. germanica* than alphacypermethrin that had 100% mortality in 10 min under the same conditions (Table 6). Lots of studies have shown that cockroaches show high level of resistance to pyrethroid compared to organophosphates (Wei et al., 2001; Cochran, 1995).

This is not the case in this situation as both insecticides were able to control *B. germanica* in less than 10 min when mixed in diesel and less than 20 min and 4 h when sniper and alphacypermethrin respectively were mixed with water. This experiment conforms with that by Agrawal et al., (2005) who found that propoxur (an organophosphate) was more effective in controlling the German cockroach, *B. Germanica,* than deltametrin (a pyrethroid).

This study also showed that efficacy and time of response were affected by time of application of insecticide and time of exposure of insects after treatment. The insecticides (sniper and alpha- cypermethrin) were more

Table 17. Percentage mortality of *B. germanica* after four hours of exposure.

Parameter	Period	2.5% (v/v)		5% (v/v)	
		I_O	I_C	I_O	I_C
Diesel	Control	36	43		
Water	Control	0	0		
Sniper/water	Initial	100	100	100	100
	One week after treatment	37	47	50	50
	Two weeks after treatment	3	3	3	10
Sniper/diesel	Initial	100	100	100	100
	One week after treatment	37	40	43	53
	Two weeks after treatment	7	10	13	17
Alpha cypermethrine/water	Initial	100	100	100	100
	One week after treatment	20	20	13	23
	Two weeks after treatment	0	3	3	7
Alpha cypermathrine/diesel	Initial	100	100	100	100
	One week after treatment	27	30	33	40
	Two weeks after treatment	7	13	17	20

Number of insects per replicate was 10 and each experiment was replicated three times

effective when the insects were exposed immediately after application of insecticides as compared to when they were exposed one and two weeks after application. Thus the residual effect of sniper and alphacypermethrin can be said to be less than one week.

B. germanica collected from several places at one geographical location, University of Lagos, Nigeria with a total area of 8194.93 m^2 (consisting of both wet and dry land) showed high susceptibility to sniper and alpha-cypermethrin. There is a need for more research to be carried out to ascertain its susceptibility on these insecticides in other geographical locations in Lagos State, Nigeria.

Conclusion

From this study, closed chambers (fumigation) are more effective than open (disinfestation) exercise. In a situation where fumigation exercise is to take place, an environment that is well enclosed should be ensured as much as possible so as to have an effective and thorough pest control exercise. Sniper and alphacypermethrin were found to be effective in the control of *B. germanica*. Sniper however, was more effective than alpha cypermethrin. Four hours of no- entry after pest control exercise is recommended for fumigation exercise using sniper. However, an additional hour may be added if alphacypermethrin mixed with water is used. Diesel was found to increase the efficacy and can be a preferred choice over water in fumigation (closed) and disin-festation (opened) exercises. However caution should be

exercised in the use of diesel as diluents due to its volatile nature and resultant toxic effect on the environment.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Full Length Research Paper

Variations in abiotic conditions of water quality of River Osun, Osun State, Nigeria

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Seasonal variations in physicochemical properties of the surface water of River Osun in Osogbo, Nigeria, were investigated from May to August 2012 and November to February, 2012/2013. The water body of the mentioned river received water and wastes from the other effluences. Physicochemical parameters were determined in triplicate at three different points of the river, across the two seasons of the year. The points were named AR, BR and CR, for the rainy season and AD, BD and CD for the dry season. Samples taken from May to August represents the rainy season in the year 2012, while that of November to February 2012/2013 represents the dry season analysis. Standard methods were used in carrying out the experiments. Parameters values were gotten by the mean calculated from the triplicate determination of each sampling point. The average result determined revealed pH level of 5.87 and 6.63 for rainy and dry seasons, respectively; 137.00 and 101.33 μscm^{-1} for conductivity, 90.50 and 21.06 mg/L for total alkalinity, 2.53 and 1.77 mg/L for biochemical oxygen demand (BOD), dissolve oxygen (DO) of 3.17 and 3.97 mg/L, chloride of 10.47 and 8.20 mg/L, total hardness of 4.13 and 2.73 mg/L, chemical oxygen demand (COD) of 3.58 and 2.81, mg/L, total dissolved solids (TDS) of 62.53 and 35.43 mg/L, total suspended solid (TSS) of 25.40 and 9.30 mg/L, nitrate-nitrogen of 1.72 and 3.87 mg/L, nitrite-nitrogen of 0.23 and 0.23 mg/L and ammonia nitrogen 0.35 and 0.31 mg/L, respectively for the months of May and August 2012 and November and February 2012/2013. Heavy metal concentration were also analyzed for iron (Fe) which gave the value of 0.001 and 0.0027 mg/L, copper (Cu) 0.0010 and 0.0013. mg/L, 0.0020 mg/L and 0.002mg/L for zinc (zn) and 0.0023 and 0.0013 mg/L for nickel, all represents the two seasons, respectively. The parameters determined revealed that in most point of the river, rainy season exhibit higher values than the dry season. This could be as a result of the effluence flowing into the river body with more loads during the rainy season as compared to the dry season.

Key word: Seasonal variations, River Osun, water, physico-chemical.

INTRODUCTION

The quality and quantity of surface water in a river basin is influenced by natural factors such as rainfall, temperature, weathering of rocks and anthropogenic changes that curtail natural flow of the river, or alter its

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hydrochemistry (Raj and Azeez, 2009).

Water quality is influenced by natural factors and human activities both of which are subject to hydrologic study (Isirimah, 2000). Industrial activities and organization in developing country including Nigeria have gradually led to the deterioration and contamination of natural environment (Agbozu and Ekweozor, 2001). Also, advancement in technology as well as increase in population has led to environment concern relative to indiscriminate dumping of refuse and discharge of industrial effluents (Wills, 2000). Quality of water generally refers to the component of water, which is to be present at optimum level for suitable growth of plants and animals. Various factors like temperature, turbidity, nutrients, hardness, alkalinity and dissolved oxygen play an important role in the growth of plants and animals in water body, on the other hand biological oxygen demand indicate the pollution level of the water body (Kamal et al., 2007). Several authors have reported that the Nigeria environment has deteriorated tremendously (Oluwande, 1974; Pickford, 1985). The natural quality of water varies from place to places with climate and geology, with stream discharge and with seasons of the year. Water quality is modified by temperature, soil bacteria, evaporation and environmental pollution and other environmental factors including live stock waste. It is desirable that industrial development brings obvious benefit; scientific evidence now claims that uncontrolled industrial and urban practice have led to unacceptable high level of harmful toxic substance in the air, pollution of rivers, lakes, coastal wastes and soil, destruction of forest and environmental hazards (UNEP, 1985).

Pollution studies on 26 rivers in some Southern and Northern state of Nigeria (Ajayi and Osibanyo, 1981), on river in Nigeria delta (Kakulu and Osibanjo, 1992), on South West Nigeria (Okoye, 1981) showed that, with the exception of iron, the concentration of most metal in the surface waters was generally lower than global average levels for surface water and the international drinking water standard.

Pollution level, be it short term or long term, reversible or irreversible, significant or insignificant and primary or secondary, must be assessed due to the harmful effect. Hence, this research work has shown the pollution level of the mentioned river water across the two seasons of the year through the determination of their physico-chemical properties and with this, the usage of the water can be determined.

MATERIALS AND METHODS

Water samples were collected from the Osun River in Osogbo, Osun State for the period of one year. Samples were collected between the months of May-August, 2013 for the rainy season samples another collection was done between November-February of the same year for the dry season samples. Sampling locations were selected along the Osun River and the points of the collection were named A, B and C. point A is the entrance of the town, point B is the heart of the town while point C is the ending of the town. The sample collected were named AR, BR, CR and AD, Bd, CD, for the rainy and dry season for each point, respectively. The samples were collected at a depth of about 15 cm in clean white polyethylene cans by dipping the cans into the river, immediately after collection, the samples were carefully stoppered to avoid contact with the air.

The parameters such as pH, conductivity and dissolved oxygen were recorded immediately on the field. Other parameters such as Biochemical oxygen demand, chemical oxygen demand, alkalinity, total hardness, chloride were analyzed in the laboratory, using standard method (APHA, 1992). The experiments were conducted in triplicate for each points of collection and the average was gotten.

RESULTS AND DISCUSSION

From the Tables 1 and 2, and Figures 1 and 2 the pH value for the rainy season at point AR, BR and CR were 5.60, 6.00 and 6.00, respectively, while that of dry season for point AD, BD and CD were 6.50, 6.80 and 6.60, respectively. These recorded values for rainy season are below the ambient water quality criteria recommend by both national and international bodies (6.5-8.50) (FEPA, 1991; WHO, 1984). The slightly acidic nature may have resulted from the effluence flowing into the river during the rainy seasons. This correlates with the fact that acidity in fresh water result from products of many complex processes such as erosion from lateritic soil etc. (Organ, 1988). The dry season show value within the recommended criteria, which is due to lesser flow into the river during the season.

Conductivity for the rainy season at point AR, BR, and CR are 101, 170 and 140, respectively while point AD, BD and CD gave 92, 110 and 102, respectively. Conductivity values depends on total concentration of ionized substances and the temperature of the water, more dissolved solids and ions are introduced into surface bodies from municipal run off and other anthro-pogenic source during the rainy season, therefore the higher value are shown during the rainy season than the dry season. The level of conductivity recorded during both seasons is low when compared with that of FEPA (1991) and WHO (1984).

Sulphate level recorded during rainy season for point AR, BR, and CR which are 60.30, 90.10 and 90.00 respectively were lower than the ambient water quality criteria of 200 mg/L (FEPA, 1991). Dry season, show the value of 50.20, 57.60 and 56.00 for points AD, BD and CD, respectively. These are also lower than the water quality criteria. Higher value during the rainy season as compared to the dry season could be attributed to the effluents which result to increase in oxidation of sulphate from waste entering into the river.

The value of dissolved oxygen is remarkable in determining the quality criteria of an aquatic system. In the system where the rate of respiration and organic

Table 1. Physicochemical properties of River Osun water samples between the month of May and August 2012 (rainy season).

Parameter	AR	BR	CR	Average
pH	5.60	6.00	6.00	5.87
Conductivity	101	170	140	137
Total alkalinity (mg/L)	72.50	99.50	99.50	90.5
Biochemical oxygen demand (BOD) (mg/L)	2.20	2.80	2.60	2.53
Dissolved oxygen (DO) (mg/L)	3.40	3.20	2.90	3.17
Chloride (mg/L)	9.10	11.30	11.00	10.47
Total hardness (mg/L)	4.00	4.60	3.80	4.13
Chemical oxygen demand (COD) mg/L	3.86	3.54	3.35	3.58
Total dissolved solid (TDS) mg/L	60.10	62.20	65.30	62.53
Total suspended solid (TSS) mg/L	22.40	25.20	28.60	25.40
Nitrate - nitrogen (mg/L)	1.35	1.84	1.96	1.72
Nitrite - nitrogen (mg/L)	0.21	0.24	0.26	0.23
Ammonia nitrogen (mg/L)	0.24	0.39	0.43	0.35

Parameter results are average of triplicate determination of each sampling point. AR = Samples collected at point A during the rainy season; BR = Samples collected at point B during the rainy season; CR = Samples collected at point C during the rainy season

Table 2. Physicochemical properties of River Osun water samples between the Month of November and February 2012/2013 (dry season).

Parameter	AD	BD	CD	Average
pH	6.50	6.80	6.60	6.63
Conductivity	92	110	102	101.33
Total alkalinity (mg/L)	20.20	21.50	21.50	21.06
Biochemical oxygen demand (BOD) (mg/L)	1.70	2.00	1.60	1.77
Dissolved oxygen (DO) (mg/L)	4.50	3.80	3.60	3.97
Chloride (mg/L)	7.50	8.60	8.50	8.2
Total hardness (mg/L)	2.70	2.90	2.60	2.73
Chemical oxygen demand (COD) mg/L	3.16	2.90	2.36	2.81
Total dissolved solid (TDS) mg/L	33.20	35	38.10	35.43
Total suspended solid (TSS) mg/L	8.20	9.50	10.20	9.30
Nitrate - nitrogen (mg/L)	0.28	0.30	0.29	3.87
Nitrite -nitrogen (mg/L)	0.23	0.23	0.24	0.23
Ammonia nitrogen (mg/L)	0.21	0.32	0.39	0.31

Parameter results are average of triplicate determination of each sampling point. AD =Samples collected at point A during the dry season; BD = Samples collected at point B during the dry season; CD = Samples collected at point C during the dry season.

decomposition are high, the DO values usually remain lower than those of the system, where the rate of photosynthesis is high (Mishra et al., 2009). During the study period, DO were found to be low, Aggarwal et al. (2000) reported that in Varuna River water, the DO was observed to be decreased in point source and increased in upstream.

The DO result showed valued of 4.50, 3.80, 3.60 mg/L for AD, BD and CD, respectively. While points AR, BR and CR gave 3.40, 3.20 and 2.90 mg/L, respectively. The river waste are being oxidized by the dissolved oxygen

depleting the DO in the river, thus depleting the waste slowly as the river flows and as much is exposed to the atmosphere, the DO is gradually replenished (Ademoroti, 1996).

The BOD_5 value of 2.201, 1.80 and 2.60 were shown for AR, BR, and CR respectively and 1.70, 2.00 and 1.60 were shown for AD, BD and CR respectively. The BOD_5 values recorded for the rainy season were higher than that of the dry season as this could be as a result of massive amount of waste flowing into the river during the rainy season, hence oxygen will be consumed faster by
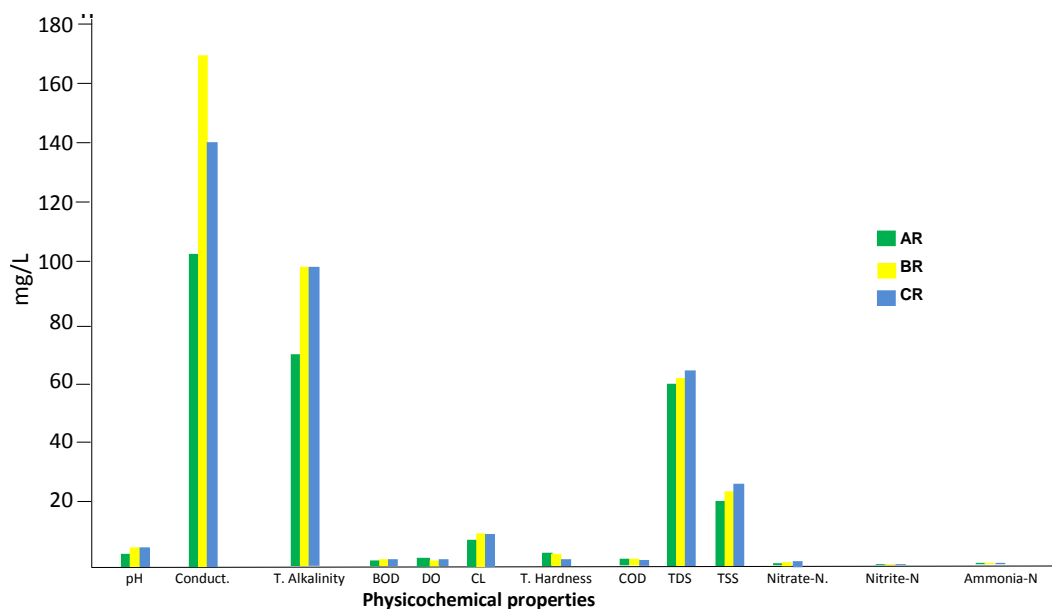
Figure 1. Phsicochemical properties of River Osun water samples between the months of May to August 2012 (rainy season).
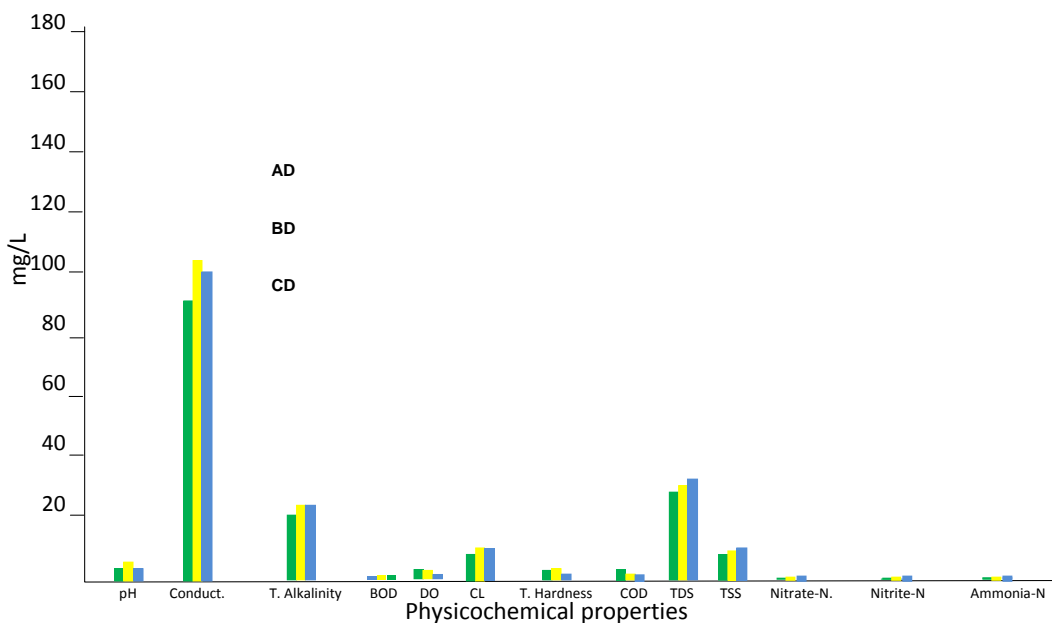
Figure 2. Phsicochemical properties of River Osun water samples between the months of November to February 2012/2013 (rainy season).

microbial population. In dry season, lesser waste found their way into the river body. The biodegradation of organic materials exerts oxygen tension in the water and increases the biochemical oxygen demand (Abida and Harikrishna, 2008).

The chloride content of the river was lower than theambient water quality criteria of 200 mg/L (FEPA,

1991) 9.10, 11.30 and 11.00 mg/L for AR, BR and CR respectively and 7.50, 8.60 and 8.60 mg/L for AD, BD and CD respectively. Chloride ions are introduced into the river system via sewages. The higher value during the rainy season could be attribute to an increase in the flow sewage finding their way into the river during the rainy season; chloride content in excess of 100 mg/L

Table 3. Average of heavy metals in River Osun water sample between the month of May and August 2012 (rainy season).

Heavy metal	AR	BR	CR	Average
Iron (Fe) mg/L	0.0010	0.0012	0.0008	0.0010
Zinc (Zn)	0.0023	0.0020	0.0017	0.0020
Nickel (Ni)	0.0023	0.0024	0.0022	0.0023
Copper (Cu)	0.0010	0.0010	0.0010	0.0010

Table 4. Average of heavy metals in River Osun water sample between the months of November and February 2012/2013 (dry season).

Heavy metal	AR	BR	CR	Average
Iron (Fe) mg/L	0.0025	0.0027	0.0029	0.0027
Zinc (Zn)	0.0020	0.0020	0.0020	0.0020
Nickel (Ni)	0.0015	0.0012	0.0012	0.0013
Copper (Cu)	0.0013	0.0013	0.0013	0.0013

could cause physiological damage while content greater than 40 mg/L indicate salt water contamination (Todd, 1980).

Total alkalinity of water is due to presence of mineral salt present in it. It is primarily caused by the carbonate and bicarbonate ions (Singh et al., 2010). Chlorides are disturbing in irrigation water and also harmful to aquatic life (Rajkumar et al., 2004). 72.50, 99.50 and 99.50 were recorded for AR, BR, CR total alkalinity, respectively, and 20.20, 21.50 and 21.50 for AD, BD, and CD, respectively, all the values are still within the target water range (20-100 mg/L) recommended for the health of fishes. The variation could be due to increase in sludge to the river during the rainy season and legal influence on the river system producing carbonates and hydroxides (Organ, 1988).

Hardness value gotten for the two season were below the WHO standard which is 500 mg/L and from the table AR, BR, CR gave the value of 4.00,4.60 and 3.80 mg/L, respectively while AD, BD, and CD gave 2.70, 2.90 and 2.60 mg/L, respectively. This variation in the two season value could also be due to the increase in the waste flowing into the river during the rainy season. High value of hardness during summer can be attributed to decrease in water volume and increase in rate of evaporation of water (Hujare, 2008).

The nitrate nitrogen of 1.35, 1.84 and 1.96 mg/L were gotten for AR, BR, CR recorded in surface water in this study is significantly lower than the ambient water quality criteria of 10 mg/L (FEPA, 1991). This also correlates with the observation of Organ (1988) that the concentration of nitrate phosphate and nitrate are low surface waters. No adverse effect can be observed with water body of such concentration in nitrate except mathaemoglobinemia in infants (Radojevic and Bashkin, 1999). Nitrite level recorded in their study is invariably much lower than the level of nitrate ammonia nitrogen in this study showing the value of 0.24, 0.39, and 0.43 mg/L for the AR, BR, CR and 0.21, 0.32 and 0.39 mg/L for AD, BD, CD, respectively. Fertilizer use, decayed vegetable and animal matter, sewage sludge disposal to river body is due to the flow of effluence in the rainy season easily than the dry season.

The total dissolved solid (TDS) of 60.1, 62.2 and 65.33 mg/L and 33.2, 35.1, 38.1 mg/L for the respective sample points of the river were found within the permitable limit

(100 mg/l) of WHO standards. Dissolved solid comprised of salt and small amount of organic matter, the principal ions contributing to TDS are carbonate, bicarbonate, chloride, sulphate, nitrate, sodium potassium, calcium and magnesium (USEPA,1976), all these flows easily in large quantity into the river during the rainy season than dry season. All the result indicated were revealed by the APHA (1992) standard methods.

The total suspended solid gave the value of 22.4, 25.2, 28.6 mg/L and 8.2, 9.5 and 10.2 mg/L for the two seasons, respectively. Clay, salt, collochial organic particles, plankton and other microorganism are the suspended matter which was higher in the rainy season than the dry season.

As shown in Tables 3 and 4 the analyzed metals were Fe, Cu, Ni and Zu. They were present in a very minute quantity across the two seasons. The value obtained fell below the WHO recommended maximum unit of 0.3 mg/L.

Conclusion

From the result, some of the determined parameters such as conductivity and chloride content were low in value as compared to the water quality criteria, although rainy season values were a little higher than the dry season but still lower than the recommended standard. The little variation may be due to the effluence carrying waste from different sources into the river body during the rainy season. The present study concluded that river water of the study area was moderately polluted in respect of the analyzed parameter due to the fact that some analyzed parameters are within permissible limit, e.g total alkalinity and the pH which were revealed during the dry season. Higher value of BOD_5 shown during the rainy season is not suitable. Therefore, there is need for the residence to safeguard the river water.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Full Length Research Paper

The next generation feedstock of biofuel: *Jatropha* or *Chlorella* as assessed by their life-cycle inventories

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Promising energy crops such as *Jatropha curcas Linnaeus* (*JCL*), which are planted on marginal lands, or microalgae such as *Chlorella*, which are cultivated in ponds located on mudflats or deserts, have been regarded with high hopes to solve the shortage of food crops and increase the amount of biodiesel (fatty acid methyl ester, FAME) production. However, the annual yields of biomass and transport fuels (t/ha) of both are still unclear and often exaggerated in the literature. Large portions of *JCL* biomass, including tree trunks and leaves, can also be used to generate electricity along with FAME, which is produced from seed lipids. Meanwhile, lipid extracted algae (LEA) is composed of proteins, polysaccharides and lipids other than glycerides which are unable to be esterified to form FAME and much more abundant in the microalgae than oil cake in the oil crops. Therefore, it was strongly suggested that not only transesterification or esterification but also Fischer-Tropsch (FT) process and bio-electricity generation should be considered as routes to produce biofuels. Otherwise, the yield of biofuel would be extremely low using either *JCL* or *Chlorella* as feedstock. The life-cycle inventories (LCI) of the biofuel processes with whole biomass of *JCL* and *Chlorella* were compared based on their net energy ratio (NER) and CO_2 emission saving (CES). It was shown that the technological improvement of irrigation, cultivation and processing for either economic-crops or microalgae are all necessary to meet the requirements of commercial biofuel production.

Key words: Biodiesel, biofuel, *Jatropha*, microalgae, chlorella, LCA, LCI.

INTRODUCTION

The need for sustainable biofuels can be attributed to both an increase in energy consumption and the tighter restriction of greenhouse gas (GHG) emissions. It was believed that the use of biodiesel instead of fossil diesel results in a significant reduction in CO_2 emission. The

development of biodiesel (fatty acid methyl ester, FAME) has met with large scale success in the EU and US with the use of rape seed and soybean, respectively, during the past 10 years. The EU hopes to radically cut GHG emissions and reduce dependency on fossil fuels

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through encouraging the production and use of sustainable biofuels. The arable land used for biodiesel production has been around 3 M ha (million hectares). Meanwhile, similar research has been conducted in other countries such as Brazil, Thailand, West Africa, and China. There have been more difficulties in China as there is much less arable and marginal land and a lower climate temperature than the countries in South Asia, Southeast Asia, and Africa.

Until 2008, US and EU biodiesel production has been up to over 2 million tonnes (Mt) and near 10 M t, respectively (Timilsina and Shrestha, 2011). However, 10 Mt is only 3% of diesel consumption in EU and far from the renewable energy directive (RED) 10% target by 2020 in 29 European countries (E27 plus Norway and Switzerland). In order to meet the gap between the 3 and 10% and find more sustainable feedstock, many sources have been tested including microorganisms, wastes, agricultural and forestry residues, energy crops and even used frying oils (UFO) or animal fats. However, among the wastes, economic-crops and algae, it is still not clear who would prevail. Economic-crops are able to be planted in marginal lands but the planting of dedicated energy crops often leads to the carbon stock change, known as land use change (LUC) (Laborde, 2011), which sheds doubt on the predicted positive GHG balance (positive CES). In contrast, microalgae are able to be cultivated in ponds or photobioreator (PBR) located on mudflats or deserts with near zero carbon stock. Meanwhile, other advanced biofuels such as hydrotreated vegetable oil (HVO) (Arvidsson et al., 2011), FT-diesel distillate (green diesel), FT-jet-fuel distillate (green jet fuel) are also candidates produced by Fischer-Tropsch synthesis and hydro treatment, which may be more compatible with existing fuel infrastructures or offer other technical benefits and be prepared with wider feedstock's.

In Francesco's (Cherubini and Stromman, 2011) comprehensive literature review on biofuel development, it was found that there are now an increasing number of papers dealing with lignocellulosic biomass, sugarcane, or palm oil in developing countries in South-Eastern Asia. By contrast, few studies are currently available on the promising feedstock of *Jatropha curcas Linnaeus (JCL)*. *JCL* is a shrub and toxic tree with a smooth gray bark and an average height of 4 m (up to 6 m), belonging to the family Euphorbiaceae. This native species to Central America was introduced to the Cape Verde islands by Portuguese sailors in the 16th century, then to Guinea Bissau from where it spread across Africa and Asia. Its natural habitat is arid and semi-arid zones but it has also been found in damp tropical regions such as North Vietnam and Thailand. *JCL* starts producing seeds within one year of growth, but the maximum productivity is after 4 or five years (typical *JCL* yields in the first 5 years are 0.5, 1.5, 3.0, 5.0 and 6.0 t/ha). Its average life span is over 20 years (up to 50 years) (Cherubini and Stromman,

2011; Kalam et al., 2012).

In this paper, the *JCL* demonstration cases implemented in Thailand, India and West Africa are reviewed and compared with several laboratory works of microalgae, such as *Chlorella,* to further contrast their life-cycle inventory (LCI) of culturing, extracting, producing and processing. The prospective productivities (annual yield) of both feedstocks were compared and discussed to readdress the exaggerated results often found in the literature.

EXPERIMENTALS

Boundaries, functional units and allocation

LCI analysis involves creating an inventory of flows. Inventory flows include inputs of water, energy, feedstock, fertilizer etc. and outputs of CO_2 emission, biofuel products, land and water. The input of water and fertilizer are converted into power, which can be used in manufacturing and irrigating, whereas the output of land and water has not been considered. To develop the inventory, a flow model of the technical system has been constructed using data from the inputs and outputs, and it has given a clearer picture of the technical system boundaries. LCI results would be very different if different boundaries (1: biomass-system; 2: transport fuel system; 3: well (culturing) to wheel system, or 4: by-product included system) were accepted, as shown in Figure 1.

The data used in LCI must be related to the functional unit (FU) defined in the goal and scope. There are four types of FU identified in the LCI of bioenergy systems to compare: 1. given feedstock; 2. different feedstock; 3. dedicated energy crops; 4. Multiple final products, that is, input, output, agricultural land or year unit. The output unit and energy basis (GJ or MJ) were selected as functional units in this paper. All the outputs of the bioenergy systems expressed through other energy units were converted with the conversion factor (1 kg biodiesel = 37.8 MJ or 1kg fossil diesel = 42.8 MJ) to compare the results published in different literatures. The FU of the power input was also converted with the conversion factor (1kWh=3.6MJ).

Allocation in life cycle assessment (LCA) is carried out to attribute the total environmental impact to the different products of a system. This concept is extremely important for bioenergy systems, which are usually characterized by multiple products (e.g. electricity and heat from CHP application, rape-cake and glycerin from biodiesel production), and has a large influence on the final results (Ndong et al., 2009).

Energy balance and fossil fuel saving

The net energy ratio (NER) of a system is defined as the ratio of the total output energy utilized from produced liquid biofuel and residual biomass (produced energy output) over the input energy required in the "production stage," which includes photobioreactor (PBR) construction and materials, nutrition production, and planting (culturing) operation (primary energy input). NER is also called the energy yield. The net energy balance (NEB) is the difference between the effective energy produced and that required in the "production stage." If the bioenergy system is economically viable, then NER and NEB would be larger than one and zero, respectively (Pandey et al., 2011).

NER = Total energy output / Total energy input
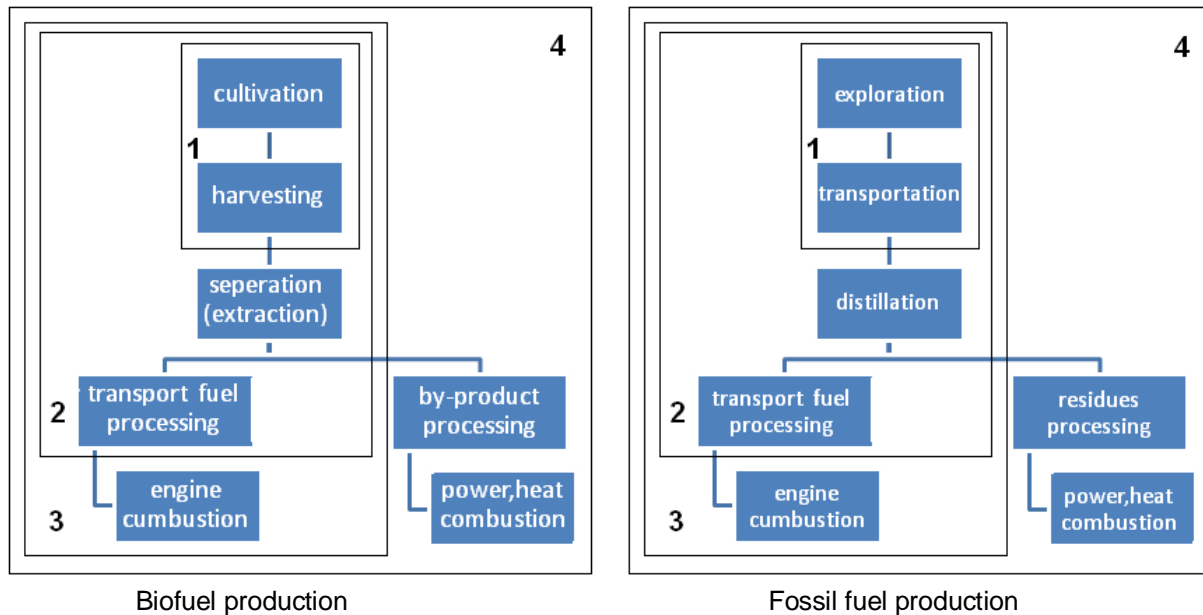NEB = Total energy output - Total energy input.

Figure 1. LCI flow model of biofuel and conventional fossil fuel with different boundaries.

Environmental balance and GHG saving

CO_2 was the only green house gas (GHG) considered in this paper and CEB (CO_2 emission of biofuel) in combustion of biofuel was calculated with either kg or MJ as the functional unit.

CEB (CO_2kg/kg) = mass (kg of biofuel combusted) × C content (normalized) × 44/12 = 2.86
CEB (CO_2g/MJ) = 1000 × 2.86 / energy (MJ producing from 1 kg biofuel) = 1000 × 2.86/37.8 = 75.7

Where, 0.78 was used as the carbon content of biodiesel and assuming all of the carbon in biodiesel was converted to CO_2; 44/12 is the ratio of molecular weight of CO_2 and atomic weight of C. CO_2 emission in the "production stage" is calculated as equivalent CO_2 emission from coal-fired electricity generation (0.83 kg CO_2/KWh), which is much greater than from natural gas (0.11 to 0.24 kg CO_2/KWh) but close to that from wood chips (0.82 kg CO_2/kwh) (Kumar et al., 2012). The CO_2 emission from coal-fired electricity in China (~1 kg CO_2/KWh) is even higher due to the use of low-grade coal.

CO_2 emission saving (CES) was used to show the CO_2 emission balance of biofuel and compare the CO_2 emission of fossil fuel used in the production of biofuel.

CES (%) = 100 × [1-(CEF+CEB+CEU)/CEF]

Assuming CO_2 emission in upstream of biofuel production (CEU) to be zero, and CEF was taken as 83.8 g CO_2/MJ fossil fuel and the CEB was -75.7 g CO_2/MJ biofuel, the maximum CES will be up to 90%, assuming GEF, GEB and CEU (CO_2 emission in upsteam of biofuel production) are 83.8, 75.7 and 0 g CO_2/MJ fossil fuel, respectively. In fact, CES is closely dependent on the upstream process and boundary shown in Figure 1, which means it would be much less than 90%. CEU is usually large and even larger than CEB (CES becomes negative) depending on the energy consumed in the upstream process and the electricity source of coal, fuel oil or natural gas-fired power station.

RESULTS AND DISCUSSION

The industrial production of *JCL* is a fairly recent development. Almost 0.9 M ha, 0.765 M ha (0.32 M ha in Senegal) and 0.12 M ha of *JCL* farm have been established to date in Asia, Africa and Latin America, respectively, but it is still far away from the targets of 5 M ha by 2010 and 13 M ha by 2015 (Ndong et al., 2009). Meanwhile, the prices of *JCL* seed have increased from 0.10 $/kg in 2005 to 0.34$/kg in 2011(Kalam et al., 2012).

Fertilizer and watering in JCL plantation

In Thailand, a demonstration of *JCL* plantation was conducted by Kasetsart University, in which annual crop cutting was set within an area of 1 ha (hectare) and a crop density of 2 × 1 m or two trees per m^2 was utilized. Land preparation comprised of plowing, harrowing, and a furrowing process using a tractor with an engine of 75 hp to adjust the soil condition for the new cutting set; ternary (N-P-K: 15-15-15) fertilizer was applied with a rate of 650 kg/ha per year; weedicides and insecticides were also used for the general maintenance of the plantation; the pumping rate was 4.5 m^3/m^2 per year for watering and manual harvesting (Pandey et al., 2011).

In India, the yield of *JCL* increased from 1.5 t/ha (rain-fed) to 5.9 t/ha (irrigated) when double fertilizers and an additional 105 kg/ha diesel were consumed in the irrigated mode as compared with rain-fed mode (Kumar et al., 2012).

In West Africa (Mali and Ivory Coast), *JCL* planting was up to 1500 ha in 2007, and at least 2000 ha more in

Table 1. Energy balance and yield (NER) and CO_2 emission saving (CES).

Reference	Energy output/MJ		Energy input/MJ	NER[1]	CES[2]/%	Plantation
	JME	By-product				
Ndong et al., (2009)	1		0.21	4.7	72	Mali/baseline
Ndong et al., (2009)	1			1.8	11	irrigation/motorized
Achten et al. (2008)	1		0.886	1.1	77	50%Faming E
Achten et al. (2008)	1		0.16	6.3	93	17%Faming E
Yale University	1		0.88	1.1	72	Thailand
Yale University	1	17.88	0.88	21.5	72	Thailand
Kumar et al. (2012)[2]	37.27		21.83	1.7	54	Irrigated
Kumar et al. (2012)[2]	37.27		27.6	1.4	40	Rain-fed
Kumar et al. (2012)[3]	37.27	107.8		1.5-8.6	50-107	Irrigated
Kumar et al. (2012)[3]	37.27	107.8		1.2-7.0	40-93	Rain-fed
Pandey et al. (2011)	1		0.578	1.73	23	Five years[3]

[1]NER was calculated by dividing the biodiesel energy as the sole energy output by the total energy consumed, which is oil yield and allocation mode dependent. [2]Conventional diesel emit 83.8 kg CO_2eq/GJ diesel. [3]NER was estimated as a ratio of biodiesel energy and net allocated process energy to biodiesel. [3]Averaged by the total yield (energy) of 5 years (3.92 t JME, 161.65 GJ) and NEB=161.65-93.51= 68.14 MJ. Faming E (energy).

2008. Two 5-ha experimental fields with plantation densities of 1111 plants ha^{-1} were selected with contrasting soil conditions. Ternary fertilizer only was applied during the first three years: 100 kg/ha in 1st year, 150 kg/ha in 2nd year, 200 kg/ha in 3rd year, whereas both 248 kg/ha ternary fertilizer and 201 kg/ha of ammonium nitrate were applied in the 4th year (Pandey et al., 2011).

Productivities of biomass, JME and by-products

The yield hypotheses had a significant impact on the GHG and energy balances of JME. The weight of each fresh fruit and seed is around 10 to 15 and 2 to 4 g, respectively. The annual yield of *JCL* fresh fruit is about 16 t/ha. The yield of seed is widely spread from 0.1 to 10 t/ha (Basili and Fontini, 2012) and an increase of 1 t/ha on seeds resulted in a 10% reduction in fossil energy use compared to the baseline value of 4 t/ha. An increase of 1 t/ha on seed production from the baseline of 4 t/ha results in a 10% reduction in fossil energy usage. Thus, it appears critical to pursue large-scale field cultivation experiments of *JCL*.

The yield of co-products such as, wood, leaves and seed shell, are 4, 2, and 0.8 t (dry weight), respectively from the process of *JCL* plantation, and press cake (91.5 kg, dry weight) is obtained when 1 FU (1GJ of JME) is produced (Prueksakorn and Gheewala, 2006).

Kumar et al. (2012) reported details of inventory requirements for the farming, oil extraction, biodiesel production and transportation stages for the entire JME production process in India. The oil percentage of *JCL* seed ranges from 21.0 to 48.2% and oil seeds were assumed to be sun-dried. The energy required for harvesting, handling and storing of oil seeds, oil and

biodiesel, and the separation of husk from the seeds, were neglected due to the cheap and abundant labor force available.

Energy balance (net energy use)

The selected JME projects of energy balance expressed in NER (energy yield) and environmental balance expressed in biofuel CO_2 emission factor per GJ energy are shown in Table 1.

Ndong et al. (2009) proposed a very detailed LCI analysis on the JEM project in West Africa in which an allocation analysis was also included. The energy yield (the ratio of biodiesel energy output to fossil energy input) is 4.7. In other words, 4.7 MJ of energy is produced from 1 MJ of fossil fuel consumed to produce JME. Biofuel production requires direct (electricity, fuels and natural gas) and indirect (manufacturing of agricultural inputs, methanol etc.) energy consumption. In the allocation of energy expense, cultivation accounted for only 12%, which is even less than the 15% in the transport of seeds, oilcake and unrefined *JCL* oil. Transesteification requires 61% of the energy expense. In an alternative scenario, all co-products and JME are considered as output energy sources. The motorization and irrigation for the first three years were also included in *JCL* production with a high consumption of fuel and irrigation water, which resulted in the energy yield being lowered down to only 1.8 compared to 4.7 in the baseline scenario. Meanwhile, GHG savings compared to fossil diesel become only marginal (11%), only one-sixth of the baseline scenario.

In a Thailand demonstration test (Prueksakorn and Gheewala, 2006), the allocation for energy expenses of transesteification, irrigation and fertilization processes was approximately 40% (0.197 GJ for producing steam),

23% (0.205GJ) and 22% (0.198GJ), respectively. The highest energy consumption was in the process of transesteification (61%) and other energy expenses were from using diesel, electricity and producing fertilizer. Others are from 100 kg of fertilizer with the chemical formula 15-15-15 (energy consumption for transportation of fertilizer is excluded). The consumption of diesel for water pumping is a main contributor to energy expense in the irrigation process. *JCL* plantation requires the process of land preparation one time every five years as the stems are cut every year but a new plantation is made every five years. The residue (by-product) produced energy is 17.883 GJ whereas JME produced energy is only 1 GJ. The highest energy by-product is wood, which produces energy of 10.289 GJ.

Environmental balance (GHG emission)

Achten et al. (2008) deducted GHG emissions from the production phase of JME, and considered the energy content of the co-products in calculating the CES (GHG emissions from JME). The result was ~77% compared to the GHG emission using fossil diesel. Totally, the production and combustion of JME emits 23.5 g CO_2e/MJ JME. The allocation of CO_2 emitted accounted for 52% in cultivation, while the shares of the transesteification and final combustion steps were 17 and 16%, respectively. Large shares of the emissions occurring during the agricultural step are due to fertilizers.

It is assumed that the energy consumed in the production stage is from 100% fossil fuel fired power plants. In India, fossil fuel is 64% of electricity generation, in which 52% of electricity is generated in coal-fired power plants, whereas the other 12% are allocated from natural gas (11%), oil (1%). The rest are from hydro (23%), nuclear (3%) and renewable materials (10%) (Pandey et al., 2011). In China, coal is the major share of fossil fuel in electricity generation (80%), resulting in more CO_2 emitted.

Sunil[8] compared energy and environmental balances of irrigated and rain-fed scenarios. Seed annual yields of irrigated (5.9 t/ha, farming energy: 9333MJ/t JME; farming emission: 680kg CO_2/t JME) and rain-fed (1.5 t/ha, farming energy: 15098 MJ/t JME; farming emission: 1114kg CO_2/t JME) scenarios are closely related.

It was found that the utilization of JME saved more energy and emitted less CO_2 (saving 1.2GJ/ha; emitting 80 kg CO_2/ha per year) than direct use of *JCL* oil (saving 1.0 GJ/ha; 67 kg CO_2/ha per year) based on the comparison of energy and environmental balance in Central India (Center for industrial ecology, Yale University, USA, 2010).

Life cycle costs

It was reported that the total cost of JME without externa-

lities is higher than the current market retail selling price of diesel in Thailand (Sampattagu et al., 2007). The cost allocation is 62.62, 25.27 and 12.12% for agricultural, bio-diesel production and environmental processes, respectively. The highest expenditure is the operation costs in agriculture stage such as fertilizers, insecticide, and electricity for water pumping system, especially in the dry season.

Generally, production of JME costs less than palm oil, soybean diesel costs more, and the cost of rapeseed diesel is the highest (Clarens et al., 2010). While as a commercially viable option, microalgae will require further improvements in genetic and metabolic engineering to and obtain promising strains and produce higher yield of oil. Moreover, the development of equipment and methodologies for cost-effective culturing, harvesting and processing are also required as year-round production of biofuels requires constant, reliable feedstock supply (Hoekman, 2009). While microalgae are projected as a future feedstock of biodiesel, production cost is much higher than for these terrestrial crops, in the range of US$2 to $22 per liter (Timilsina and Shrestha, 2011). In addition, the entire microalgae biomass has to be used to produce biofuel otherwise the yield of biofuel would be too low to be accepted (Milledge, 2010).

Situation in China

It's widely hoped that JME production will offer a newer, more sustainable energy source; but that is yet to be proven. In 2007, the global output of biodiesel (FAME) was 8.82 Mt but only 0.1 Mt in China, and there has been no obvious change in suffering from arable land limitation since then (Timilsina and Shrestha, 2011). Therefore, there has been more effort to search energy crops in China than EU, US, and even Asia countries, such as India and Thailand. However, the climate is not suitable to plant *JCL* on most of land in China. Although Southwest China is considered as a prospective area to plant JCL, it has been discovered that both prospective planting area and yield of seed had been overestimated after comprehensive consideration using Agro Ecological Zone method. Based on the remote sensing data on land use, meteorological, soil and land slope, and suitable environment for *JCL* plantation in Southwest China, the potential lands to expand *JCL* areas is only 0.15 M ha by 2008, which is far from the government goal (1.667 M ha by 2020). Although the moderately suitable land was increased to 1.433 M ha after softening the terms, the poor yield of seed on the moderate land would definitely destroy the balance of both energy and environment (NER and CES become minus value) (Wu et al., 2009).

In China, the yield of fresh fruit, dried seed and extracted oil would be less than the countries in the tropic zone, and there is little data from farming sites. The prospective yield of *JCL* seeds and JME are often

Table 2. Energy input (expense) and GHG emission for producing 1 kg algal oil and energy yield (NER).

Reference	Yield[1] (t/ha)	Lipid %(DW)	Output (MJ)	input (MJ)	NER	CES[2] (%)	Cultivation Harvesting	Algal species
Kalnes et al. (2012)		25.0	83.6	85.8	0.97	-2	Dewatering	*Nannochloropsis*
Kalnes et al. (2012)		25.0	83.6	59.0	1.42	57	HRJ	*Nannochloropsis*
Batan et al. (2010)	91	42.5	1	0.93	0.93	29	PBR bags	*Nannochloropsis*
Lardon et al. (2009)	62	17.5	103.8	106.4	0.98		Dry	*Chlorella vulgaris*
Lardon et al. (2009)	62	17.5	146.8	41.4	3.55		Wet	*Chlorella vulgaris*
Xu et al. (2011)	128	40.0	37.2	27.5	1.35	41	Tubular	*P. tricornutum*
Vasudevan et al. (2012)	76	25.0	9.2	32	0.3	-232	Dry extract.	Algae
Vasudevan et al. (2012)	76	25.0	9.2	3.7	2.5	37	Wet extract.	Algae

[1]Yield of algal biomass per year, 2 minus means net GHG emission but not fixation.

exaggerated and questionable. For instance, the JME yield (5t/ha) and farming (planting) energy (160MJ/t JME) were accepted in a published LCA research. Nevertheless, the energy of soybean farming is as high 2497 MJ/t FAME as usual and the average yield of *JCL* seed in the tropic zone is only 4t/ha (the JME content is less than 40% of *JCL* seed). A misleading NER of JME (2.004) even higher than soybean (0.981) was proposed based on a unconfirmed *JCL* annual yield (5 t/ha) in Hainan province of China which was greatly overestimated and even over the field obtained in the tropic zone (Ou et al., 2009). The reasonable annual yield of JME is 1 to 2 t/ha based on the demonstration test in Thailand (Prueksakorn and Ghewala, 2006), Malaysia (Kalam et al., 2012) and West Africa (Ndong et al., 2009); where, JME content of 30 to 50% is usually accepted.

Comparison with microalgae

It is known that microalgae has attracted the spotlight around the world during past years and was considered as a very hopeful competitor to replace terrestrial plant as feedstock of next generation biofuels. One reason for the superiority of microalgae is that it is unnecessary to use fresh water and arable land in the culturing. Waste, saline, or brackish water and land resources, such as mudflats or deserts, are all usable for the microalgae culturing so that there is no interference in food production as there was for the first generation biofuels (Clarens et al., 2010). Another benefit of microalgae is due to the high expected yield of biomass, which can be as high as over 100 t/ha and oil content as high as 70% of its dry weight in the form of triglycerides (Chisti, 2007). However, these are only speculations based on the excessively optimistic assumptions or laboratory data using minimalistic culturing volume of several milliliters to liters, which largely deviated from the larger scale culturing results either in ponds or PBR. Although *Chlorella*, *Diatom*, *Scenedesmus, Tetraselmis*, *Nannochloropsis*

and *Haematococcus pluvialis* have been preferred as hopeful candidates, the real potential of their productivity was not clear until their production was realized at a large scale, resulting to the differences of published biomass and oil (lipid) yield potentials which are as much as 16 times (Quinn et al., 2011).

In this paper, NER was selected to qualify the energy balance and closely related to both the boundaries of LCI and the yield of algal biomass and lipid. Meanwhile CES was selected to qualify the GHG balance. Some of the calculated NER and CES based on published LCA results were summarized in Table 2, and some of them were from laboratory data and extremely exaggerated. The results are dependent on the manner of culturing (pond or PBR), harvesting, biomass yield and lipid content and the boundary. NER for *Nannochloropsis* cultivation process is 4.33 for flat-plate PBR but 7.01 for raceway pond, indicating that both processes were energetically favorable for biomass production (boundary 1) (Jorquera et al., 2010). NER became less than 1 when harvesting stage was included (boundary 2) (except for HRJ or wet harvesting) indicating that dewatering is the most energy consuming process in the upstream (Table 2). The NER is closely dependent on the yield of biomass or lipid and varies as much as six times as reported from different sources (Xu et al., 2011). In order to attain the energy benefit (NER>1), the overestimated LCI data (biomass yield or lipid fraction) were often accepted in the published papers (Chisti, 2007; Yanfen et al., 2012).

If FAME is considered as the only product of algal fuel (boundary 3), it is almost impossible for NER and CES to be >1 and >0, respectively (net energy and CO_2 emission reduction are positive) as large amounts of energy are consumed in the dehydration and extraction processes as shown in Table 2 (Xu et al., 2011).

In fact, current commercial microalgae production is only focused on a few high-value products used mainly for human nutritional supplements, including entire algal biomasses, such as of *Spirulina* (Arthrospira) (3000 t/a) and *Chlorella* (2000 t/a) and extracted products, including

β-carotene, astaxanthin and docosahexanoic acid (DHA). The total annual yield of microalgal biomass (dry matter basis) around the world is only about 10 Kt. However, the total revenue of the microalgae-containing products is up to several billion dollars per year, with a typical selling price of $5,000 to $100,000 per dry ton of biomass or extracted products (Spolaore et al., 2006). The biomass of microalgae is also used as live feeds in aquaculture, and in waste-water treatment systems with the lower price in the culturing stage (Pulz and Gross, 2004). Over 90% of the world's commercial microalgae production uses shallow, open, paddle wheel mixed raceway type ponds, in addition to open circular ponds for *Chlorella* production in Japan.

In China, the production of *Spirulina* (*Arthrospira*) and *Chlorella* are sold as nutrients and high nutrition feeds have increased rapidly recently. The annual yields of *Spirulina* (*Arthrospira*) and *Chlorella* have attained to 3000 and 1000 t, respectively. The protein content and lipid content of *Spirulina* sold as a nutrient are as high as 60% and less than 10%, respectively. The *Chlorella,* with lower protein content and higher lipid content than *Spirulina*, was recommended to be used as feedstock of biodiesel, although the price makes it too expensive to be used nowadays. A several-fold increase in algal biomass or lipid production is not feasible by cultivation in either low-nitrogen nutrient or rich-CO_2 environments. When low-N nutrients are used in algal cultivation, lipid content increases but the yield of biomass usually decreases (Illman et al., 2000). The improvement of biomass yield with additional (5 to 14%) CO_2 aeration is only 1.5 times and difficult to double as compared with air aeration without additional CO_2. In the lipid fraction, there are not only triglyceride (TAG) and free fatty acids (FFA) but also sterol, terpene and hydrocarbon, which are unable to be transesterified or esterified to form FAME so that the yield of FAME would be lower than the lipid content of *Chlorella* (Yanfen et al., 2012).

Besides FAME (biodiesel), in order to increase the yield of algal biofuels, other hydrocarbon fuels including methane and FT-fuel have to be considered as the algal biofuels produced from lipid extracted fraction (lipid extracted algae, LEA) which is difficult to be esterified to form FAME (Kalnes et al., 2012). Even now, the algal biofuel has not been produced or demonstrated in China due to the low algal biomass productivity and the complexity of the algal biomass. This is also the reason that the species of microalgae are often not specified in the literature of LCA, easily misleading the reader, as the productivity and lipid composition of various species of microalgae are very different and dependent on the area and time of culturing. Robert summarized the worldwide LCA results of the prior literature and investigated the wide variance in predicted environmental impacts from microalgae cultivation in open-air raceway ponds and deduced a very wide range of CO_2 emission (0.1 to 4.4 g CO_2e/g microalgae) (Handler et al., 2012).

The difficulties of commercialization

Jatropha

The *JCL* has been successfully planted on a large scale, especially in Asia and Africa where planting areas have been near to 1 M ha, respectively. The seed yield ranges 4 to 5 t/ha in above area but is relatively area and climate dependent. The oil content ranges from 20 to 50% and typically 30 to 40%, depending on the culturing area and conditions. The energy and environmental balance of culturing, harvesting and processing show *JCL* to be a preferable sustainable feedstock of biofuel, and the use of JME shows more favorable results in energy saving and CO_2 emission than direct use of *JCL* oil.

In the subtropical zone and even in south of China, the feasibility of *JCL* cultivation must be carefully considered. The yield of *JCL* oil is dependent on the climate and planting area. The published data from tropical zones such as south Asia, south-east Asia and Africa are not suitable for the LCI in China. The real, domestic and large-scale planting data strongly suggests the acceptance as LCI instead of published data from different zones of the world.

On the environmental balance assessment of JME, the CO_2 emission due to LUC was not considered in the paper. Based on the accomplished production scale in South Asia, Southeast Asia and West Africa, Jatropha may be closer to us as the next generation feedstock of biodiesel if there is enough land with proper climate, and we can avoid the CO_2 emission resulting from LUC at the same time.

Microalgae

The cultivation of microalgae even *Chlorella* and *Spirulina* is still in the beginning stages. The biggest farm for culturing *Spirulina* is only 0.1 M ha scale, which is much less than big *JCL* farm up to 1 M ha scale. Therefore, more demonstration farms or projects need to be created to verify the feasibility for microalgae to become the feedstock of biofuel in the future.

The triglyceride and free fatty acid (FFA) contents in the lipid fraction of microalgae are much less than that in the lipid fraction of *JCL*. Therefore, the biodiesel yield cannot be deduced from the lipid content of microalgae directly.

The lipid in microalgae should be referred to as bio-crude other than biodiesel. All of bio-crude or biomass has to be processed to produce the sustainable bio-energy instead of biodiesel (FAME) only so that biohydrogenated diesel (BHD), FT-fuel, bio-gas, bio-power and bio-heat can be produced and used together. The NER and NEB are hardly larger than one and positive, and CES is also rarely positive if the energy prepared from LEA was not accounted for at the present stage.

Conclusion

The biomass yields of both *JCL* and *Chlorella* per hectare have to be increased further by using the high efficiency irrigation systems for *JCL* plantation and well-designed PBR for *Chlorella* cultivation so as to get economic and environmental benefits. Moreover, it was strongly suggested that not only transesterification or esterification but also Fischer-Tropsch process and bio-electricity generation should be considered as routes to produce biofuels. Otherwise, the yield of biofuel would be extremely low using either *JCL* or *Chlorella* as feedstock. Overall, there is a long way to go for either *Jatropha* or *Chlorella* to become real 2nd generation feedstock at the scale corresponding to 1st generation feedstock.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Full Length Research Paper

Assessment of the energy recovery potentials of solid waste generated in Akosombo, Ghana

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The main attributes of waste as a fuel are water content, calorific value, and burnable content. The study was conducted to evaluate the energy recovery potential of solid waste generated in Akosombo. A total of twelve (12) samples were collected from the township in December, 2012 (dry month) and May, 2013 (Wet month). Samples were weighed and segregated into organic and inorganic components. The organic component was thoroughly mixed, shredded and sieved for analysis at Ghana Atomic Energy Commission Laboratory, Accra. Proximate analysis was conducted to obtain the chemical characteristics of the solid waste. Dulong's Equation was used to determine the heating values with the data obtained from the ultimate analysis. The study obtained moisture contents of 58 and 36% for the wet and dry months respectively that shows the prospects of bio-chemical conversion for the wet month and thermo-chemical conversion for the dry month. The study obtained high percentage organic matter (70%) that can support both conversions. The calorific values ranged between 1.39×10^4 to 2.99×10^4 kJ/kg making it suitable for thermo-chemical conversions. The study reveals that the types of solid waste generated in Akosombo have substantial organic matter, moisture content and calorific value or energy content, making them suitable for energy generation. It is therefore recommended that thermal plants that can convert solid waste into fuel should be provided to harness the potentials of waste in the country.

Key words: Municipal solid waste, waste, energy, heating values, calorific value.

INTRODUCTION

Municipal solid waste generation rates are influenced by economic development, the degree of industrialisation, public habits, and local climate. As a general trend, the higher the economic development, the higher the amount of municipal solid waste (MSW) generated. Nowadays more than 50% of the entire world's population lives in urban areas. The high rate of population growth, the rapid pace of the global urbanisation and the economic

expansion of developing countries are leading to increased and accelerating rates of municipal solid waste production (World Bank, 2012).

With proper MSW management and the right control of its polluting effects on the environment and climate change, municipal solid waste has the opportunity to become a precious resource and fuel for the urban sustainable energy mix of tomorrow: only between 2011 and 2012, the increase of venture capital and private equity business investment in the sector of waste-to-energy - together with biomass has registered an increase of 186%, summing up to a total investment of USD 1 billion (UNEP/Bloomberg NEF, 2012). Moreover, waste could represent an attractive investment since MSW is a fuel received at a gate fee, contrary to other fuels used for energy generation, thus representing a negative price for the waste to energy plant operators (Energy Styrelsen, 2012).

Globally, so much effort is being channelled towards developing processing technologies to release the resource and economic value of residual wastes as population grows and the demand for the best sustainable management of waste is needed. The effectiveness of solid waste management is of great importance for human health and for environmental protection (Wikner, 2009). Growing population, increased urbanization rates and economic growth are dramatically changing the landscape of domestic solid waste in terms of generation rates, waste composition and treatment technologies. The global MSW generation is approximately 1.3 billion tonnes per year or an average of 1.2 kg/capita/day. It is to be noted however that the per capita waste generation rates would differ across countries and cities depending on the level of urbanization and economic wealth. The amount of municipal solid waste generated is expected to grow faster than urbanization rates in the coming decades, reaching 2.2 billion tons/year by 2025 and 4.2 billion by 2050 (World Bank, 2012). Municipal solid waste is generated by households, commercial and industrial sectors as a result of the concentration of population and activities in urban areas. It is estimated that approximately 760,000 tonnes of MSW annually or approximately 2,000 tonnes per day is generated in Accra, but only 1,200 to 1,300 tons are properly collected (AMA, 2009).

Biomass referred to organic materials that have become residues and they are mainly from plants and animals. Biomass from fossil energy carriers begins with peat; biomass has been grouped into two categories namely primary and secondary products. The primary products come from direct photosynthetic exploitation of solar energy which includes the entire phytoplankton, such as agricultural and forestry products such as fast-growing trees, energy grass, vegetable residues, waste from agricultural including straw and residual wood from forest and industry. The secondary products of biomass are formed by decomposition of organic matter other organisms like animals, such as manure, solid waste, kitchen waste and garbage (Kaltschmitt et al., 2007). Bioenergy is currently the primary energy resource for about 2.7 billion people worldwide (Wicke et al., 2011), playing a traditional role in Africa. The total primary energy demand (TPED) for Africa is predominantly determined by biomass demand, with almost half of the energy demand (47.9%) being covered by biomass and waste. The International Energy Agency (IEA) projects a decline in the total energy share of biomass and wastes by 2035, but biomass will still continue to remain an important energy resource for Africa in the future (IEA, 2010).

The government of Ghana faces the challenge to increase renewable energy in the national energy mix in a sustainable manner. Its goal is to increase the proportion of renewable energy, particularly solar, wind, mini hydro and waste-to-energy in the national energy supply mix and to contribute to them mitigation of climate change (Ghana Renewable Energy Bill, 2011). Non-conventional energy exploitation through useful harnessing of biomass energy locked up in urban solid waste stream into grid energy seems to be a more probable option that has gained both political and public discussions on alternative energy sources (Akuffo, 1998).

Electricity is a basic input for the development of human beings, since it contributes to improving the quality of life and the social and economic growth of the people. However, the rampant use of natural resources cause harmful effects on the global climate, increasing the search for alternative sources of clean energy generation and less impact on the environment. In this sense, the use of municipal solid waste (MSW) emerges as a promising and advantageous alternative from the standpoint of environmental and financial. The proper reuse of the "trash" improved sanitation in urban centers, decreases emissions of greenhouse gases due to its decomposition and helps reduce the consumption of fossil fuels (Possoli et al., 2013).

The process of utilization of biogas generated in landfills is the simplest to explore the energy potential of MSW for energy generation. This is an alternative that can be applied to manage and solve the problems related to greenhouse gas emissions. The transformation of the energy potential of biogas into electricity is made from a process central station, where is the equipment of biogas capture and power generation (Alves, 2000). People, having become conscious of environmental impacts and the cost of fossil fuels and of landfill increases, the incinerators of the past were progressively transformed to the modern waste-to-energy (WTE) power plants that are fuelled by solid waste (Themelis, 2006).

According to Johannessen and Boyer (1999), the design and optimisation of solid waste management technologies and practices that aim at maximising the yield of valuable products from waste, as well as minimising the environmental effects have had little consideration in the Africa Region.

The MSW matter is a structural problem that requires great investments based on efficiency and in the environmental impacts. The MSW consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food, scraps, newspapers, appliances, paint and batteries. The dump is an inappropriate way to dispose municipal solid waste. The indiscrimate disposal of waste promotes the proliferation of infectious diseases, soil pollution and the emission of greenhouse gases.

Many alternatives for dealing with municipal solid waste to provide a sustainable solution that reduces greenhouse gas emissions lower the risk of ground water contamination and conserves land are now becoming more significant. The importance of energy to economic development as almost every single activity is more or less dependent on energy. The possibility of power crisis in the country is inevitable once our water levels go down or supply of gas from the West Africa Gas company is cut. Shortage of power has reoccurred so many times in Ghana. The main objective of the study was to evaluate the energy potential of solid waste streams in the Akosombo Township.

MATERIALS AND METHODS

Study area

The study was conducted at Akosombo in the Asuogyaman District of the Eastern region, Ghana. Where the country's largest hydropower station is found. It is mainly made up of Volta River Authority (VRA) estates with a population of about 0.22 million. It is situated at the south west of the Volta basin, the township lies on latitude 6°16'0.47"N and longitude 0°2'40.75"E (Google Map Data, 2013). The Eastern Region harbours the two major hydropower plants in the country, found in Akosombo and Akuse.

Sample collection and analysis

Solid waste characterisation methods used was in accordance with USEPA (1999) and Shukla et al. (2000). Random sampling was used to collect samples directly from six waste temporal and final disposal sites; dumping site, dustbins, trucks, market, slaughter house and the drains for the characterisation of solid waste. Seasonal conditions were considered as Akosombo has two main seasons: wet and dry seasons. A total of twelve (12) samples were collected from the township within the months of December, 2012 (dry month) and May, 2013 (Wet month) (Figures 1, 2 and 3).

Samples were labelled independently as dumping site, dustbin, garbage track, slaughter house, drains and market bin after collection. The mass of solid waste sample collected during each sampling was about 10 kg throughout the study period. The samples were transported to the Ghana Atomic Energy Commission laboratory and stored in a fridge at 4°C. Determination of waste material composition was done by way of physical segregation (manual sorting) and observation of collected wastes components. Each bag of waste was weighed, and then its contents emptied, sorted and weighed again. The percentage (%) composition was categorised into ten major categories as organic material. The organic components was thoroughly mixed, shredded and sieved to a quality size of < 2 mm which can be handled in the laboratory for further analysis.

Chemical composition of the solid waste sample

This was done in accordance with Bank (2009) who conducted proximate analysis by looking at moisture, volatile matter, ash and carbon. Dulong's formula as adopted by Nithikul (2007) was used to determine the heating values with the data obtained from the ultimate analysis.

This volatile matter is measured by igniting waste at 950°C (additional loss of weight on ignition at 950°C in the covered crucible). Moisture content was determined by the loss of moisture when heated to 105°C for 1 h. The ash was determined by the weight of residue after burning in the crucible, this time around opened. Compositions were experimentally determined using head space analysis and colorimetric method.

Moisture content determination

The various component of waste was weighed and placed in the oven and heated to 105°C for 1 h. Samples were cooled in desiccators and then reweighed. The percentage moisture was determined using the formula below:

$$M = \frac{(w - d) \times 100}{W} \tag{1}$$

Where: M = wet-mass moisture content, %
w = initial mass of sample as delivered, kg
d = mass of sample after drying, kg

Determination of volatile matter and ash

The dried sample and crucible was placed into a muffle furnace and ignited at 950°C for 30 min, till the ash was charred to a clear white colour. The crucible plus ash was removed from the muffle furnace, cooled for at least 30 min and carefully weighed on an analytical balance. The weight of volatile matter (on a dry basis) was computed as the difference between the dry weight of solid waste and the weight of the residue after ignition. Therefore:

$$\% \text{ volatile matter (dry basis)} = \frac{\text{Weight of dry solid waste - Weight of residue after ignition} \times 100}{\text{Weight of dry solid waste}} \tag{2}$$

Ash content is the amount of residue obtained after ignition of solid waste. Therefore:

$$\% \text{ ash (dry basis)} = \frac{\text{Weight of residue after ignition} \times 100}{\text{Weight of dry solid waste}} \tag{3}$$

Determination of calorific value

The calorific values (higher heating values) were determined using the modified Dulong equation.
The formula is as follows:

$$\text{HHV (KJ/kg)} = 337°C + 1428 (H_2 - O_2/8) + 9S \tag{4}$$

The calorific values were again calculated by using the Dulong equation, considering Nitrogen in the formula below:

$$\text{HHV (KJ/kg)} = 337°C + 1419 (H_2 - 0.125 O_2) + 93 S + 23 N \tag{5}$$

Where, C = Carbon (%), H = Hydrogen (%), O = Oxygen (%), S = Sulphur (%), N = Nitrogen (%).

Figure 1. Map of Ghana.

Lower Heat Value (kJ/g) (LHV) is the net energy released on combustion.

LHV (kJ/kg) = HHV - (2.766 x W)   (6)

Where, W = moisture content, 2.766 kg/g = coefficient of heat requirement for evaporation (Enthalpy of vaporisation) (Banks, 2009).

Determination of energy content

The energy content of the solid waste sample on both dry basis and ash-free dry basis was estimated by using the data on typical energy values of various components.

Energy values converted to dry basis: kJ/kg (dry basis) = $\frac{kJ/kg\ (as\ discarded)\ x100}{100\% - \%moisture}$ (7)

RESULTS AND DISCUSSION

Proximate analysis

Percentage composition of solid waste generated in Akosombo Township

The study obtained organic matter content that ranged between 60 to 100% with the highest value recorded from slaughter house in both seasons while the least was recorded from truck samples in dry season (Table 1). The study recorded organic matter in percentages that was higher than that of Wikner (2009), who conducted three consecutive tests and recorded the organic material (biodegradable, plastics etc) ranging between 40 and 60% of the total solid waste of the unsorted municipal solid waste (UMSW) used for experiment at Kumasi.

Figure 2. A Layout of Akosombo Township. Source of maps (Google Map Data, 2013).
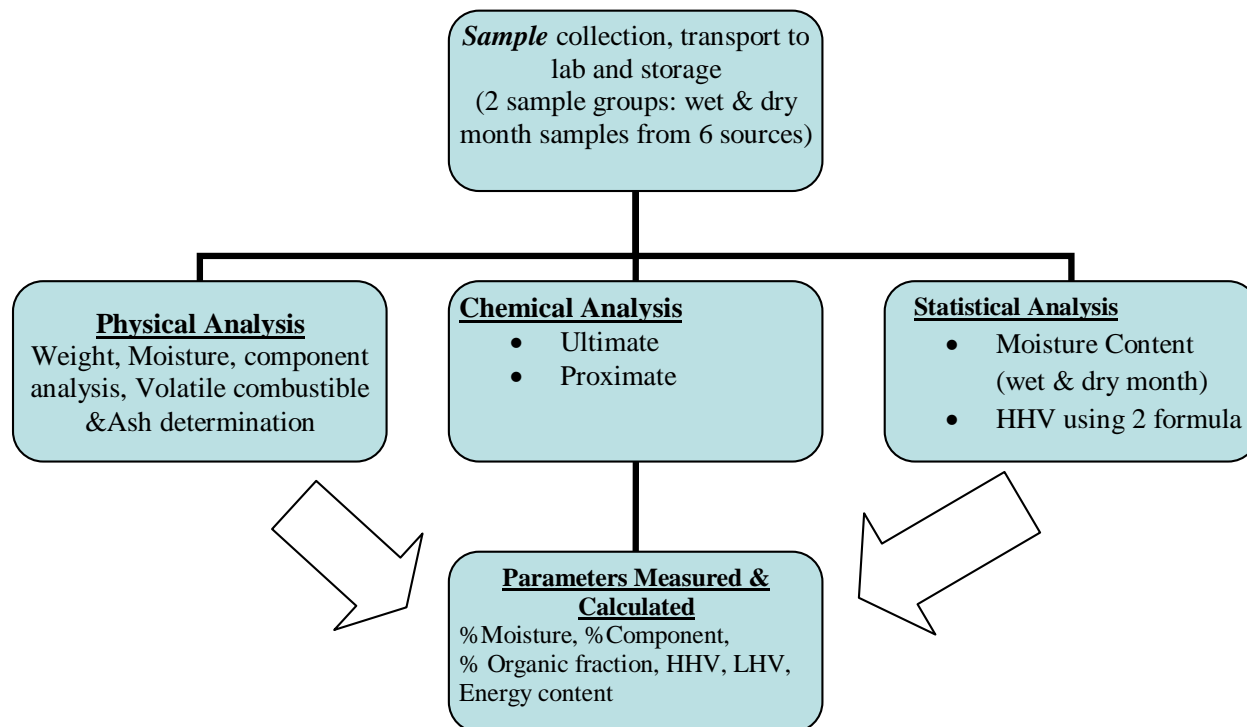
Figure 3. Work plan for precision measures.

Table 1. Percentages of the various components of solid waste generated from the study area.

Sample source	Season	% Organic component	% Inorganic component	% Moisture	% Volatile matter	% Ash
Dumping site	Wet	70.6	29.4	53.32	74.1	17.02
	Dry	65	35	26.72	75.9	19
Dustbin	Wet	75	25	26.2	85.8	1.07
	Dry	68	38	52.4	87.5	1.2
Truck	Wet	60	40	73.71	86	1.04
	Dry	67	33	43.11	68.5	1.05
Slaughter House	Wet	100	-	24.63	75.4	4.87
	Dry	100	-	28.7	70.5	4.52
Market	Wet	75	25	66.49	52.0	11.12
	Dry	62	38	60.35	70.6	10.85
Drains	Wet	64	36	71.74	30.5	2.34
	Dry	65	32	75.6	42.5	2.21

Solid waste generated in the study area has organic material of about 70% on the average. According to Shukla et al. (2000), the desirable range of organic component of the solid waste as a parameter for technical viability of energy recovery methods should be greater than 40%. The present study revealed that solid waste generated from Akosombo have sufficient amount of organic matter for bio-chemical conversion energy plants. Hence, a microbial fuel cell will able to produce electricity by converting the chemical energy content of

organic matter of the solid waste generated. This is done through catalytic reaction of microorganisms and bacteria that are present in nature. This technology could be used for power generation in combination with a waste water treatment facility (Min et al., 2005). Inorganic matter of the waste ranged from 0 to 40% with the highest recorded from track samples in wet season while the least was recorded in slaughter house samples in both seasons (Table 1). Moisture content of the waste ranged between 24.63 to 75.6% with the highest recorded from
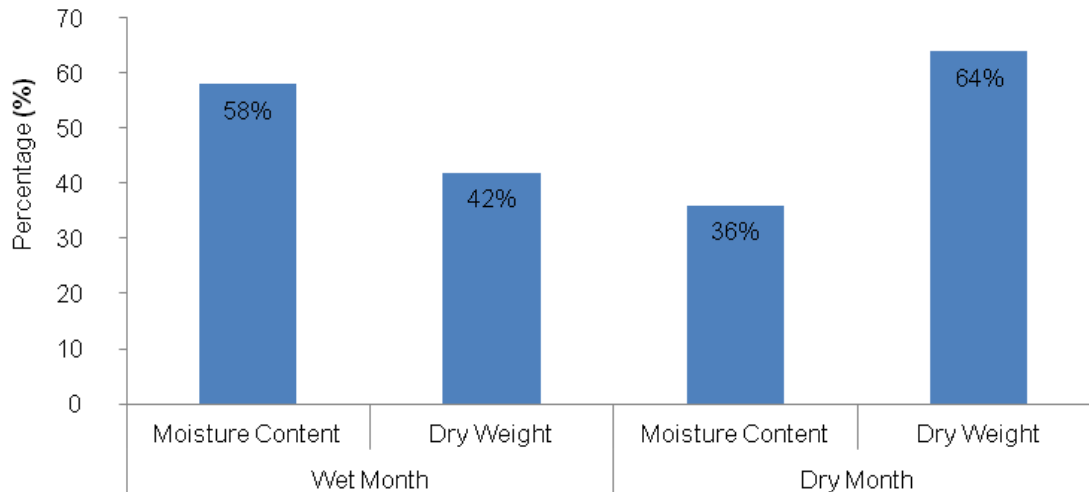
Figure 4. Wet and dry month moisture content and dry weigh of the soild waste.

Table 2. Heating values of the solid waste generated in Akosombo

HHV (kg/kJ)	Dumping site	Dustbin	Truck	Slaughter house	Drain	Market
HHV (Dulong's modified equation)	22906.2	21545.77	13882.95	29859.05	15428.12	18419.09
HHV (Dulong's equation)	22854.2	21521.47	13784.13	29808.83	15419.39	18404.87

drains in dry season while the least was recorded from slaughter house samples in wet season (Table 1). Volatile matter ranged between 30.5 to 87.5% with the highest recorded from dustbin in dry season while the least was recorded in drains samples in wet season (Table 1). According to Shukla et al. (2000), the volatile and the organic component should be greater than 40 % of the total mass of the solid waste to qualify the waste as fuel. Hence, solid waste generated from the study area can be used as fuel. The percentage ash content of the waste ranged between 1.04 to 19% with the highest recorded from dumping site in dry season while the least was recorded in track samples in wet season (Table 1).

Moisture content and dry weight of the solid waste generated in Akosombo Township

The study obtained moisture content of about 58% for wet month and 36% for the dry month (Figure 4). This implies that the moisture contents for the wet month can support a bio-chemical conversion system (plant), as it has been reported by Shukla et al. (2000) that the moisture content for such a convention should be greater than 50% while the moisture content for a thermo-chemical conversion plant should be less than 45%. This means that the waste generated during the dry month can be used as fuel to feed a thermo-chemical plant

(incineration, pyrolysis or gasification) since both values recorded by this study fall within the specified range. Cheremisinoff (2003) also reported that water content for municipal solid waste should be under 60% to be able to sustain an incineration without additional fuel. This indicates the possibility of using co-generation system for the utilisation of water as fuel in the dry and wet seasons.

Calorific values or heating values of the waste generated in Akosombo

The main attributes of waste as a fuel are water content, calorific value and burnable content. The study obtained calorific values or heating values that ranged from 1.39×10^4 to 2.99×10^4 kJ/kg (Table 2). The Lower Heating Values (LHV) obtained in this study ranged between 1.00×10^4 to 3.00×10^4 kJ/kg (Table 3). Shukla et al. (2000) reported that the calorific value is a very important parameter in establishing a thermo-chemical conversion technology to generate electricity. The average lower calorific value of the waste must be at least 6,000 kJ/kg throughout all seasons. The annual average lower calorific value must not be less than 7,000 kJ/kg (World Bank, 1999). Some studies reported that calorific value for incinerated waste should not fall lower than 6500 kJ/kg (Rand et al., 2000) otherwise, additional fuel is necessary to maintain efficient combustion. Shukla et al.

Table 3. The lower heating values and energy content of the unsorted solid waste.

Sample source	Season	LHV (kJ/kg)	Energy on dry basis (kJ/kg)	Energy on ash free dry (kJ/kg)
Dumping site	Wet	22912.4	49084	77250.2
	Dry	22985.9	31367.2	42346.8
Dustbin	Wet	21528.5	29171.4	29491.1
	Dry	21555.1	45227.9	46454.9
Truck	Wet	13684.1	52050.5	54194.3
	Dry	13768.7	24202.3	24657.4
Slaughter house	Wet	29012.4	33984.3	41152.4
	Dry	29128.9	40854	43619.2
Market	Wet	29996.3	89514.3	133972
	Dry	10013.2	25254.1	34768.2
Drains	Wet	11611.9	41089.4	44798.8
	Dry	11711.8	47999.3	52779.7

(2000) reported standard value of 286.800 kJ/kg or 1200 k-cal/kg for electricity generation. According to Incine-ration Mauritius (2007), the minimum LHV required for the waste to combust without the addition of other fuel is 7,000 kJ/kg MSW or 1.94 MWh/ton. The heating values (calorific values) of the solid waste generated from the study area are greater than the standard values for incineration of waste as fuel hence the solid waste can be used as fuel. A higher calorific value will increase the actual investment costs and vice versa (World Bank, 1999).

The study also reveals that the energy content values ranged from 2.4×10^4 to 9.0×10^4 kJ/kg on dry basis and 2.5×10^4 to 13.4×10^4 kJ/kg on ash-free dry basis (Table 3). This study also records energy values that are similar but a bit greater than values obtained from a study conducted at Kitwe in Zambia which were 15,021 to 25,956 kJ/kg on the dry basis and 16,161 to 20,313 kJ/kg on ash-free dry basis (Kazimbaya-Senkwe and Mwale, 2001). The energy values from this study ranged from 1.5×10^4 to 2.6×10^4 kJ/kg on dry basis and 1.6×10^4 to 5.0×10^4 kJ/kg on ash-free dry basis. Hence, the solid waste from the study area can be used as a fuel for a thermo-chemical conversion plant.

Conclusion

The use of renewable energy sources is becoming important to reduce global warming and to provide fuel supply which can contribute to countries' energy mix. The study recorded moisture contents of 58% and 36% for the wet and dry month of the solid waste sampled res-pectively. The study also recorded high percentage of organic matter (70% on average). The calorific values ranged between 1.39 and 2.99×10^4 kJ/kg, making the

waste suitable for thermo-chemical conversion. The energy content values of the waste generated ranged between 2.4×10^4 to 9.0×10^4 kJ/kg on dry basis and 2.5×10^4 to 13.4×10^4 kJ/kg on ash-free dry basis. The study revealed that the types of solid waste generated in the study area have substantial organic matter, moisture content and calorific values or energy content, making them suitable for energy generation. This implies that the solid waste generated have the prospects of bio-chemical conversion and thermo-chemical conversion. Based on the findings of this study it is therefore recommended that thermal plants that can convert solid waste into fuel should be provided to harness the potentials of waste.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Full Length Research Paper

Assessment of pond effluent effect on water quality of the Asuofia Stream, Ghana

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The study was done to assess the effects of potential pond effluent on the physico-chemical parameters of the receiving streams. Forty two (42) samples were collected from five ponds, upstream and downstream stations of the receiving stream for a period of six months. *In situ* measurement was conducted for physical parameters using a portable multi-parameter water quality meter (HANNA, HI9828). Samples were collected and transported to the Water Research Institute laboratory, Tamale for the analysis. pH values recorded ranged between 7.6 and 7.9 pH-unit with a mean of 7.69±0.13 pH-unit for pond samples, 7.48 to 7.73 pH-unit with a mean of 7.59±0.1 pH-unit for downstream samples and 7.25 to 7.5 pH-unit with a mean of 7.36±0.11 pH-unit for upstream samples. The nitrate concentrations at the upstream stations (7.57±0.93 mg/l) was found to be higher than that of downstream (5.02±0.25 mg/l) and in ponds (5.0±0.25 mg/l). Comparatively, aquaculture ponds recorded physico-chemical parameters that are significantly higher than those recorded in stream locations. Nitrate and dissolve oxygen were significantly higher at the upstream than downstream and ponds. The study reveals that activities such as vegetables and cereal cultivation, livestock farming and refuse dumping within the watershed serves as source of pollution and nutrient enrichment in the receiving stream.

Key words: Nkawie, physico-chemical parameters, upstream, pond, effluent.

INTRODUCTION

The fisheries sector has played a vital role in the socio-economic development of Ghana since independence. The sector has the potential to contribute substantially to the national economy through employment, gross domestic product (GDP), foreign exchange earnings, food security and poverty reduction. Despite this great potential, the sector has over the past two decades registered a slow growth of 3% per annum, falling short of its expected potential. The sector accounts for 4.5% of the national GDP (DOF, 2009). Fish is the most important source of animal protein in Ghana. The country's total annual fish requirement has been estimated to be

to be 880,000 tonnes while the nation's annual fish production average is 420,000 tonnes, leaving an annual deficit of 460,000 tonnes (DOF, 2009). This deficit is made up for, through fish imports which were estimated at 213,000 tonnes in the year 2007 and valued at US $262 million (DOF, 2007).

Aquaculture is an important economic activity in many countries and offers opportunities that contribute to poverty alleviation, employment, community development, reduction of exploitation of natural resources and food security in tropical and subtropical regions. Also, aquaculture can have direct negative impacts on wild populations of fish, birds and mammals such as seals and sea lions (Siyanbola and Adebayo, 2012). Aquaculture in Ghana is still in the developing stage even though it started about 50 years ago.

Ghana is endowed with good natural resources such as land and water (rivers, lakes and the sea) that can support aquaculture production (Cobbina, 2010). According to reports from the Directorate of Fisheries (2009) there are a number of constraints affecting the expansion of aquaculture in Ghana. These include lack of adequate supply of seed, lack of quality fish seed and suitable feeds. Low investment from the private sector is also listed as one of the major problems as well as lack of information concerning economic profitability of aquaculture. Aquaculture in Ghana is mostly done on a subsistence basis with very few commercial operators. According to Hiheglo (2008) most people in Ghana see aquaculture as a part-time, limited investment hobby due to the poor regard they have for aquaculture as an economic activity.

Water released from ponds that are partially or completely drained has greater concentrations of nutrients, organic matter and suspended solids than overflow from ponds following storms. The majority of food fish ponds are partially drained at 5 to 6-year intervals with complete draining after 15 to 20 years. However, some ponds are drained each year such as: most fry and fingerling ponds and food fish ponds that are not seinable. Concentrations of most water quality variables are highest in the final 20 to 25% of water released when ponds are completely drained. Thus, particular attention should be given to techniques for enhancing the quality of pond draining effluent and especially the final effluent from ponds (BMP, 2002). Pollution of water resources by fish farm effluents is probably the most common complaint, and this concern has attracted the greatest amount of official attention in most nations (Boyd, 2003). Four main components of aquaculture wastewater of interest include: nutrients (including nitrogen (N) and phosphorus (P)), biochemical oxygen demand (BOD), suspended solids, and pathogens (Cripps and Kelly, 1996). Up to 80% of feed ingested by fish is released to the pond environment as faecal solids and dissolved nutrients and organic matter, with just about 20% retained as fish biomass (Boyd and

Tucker, 1998; Tucker and Hargreaves, 2003). Nitrogen and phosphorus are the key nutrients generated in aquaculture systems (Boyd and Massaut, 1999). Increase in concentration of organic matter, nutrients and suspended solids in culture ponds leads to an increase in oxygen demand, eutrophication and turbidity in receiving waters (Naylor et al., 2000).

With the current high rate of global population growth the reliance on farmed fish production as an important source of protein is likely to increase (FAO, 2007; Naylor et al., 2000). The rate of waste generation within the system also increases. The concentration of organic matter, nutrients and suspended solids in ponds increases, and this directly increases oxygen demand, eutrophication, and turbidity in receiving waters (Lin and Yi, 2003; Naylor et al., 2000). This is especially the case in developing countries where there is a high reliance on organic fertilizer and natural feeding in the mostly semi-intensive systems (Diana et al., 1997; Ofori, 2000). In Ghana, it is required that, all aquacultural projects and recreational fishing obtains a permit from the Fisheries Commission, which is accompanied by environmental impact assessment upon which a licensed is issued for any project to be commenced because aquaculture is a potential polluter of the environment (Fisheries Act, 2002). The Aquaculture Adaptive Trial Centre has been in operation since 1992 and there has not been any measure to control its effluents from getting into the receiving stream, Asuafia. These effluents can pose serious threat to environmental media such as water. The main objective of this study was to assess the potential effect of the effluents from the pond on the Asuofia stream.

MATERIALS AND METHODS

Study area

The study was carried out in Nkawie, the capital of the Atwima-Nwabiagya district in the Ashanti Region (Figure 1). The district lies within the latitudes 6°.40 N and 1°.49 W and longitude 6°.67 N 8°.17 W with an elevation of 317 ft (97m) above sea level. The district records an average annual rainfall of 1270 mm. It has two rainy seasons; the major rainy season starts in March, peaking in May, and the minor from July with a peak in August, tapering off in November. The period from December to February is dry, hot and dusty. The average daily temperature is approximately 27°C (ANDA, 2006).

Site description

The study was carried out in the Aquaculture Adaptive Trial Centre, Nkawie (Figure 2). The centre is a fish farm and a demonstration centre for the fisheries Commission of the Ministry of Food and Agriculture, established in the 1992 by the ministry. The main objective of its establishment is to conduct trials on fish species, fish feed and all agro chemicals used in the fish farm industry before they are recommended to farmers. The centre has four (4) production ponds having an average size of 2500 m^2 and five nursery

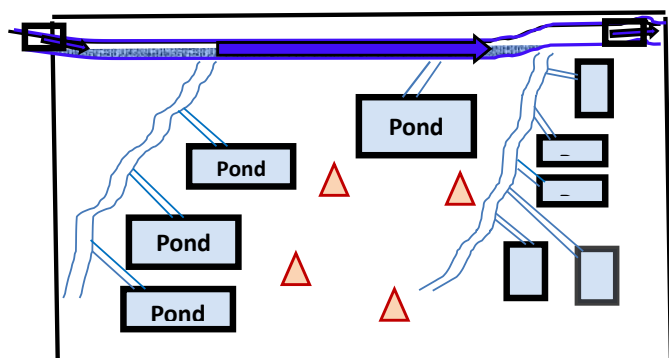**Figure 1.** Map of Ghana with Atwima Nwabiagya District (Nkawie).

Figure 2. The Aquaculture Adaptive Trial Centre, Nkawie.

ponds with an average size of 200 m². The centre shares a southern boundary with the Asuofia stream and it is designed such that the pond effluent drain into the stream by gravity through constructed drainage pipes. The stream runs through Toase, Nkawie Panyin, where the centre is located, and to Anwona Krom where it joins the Kobiri River.

Water sampling and physico-chemical analysis

In situ measurements were conducted for physical parameters such as pH, temperature, total dissolved solids and electrical conductivity using a portable multi-parameter water quality meter (HANNA, HI9828). Samples collected were kept at 4°C in ice chest and transported to the CSIR-Water Research Institute, laboratory, Tamale, on the same day of collection for analysis of total phosphate, dissolved oxygen and nitrate. A total of 42 samples were

collected from seven different locations thus, five (5) ponds, downstream station (150 m from the entry point of the effluent) and upstream station (100 m from the entry point of the effluent) of the receiving stream and were taken at two different points within each sampling unit between 8:00 am and 9:30 am for a period of six months (November 2012 to April 2013). For dissolved oxygen (DO) determinations, separate samples were collected into 300 ml plain glass bottles and the DO fixed using the azide modification of Winkler's method. Nutrients (nitrate-nitrogen and phosphate-phosphorous) were determined spectropho-tometrically. Dissolved oxygen, nitrate and phosphate analyses were in accordance with APHA et al. (1998) standard procedure.

Statistical analysis

Mean values of each parameter measured at all locations were compared and analyzed statistically, using one and two-sample t-tests, of Genstart Recovery, Edition 4 adjusted to 95% confidence limits.

RESULTS AND DISCUSSION

The pH values recorded ranged between 7.6 and 7.9 pH-unit for pond samples, 7.48 to 7.73 pH-unit for downstream samples and 7.25 to 7.5 pH-unit for upstream samples (Table 1). The pH values recorded were within the acceptable range (6.5-8.5) of WHO for natural waters. The present study observed pH values that indicate minimal productivity of water in the receiving pond hence pond effluent effect is minimal. However, pH of the ponds (7.69±0.13 pH-unit) were found to be higher than downstream (7.59±0.10 pH-unit) and upstream (7.36±0.11 pH-unit) (Table 1). The statistical analysis indicates that the effect of pond effluents on the pH at the downstream was not significantly different (p = 0.20). Pulatsu et al. (2004) also reported similar trend on the impact of trout farm on the receiving stream, Karasu, Turkey. The high pH levels in ponds can be attributed to over feeding, photosynthesis and respiration of algae as it can affect the natural acid-base balance of aquatic systems (WQA, 1996). Although, the ponds recorded higher pH than downstream and upstream, its contri-bution to downstream's pH is not significant (p=0.2) (Table 2). This suggests that there are other sources that contribute to the pH level of the stream.

The temperature values recorded ranged between 23.9 and 29.2°C for pond samples, 22.3 to 28.32°C for downstream samples and 22.1 to 27.38°C for upstream samples. The temperature of the ponds (27.1±2.26°C) were found to be higher than downstream (26.0±2.12°C) and upstream (25.16±2.10°C) (Table 1). Statistically, the study revealed that the pond's effluent have a significant impact on temperature of the stream, at the downstream station (p = 0.001) (Table 2). This can be attributed to the high exposure of standing ponds water to the sun. Similar trend was reported by Ansah (2010) who studied the impacts of pond effluents on receiving streams in Ashanti and Brong- Ahafo regions of Ghana. The high levels

Table 1. Results of physico-chemical parameters measured in ponds and stream samples.

Parameter	Pond		Downstream		Upstream		WHO STD
	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	
pH	7.6-7.9	7.69±0.13	7.48-7.73	7.59±0.1	7.25-7.5	7.36±0.11	6.5-8.5
Temperature (°C)	23.9-29.2	27.1±2.26	22.3-28.32	26±2.12	22.1-27.38	25.16±2.1	-
EC (µS/cm)	0.16-0.19	0.17±0.01	0.26-0.34	0.3±0.03	0.15-0.18	0.16±0.01	0.1-10
DO (mg/l)	8.8-9.7	9.35±0.36	7.5-9.4	8.38±0.63	12.9-16.5	14.78±1.45	41866
TDS (mg/l)	100-120	105±7.64	210-250	227±14.91	100-110	102±3.73	1000
PO_4 (mg/l)	0.58-0.72	0.64±0.06	0.06-0.13	0.09±0.02	0.05-0.08	0.07±0.01	2.5
NO_3 (mg/l)	4.7-5.39	5±0.25	4.69-5.25	5.02±0.23	6.35-8.7	7.57±0.93	10

Table 2. One-sample t-test analysis summary.

Parameter	Sample	Size	Mean	Variance	Standard deviation	Standard error of mean	Probability (p)
pH	Pond-DS	6	0.13	0.18	0.39	0.17	0.2
Temp (°C)	Pond-DS	6	-1.1	0.18	0.43	0.17	0.001
EC (µS/cm)	Pond-DS	6	0.13	0.002	0.05	0.02	0.001
DO (mg/l)	Pond-DS	6	-1	0.19	0.43	0.18	0.303
TDS (mg/l)	Pond-DS	6	121.7	216.7	14.72	6.01	<0.001
PO_4 (mg/l)	Pond-DS	6	-0.54	0.01	0.09	0.04	<0.001
NO_3 (mg/l)	Pond-DS	6	0.02	0.26	0.51	0.21	0.92

of temperature in ponds could also be attributed to sediments loads in ponds as it is reported by Poole and Berman (2000).

The electrical conductivity recorded ranged from 0.16 to 0.19 µS/cm for pond samples, 0.26 to 0.34 µS/cm for downstream samples and 0.15 to 0.18 µS/cm for upstream samples (Table 1). The electrical conductivity of downstream (0.30±0.03 µS/cm) was found to be higher than upstream (0.16±0.01 µS/cm) and ponds (0.17±0.01 µS/cm). Electrical conductivity (EC) is a measure of water capacity to convey electric current. It signifies the amount of total dissolved salts (Dahiya and Kaur, 1999).

The present study indicates that the impact of pond effluents on the down stream's electrical con-ductivity (EC) was highly significant (p = 0.001) (Table 2). Surface runoff from farming activities and refuse dumping sites close to the stream might have contributed to the high electrical conductivity levels in the stream. Earlier study by Adam and Keith (2012) reported that surface runoff, effluents, minerals and salts from urban runoff during heavy rainfall contribute to high levels of electrical conductivity in the receiving streams. The high electrical conductivity levels at the downstream station could also be attributed to the high levels of total dissolve solids because electrical conductivity is a function of total dissolved solids (TDS) (ions concentration) which determines the quality of water (Tariq et al., 2006).
The dissolved oxygen concentrations recorded ranged

from 8.8 to 9.7 mg/l for pond samples, 7.5 to 9.4 mg/l for downstream samples and 12.9 to 16.5 mg/l for upstream samples. The dissolve oxygen (DO) at the upstream (14.78±1.45 mg/l) was found to be higher than down-stream (8.38±0.63 mg/l) and ponds (9.35±0.36 mg/l) (Table 1). Dissolved oxygen is important parameter in water quality assessment and reflects the physical and biological processes prevailing in the water. The DO values indicate the degree of pollution in water bodies. The values were higher in the months of November, December, March and April when rainfall was high than in January and February when rainfall was minimal at all locations. The DO values recorded in the downstream are lower when compare with ponds and upstream indicating oxygen consumption is taking place. The demand for oxygen does not occur directly where the effluent or runoff water is discharged but instead somewhere downstream where decomposition finally occurs (Adam and Keith, 2012). Hamblin and Gale (2002) also added that, the biological and chemical oxygen demand of wastes discharged from land-based aquaculture facilities can reduce dissolved oxygen concentrations in lotic waters for short distances downstream. This explains why downstream recorded the least dissolve oxygen level. The pond effluents contributions to the downstream's dissolve oxygen was found to be significant (p= 0.003) (Table 2). This findings conforms to that of Pulatsu et al. (2004) who reported significant dissolved oxygen levels as a result of the

impact of trout farm on the receiving stream, Karasu.

The total dissolved solids concentrations recorded ranged from 100 to 120 mg/l for pond samples, 210 to 250 mg/l for downstream samples and 100 to 110 mg/l for upstream sample. The total dissolve solids (TDS) of the downstream (230±0.02 mg/l) were found to be higher than upstream (100±0.004 mg/l) and ponds (110±0.004 mg/l) (Table 1). The level of TDS of the stream is within the acceptable standards (<1000 mg/l) and is considered to have an excellent taste (< 300 mg/l) (WHO, 1996). Total dissolved solids indicate the salinity behaviour of groundwater. Water containing more than 500 mg/l of TDS is not considered desirable for drinking, but in unavoidable cases 1500 mg/l is also allowed (Shrinivasa and Venkateswaralu, 2000). Statistical analysis indicates that the effect of pond effluent on the downstream TDS was highly significant (p< 0.001) (Table 2). Similar trend was reported by Ansah (2010) who study the impacts of pond effluents on receiving streams in Ashanti and Brong- Ahafo regions of Ghana. The high levels of TDS concentrations at downstream station could be attributed to the pond's effluent. However, surface runoff from farming activities and refuse dumping site closed to the stream might have also accounted for the high levels of TDS concentrations in the downstream.

The phosphate concentrations recorded ranged from 0.58 to 0.72 mg/l for pond samples, 0.06 to 0.13 mg/l for downstream samples and 0.05 to 0.08 mg/l for upstream sample. The phosphate concentration of the pond (0.64±0.06 mg/l) was found to be higher than down-stream (0.09±0.02 mg/l) and upstream (0.07±0.01 mg/l) (Table 1). The phosphate concentrations were within WHO standard of 2.5 mg/l.

Phosphate may occur in surface water as a result of domestic sewage, detergents and agricultural effluents with fertilizers. The values were lower in ponds during the months of November, December, March and April, when rainfall was higher than in January and February when rainfall was minimal. Statistical analysis indicates that the impact of pond effluents on the downstream phosphate concentration was highly significant (p< 0.001) (Table 2). This collaborates with Ansah (2010) and Pulatsu et al. (2004) findings, that study the impacts of pond effluents on receiving streams in Ashanti and Brong- Ahafo regions of Ghana and the impact of trout farm on the receiving stream, Karasu, respectively. The high phosphate concentrations in ponds could probably be attributed to an agro-chemical, vitazyme, which was used to boost phytoplankton growth in the ponds as they contain high concentration of phosphate (Meertens et al., 1995). The accumulation of decomposed solid waste releases labile phosphorous to the water column (Kelly, 1992, 1993). This could have contributed to the high levels in receiving streams during rainfall periods (Rao, 2011). The fish feed and faeces might have contributed to high phosphate concentrations. Bureau and Cho (1999) reported that, dissolved carbon, nitrogen and phosphorus are released into the water column by solubilization from feed and faeces and through the gill and urinary excretions of fish. According to Perry et al. (2007), it is not possible to find a high phosphate concentrations if the algae are already blooming, as the phosphates are already in the algae but not in water. This explains the low levels of phosphorus observed at the upstream because algae were observed at some sections of the upstream.

The nitrate concentrations recorded ranged from 4.7 to 5.39 mg/l for pond samples, 4.69 to 5.25 mg/l for downstream samples and 6.35 to 8.7 mg/l for upstream samples. The nitrate concentrations at the upstream stations (7.57±0.93 mg/l) was found to be higher than downstream (5.02±0.25 mg/l) and in ponds (5.0±0.25 mg/l) (Table 1). The mean concentrations were higher in the months of November, December, March and April when rainfall was higher at the upstream and downstream stations than in January and February when rainfall was minimal. However, the mean values reduced in ponds when rainfall was higher and increased with minimal rainfall. Surface water contains nitrate due to leaching of nitrate with the percolating water. Surface water can also be contaminated by sewage and other wastes rich in nitrates. Statistically, the effect of pond effluents on the downstream nitrate concentration was not significant (p= 0.07) as compared to the upstream (p < 0.001) (Table 2). This contradicts Ansah (2010) and Pulatsu et al. (2004) findings, that reported high levels in ponds than receiving streams. Runoff from refuse dumping sites and farming activities affect nitrate concentrations greatly in receiving waters as fertilizers used on farms, through leaching and surface runoff into the stream during heavy rainfall could have contributed to the high levels in receiving streams (Rao, 2011). This further explains why nitrate concentrations were higher at upstream and downstream stations during rainfall periods. However, the nitrate concentrations observed did not exceed the Environmental Protection Agency (EPA) maximum contaminant level (MCL) of 10 mg/l for drinking water (Self and Waskom, 2008).

Conclusion

The study revealed that ponds effluents have no significant effect on the receiving stream based on all physico-chemical parameters considered. The physico-chemical values recorded from ponds and the stream were within WHO stipulated limits. However, the study revealed that activities such as vegetables and cereal cultivation, livestock farming and refuse dumping within the watershed serves as source of pollution and nutrient enrichment in the receiving stream. The high concen-tration of nitrate at the upstream and high levels of total dissolve solids and electrical conductivity at the down-stream station could have resulted from farming activities

and a refuse disposal close to the stream. The study recorded concentrations of parameters at downstream sites that were close to that of fish ponds values. Which implies that, fish farms actually contributes to the concentrations of the parameters considered in the stream, and any potential effects in the future will depend on how effluents are managed, including effluent treatment, drainage design, frequency and volume of waste released.

In conclusion, the ponds effluent has a significant effect on almost all the parameters assessed in the stream with the exception of pH and nitrate. However, the effect of the pond effluents on the stream is currently not severe as all the parameters assessed were within the acceptable approved standards.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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