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Table of Contents: Volume 11 Number 7 July 2017

ARTICLES

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Review

Another decade of water quality assessment studies in Tanzania: Status, challenges and future prospects

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Increased population pressure and environmental stressors have amplified research on water quality both locally and globally. In Tanzania, water quality assessment is a mature discipline, with an over four-decade history. In this article, studies on water quality assessment in Tanzania from 2006 through 2016 are reviewed. The approach used is to scan selected publications to gather data and information on types and concentration levels of contaminants measured in surface and ground waters; their status, trends and potential health risks. The aim is to establish research gaps that call for further investigations and factors that hinder such efforts so as to provide insight that can facilitate future studies. Significant outputs were found in terms of study focuses and investigated locations. Lack of analytical facilities, complexity in the interpretation of toxicological data and data management practices represent major setbacks, while land-use practices, sea water intrusion, climate change and biogeochemical features continue to the scale-up threat on surface and ground water quality in the country. It is pragmatic that there is still a gap in research on such subjects as effects of climate change; effects of mixed toxicity of chemicals; risk characterization; analysis of emerging contaminants of concern and development of remediation plans for specific contamination problems. Some strategies towards ameliorating the challenges are suggested. The study puts forwards some recommendations, including the establishment of a National Water Quality Assessment Programme that will provide central water quality descriptions of the nation water resources.

Key words: Water quality assessment, contamination status, analytical challenges, Tanzania.

INTRODUCTION

Assessment of the quality of surface and ground waters has remained one of the major interests of environmentalists, scientists, policy makers and regulatory authorities, locally, regionally and globally. Poor water quality is directly associated with inadequate water supply, health risks and effects to aquatic life (Tiwari et al., 2017; Tiwari et al., 2016; Mahato et al., 2016; Myers, 2015). Water quality assessment is the overall process of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and

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its suitability for intended uses (Chapman, 1996). The aim is to define the condition of the water so as to provide the basis for detecting trends and to provide information enabling the establishment of the cause-effect relationship. It involves a programmed process of sampling, measurement and subsequent recording or signaling, or both, of various water characteristics, often with the aim of assessing conformity to specified standards (WHO, 2004). The activities can be differentiated as long-term, short-term and continuous.

A complete assessment of water quality is based on three components, namely hydrology, biology and physico-chemical. The hydrological aspect deals with how the water movement through its endless circulation affects its quality. Water is studied as an element of the landscape together with its interaction with the environment. It seeks to explain the water balance in terms of flow, direction, discharge, time and space (Jing et al., 2017). The biological aspect deals with the presence of microbial organisms and water-borne pathogens. It aims at achieving a water quality standard that will not harm aquatic organism and is safe for human consumption. This can be carried out in terms of the response of individual species or biological communities to changes in their environment. The physico-chemical aspect of water, normally measured by suitable analytical methods, studies the physical and chemical characteristic of water that is determined by different factors such as climatic conditions, the local geology of the area, soil cover, land use practices and others (Gordalla, 2011). Comprehensive water quality assessment is, therefore, a complex endeavor and involves multiple factors, for example, determination of the hydrological, biological and physicochemical characteristics can be carried out in the field or in the laboratory using varieties of methods and combinations of methods to produce a wide range of data. The key elements include preliminary surveys; field sampling; shipment of samples; analysis of targeted chemical and biological species; determination of other key variables; data analysis and data interpretation.

Globally, water quality assessment has a long history; in the earlier decades, systematic water quality assessment was only known in the industrialized countries, where the main water quality issue of concern was feacal as well as metal pollution (Jing et al., 2017; Tiwari et al., 2015). The assessment was therefore mostly on the biological aspect and was solely for the purpose of diseases prevention (Trudgill et al., 1999). However, with modern discoveries, technological advancements and realization of new concerns, there have been significant changes, new developments and paradigm shifts. Water quality assessment is now a well-known body of knowledge and includes aspects of preservation of the entire systems, together with the diverse groups of endangered species of natural or pristine conditions making up the whole aquatic ecosystem. This paper is based on thorough review of publications, including research papers, government reports from various departments and consultancy reports. The aim is to develop a comprehensive picture and provide an overview of the status, new developments and existing challenges so as to put forward some recommendations.

STUDY AREA

Geographical setting and climatic condition

Tanzania is one of the East African countries, located between Latitude 1° and 12° south and Longitude 29° and 41° east. It is bordered by Kenya and Uganda on the north; Mozambique, Zambia and Malawi on the south; Rwanda, Burundi and Democratic Republic of Congo on the west and by the the Indian Ocean on the east. It has a total area of about 945,000 km^2, of which about 886,000 km^2 is land that includes three major coastal islands of Mafia, Pemba, and Zanzibar and a coastline that is about 800 km long; and 59,000 km^2 is surface water. The country's landscape is characterized by a wide variety of topography, including large freshwater and salt water bodies, the East African Great Rift valley, narrow coastal plains, savannah landscape, steppe landscape and tropical forests. The northeast part of the country is mountainous and includes Mount Meru, Mount Kilimanjaro, and the Usambara and Pare mountain ranges. The eastern part is the coastal strip that is rich in biodiversity, including mangrove swamps.

The Tanzanian climate is mainly tropical but varies widely according to topography. Temperatures rarely fall lower than 20°C except in the highlands and may reach above 31°C during the hottest periods of the year in some parts. The country has seasonal rainfalls where the north and east part experience two distinct wet periods; the short rains "Vuli" in October to December and the long rains "Masika" from March to May; while the southern, western, and central parts of the country experience one wet season that continues October through to April or May. Figure 1 is the map of Tanzania showing climatic classification.

Water resources

Tanzania has abundant surface and groundwater resources, including wetlands, natural streams, rivers and lakes, including nine water basins. Among the Tanzanian water basins are the Rufiji River Basin (177,000 Km^2) which is the largest, followed by Ruvuma (53,330 Km^2) and Pangani (43,650 Km^2). Others are Wami-Ruvu, Lake Tanganyika, Lake Victoria, Lake Nyasa, Lake Rukwa and the internal drainage basin. Figure 2 is the map of Tanzania showing the major water bodies. Tanzania

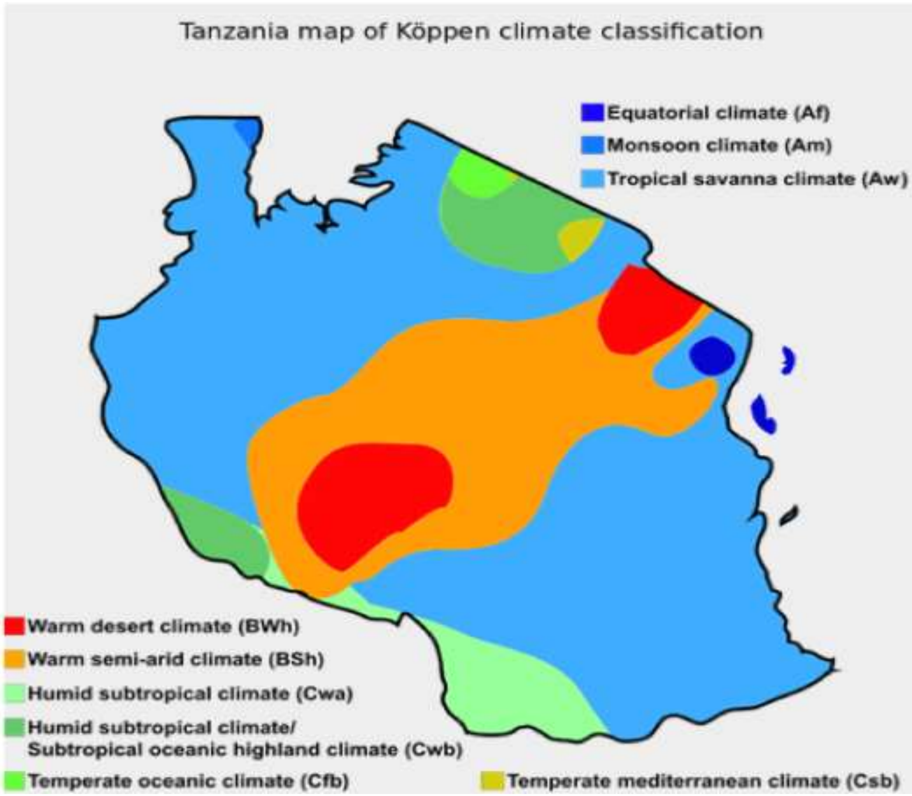

Figure 1. Climatic classification of Tanzania. Source: Ali Zifan (Enhanced, modified, and vectorized). - Derived from World Koppen Classification.svg., CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47085579.

shares all the great lakes in east Africa with the neighboring countries, these including Lake Victoria, Lake Tanganyika and Lake Nyasa/Malawi. Additionally, the country shares major trans-boundary rivers with the neighbors including rivers Kagera and Mara (Kimaro, 2010).

Studies indicate that the contribution of ground water potential to total water resources is not well documented (Kashaigili, 2010). Groundwater resources are mainly used in the form of shallow wells for domestic purposes over a wide part of the country, mainly rural areas. They are also commonly used in the peri-urban suburbs where there is no distribution network and in places with unreliable supply. Most boreholes are located in the internal drainage basin. However, there have been concerns that the rapid increase in the use of shallow wells may lead to an increased risk of groundwater contamination from pit latrines in such locations (Kashaigili, 2010).

Tanzanian is among the African countries with a high rate of population growth, its population is said to have quadrupled in the last 50 years (World Bank, 2014). The Tanzanian population was estimated at more than 51 million in 2016 (UNSD, 2017). The country depends on its surface and ground water resources for the provision of clean water, food and other livelihood resources to the population. Apart from that the surface water resources in Tanzania are contributing to the tourism sector, agriculture, power generation and industry. They are also essential as habitats for aquatic plants and animals. However, like most developing countries, the economic activities in industry, energy production, mining, agriculture and livestock keeping depend largely on these resources, exerting much pressure on them, including possible contamination by different kinds of micro-contaminants (Ngoye and Machiwa, 2004; Mtanga and Machiwa, 2007; Hellar-Kihampa, 2011).

Potential stressors of water quality

Among the key aspects that researchers put into considerations when planning for water quality assessment are what parameters to monitor, where to monitor and when to monitor. In studying the anthropogenic influences on water quality, researchers have been able to link different contaminants to specific categories of land-uses. For example, agricultural land-use, including

Figure 2. Map of Tanzania, showing location, administration regional boundaries, major rivers and water basins (Source: Elisante and Muzuka, 2015).

croplands, horticulture, gardening and livestock keeping, has been linked to the high concentration of nutrients (N, P), pesticide residues and enrichment of some major elements (Cl, Na, Ca, Mg) (Brodie and Mitchell, 2005). Urban land-use, including commercial, residential and transportation activities, has been associated with elevated concentrations of trace-elements (As, Cu, Cr, Zn, Cd, Mn, Pb, Ni and V) and enrichment of nutrients (NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, SO_4^{2-}) both in water and sediment (Fitzpatrick, 2007). Mining and smelting activities have been linked to heavy metal pollution, especially As, Hg, Zn and Pb (Mataba el at., 2016).

Studies have shown that in the Sub-Saharan Africa countries including Tanzania, water contamination is caused by a number of stressors, including land-use practices. It has further been indicated that the extent of water contamination might be compounded by pressures from structural adjustment programmes launched in response to economic crises, over-exploitation of natural resources, lack of state control and lack of proper enforcement of environmental regulations (Nyenje et al., 2010).

According to the National Environmental Policy of Tanzania (NEP), the major environmental challenges of Tanzania include lack of accessible, good quality water for both urban and rural inhabitants; pollution; loss of wildlife habitats and biodiversity. Others are deterioration of aquatic systems and loss of land-cover. The National Environmental Policy further stipulates that the productivity of lake, river, coastal and marine waters in the country are threatened by pollution and poor management. Human activities in towns and the country-sides are said to have affected the health of many surface water bodies, and lowered the productivity of the environment in general (NEP, 1997).

Both surface and ground waters are under a threat of contamination from different sources of stressors, including agricultural activities, industrial activities, transportation, mining, urban settlements and even rural settlements. Agriculture is the main land use sector in the country. It is estimated that more than 13 million hectares of land are being cultivated. This is however only 33% of the total arable land in the country (Tanzania Agriculture, 2017). Among the main food crops in Tanzania are maize, sorghum, millet, rice, wheat, beans, cassava, potatoes and bananas, whereas main cash crops include coffee, sisal, cashew nut, tea, cotton and tobacco. At one point in history, Tanzania was the largest producer of sisal in the world. Agricultural products also contribute largely to the country's foreign exchange in terms of cash crop exports. Owing to this, the use of agrochemicals in Tanzania is widespread.

Studies conducted in various agricultural locations in the country revealed environmental contamination due to pesticide residues (Kishimba et. al., 2003). For example, the sugarcane plantations at Arusha Chini in Kilimanjaro region which have been operational since the early 1940s are one of the largest and oldest users of pesticides in the country (Mtambo and Katundu, 1996), with an over sixty years history of pesticide use. Analysis of surface waters collected close to the plantations has revealed contamination by different types of pesticide residues (Hellar and Kishimba, 2005). The country has also been a long time the chief producing area for the famous Arabica Coffee and flowers for export, both of them chemically intensive (Msogoya and Maerere, 2006). Studies have further established that pesticide management practices in the country, including storage, disposal of empty containers and disposal of obsolete pesticides are generally poor (Mwema and Sharp, 2016). This increases the risk of surface and ground waters contamination by pesticide and their residues. In other parts of the country such as the Lake Victoria basin, non-point source pollution from agricultural practices and unplanned urban settlements were found to affect the quality of water bodies (Machiwa, 2003).

Livestock keeping is another activity that poses contamination threat in the country, especially in the locations where households keep large numbers of cattle, goats and sometimes sheep. There some large concentration of pastoral communities, who are nomadic and depend on livestock for their livelihoods, moving constantly in search of water and pasture. Altogether, livestock keeping has been linked to the inputs of chemical species to the water sources worldwide (Hellar-Kihampa et al., 2013a).

Discharge of industrial effluents is another serious environmental issue of concern. The existing industrial activities, especially in main towns, include textile and garments, soap and detergents, agro-industries such as sugar, sisal, vegetable oil/fat refineries, dairies, breweries, cotton ginneries, distilleries, coffee processing; fruit canning and tanneries. Other important industries include paper and plastic production, fertilizer, cement, metal works, timber and bottled water production. Most of these industries are relatively small, but may cause pollution of surface and ground waters due to the large organic load and the use of some chemicals such as dyes. It has also been reported that at some locations, freshwater bodies are used as points of disposal for domestic wastes, including outlets of municipal waste water, a practice associated with pollutant loading into water (Mwegoha and Kihampa, 2010). Environmental challenges associated with wastewater management especially in urban centers in the country arise from haphazard and unplanned expansions of towns and cities, while municipal authorities or other utility service providers have limited resources. This has been indicated as a contributor to pollution of surface waters and deterioration of environmental quality (Kihampa et al., 2016).

Another potential source of contamination in Tanzania is mining activities. The country is rich in mineral deposits which include gold, diamond and tanzanite. Others include tin, phosphate and limestone. In some locations, there are uncontrolled mining activities that are considered as significant environmental risks due to the likelihood of contamination of freshwater systems, especially from toxic metals and poor sanitation of the mining camps (Macfarlane and Mitchell, 2003). Studies conducted close to the mining sites indicate different degrees of contamination by toxic metals and dispersion in environmental matrices including Hg and As, for example, the Mugusu and Rwamagaza artisanal mines in the Lake Victoria goldfields (Ikingura et al., 2006).

REVIEW OF WATER QUALITY ASSESSMENT STUDIES IN TANZANIA 2006 TO 2016

Study approach and objectives

The earliest records found in respect of water quality research in Tanzania were from the early 1970s (Mohamed, 2003), including those by Steinbach (1974). In the decade that followed, more water quality assessment studies were carried out in the country, including those by Mashauri and Mayo (1989); Kandoro (1997) and Mohamed (1997). Other studies conducted in the more recent past include those by Machiwa (2000), Ikingura and Akagi (2003), Kishimba et al. (2003), Ngoye and Machiwa (2004), among others.

The 2006 to 2016 decade is characterized by increased public awareness of environmental protection and concerns over public health. This is evidenced by the increase in the number of documented studies that investigated the quality of different types of water in the country, probably due to increased awareness on water quality issues, and also increased the availability of modern technologies for water quality assessment. For example, it was during this decade that Tanzania established its own water quality standards through the Tanzania Bureau of Standards (TBS, 2008). Some review articles have been written on the subject, including that by Byrceson et al. (1990) which featured the East African Region by Mohamed (2003) which featured studies conducted between late 1970s to late 1990s and by Elisante and Muzuka (2015) which featured occurrence of nitrate in ground water aquifers, among others. However, no review has been done on studies conducted in the most recent decade (2006 to 2016).

Findings from different studies

Some of the water quality assessment studies conducted in the country within the specified decade (2006 – 2016) are summarized in Table 1. The information includes types of parameters measured and types of water sampled; locations where the studies were conducted and summary of the key findings obtained.

The summary in Table 1 shows that researchers investigated different types of water in various locations to assess levels of toxic metals, inorganic contaminants, nutrients, bacteria, organic matter and physic-chemical parameters, among others. In all these studies, quality of water was found to be affected by different stressors related to human activities. For instance, the study by Mataba et al. (2016) investigated the distribution of trace elements in the aquatic ecosystem of the Thigithe River, the main community source of water for human and livestock consumption in over 15 villages of Ingwe division close to the Mara Gold Mine in Mara Region, north Tanzania. It was found that water was contaminated by the trace elements As, Cd, Co, Cr, Cu, Hg, Ni, Pb and Zn, even though their concentrations were below or near the detection limits.

The study by Mihale (2015) assessed levels of nitrogeneous (ammonia, nitrite and nitrate) and phosphate compounds in the Great Ruaha River water in response to natural and human pressures. High levels of ammonia and nitrite were observed in some locations with indications of the influence of land cover, land use, soil type and groundwater level. Phosphate levels were also high with indications of anthropogenic influences such as fertilizer applications. Nitrogen (N) and phosphorus (P) are essential for the growth of plants and animals, for this reason they are often identified as nutrients. However, when in excess concentrations in natural waters, the two may lead to what is known as 'nutrients pollution'. This is among the leading causes of water degradation in rivers and lakes, both in the developed and developing the world (Leone et al., 2009).

Kihampa et al. (2016) found high levels of dissolved solids, nutrients, and toxic metals in urban rivers receiving treated industrial wastewaters in Dares Salaam city. It was revealed that poorly treated wastewaters contributed into contaminating the receiving waters. This was again observed in Kilimanjaro Municipality where treated wastewater used for fish raring was still contaminated with toxic metals Cd, Cr, Cu and Pb in levels that exceeded the TBS limits for metals in reclaimed wastewater used for aquaculture (Tarimo and Hellar-Kihampa, 2016). This indicates that the national standards for effluents discharge into rivers and streams are not enforced

The study by Hellar-Kihampa et al. (2013a, b, 2014) analysed a number of micro-contaminants, including toxic metals, inorganic ions, nutrients, pesticide residues and organic contaminants in the main Pangani River and its tributaries to determine the impacts of natural and anthropogenic influences. The results indicated a low level of contamination of river water by various diffuse sources, including applications of agro-chemicals in agricultural fields and livestock keeping. Although concentrations or organic contaminants detected are rather low, their mere presence in the water body is of particular environmental concern due to their persistent, toxic and bioaccumulative nature. Their lipophilic tendency, hydrophobicity and low chemical and biological degradation rates cause them to have high levels of

Table 1. Some water quality assessment studies in Tanzania 2006 - 2016.

Location	Water type	Parameter	Status	Reference
Thigithe River (North Mara Gold Mine)	Surface water	Trace elements	High levels of As and Hg in downstream site where artisanal mining is performed	Mataba et al. (2016)
Maji ya Chai River, Arusha	Surface water	Natural organic matter	Water quality influenced by precipitation and humic substances	Aschermann et al. (2016)
Dares Salaam City	Wastewater discharged into river systems	Nutrients and toxic metals	Poorly treated industrial effluents contaminate urban rivers with nutrients and toxic metals	Kihampa et al. (2016)
Mount Meru,	Ground water	Stable isotope compositions of nitrogen-nitrate and oxygen-nitrate and concentration of nutrients	80% of all water sources had nitrate concentration higher than background concentration of 10 mg/l	Elisante and Muzuka (2016a)
		Total coliform (TC), faecal coliform (FC), *Escherichia coli* (*E. coli*) and faecal streptococci (FS)	Ground water sources contaminated by bacteria due to the positioning of pit latrines, inoculation of microbes by exposed buckets and inefficiency of the casing material.	Elisante and Muzuka (2016b)
Great Ruaha River	Surface water	Nitrogen and phosphorus	High levels of ammonia and nitrite in some locations associated with anthropogenic activities	Mihale (2015)
Kilimanjaro Municipality	Wastewater	Toxic metals, nitrogen, and faecal coliforms	Concentrations of toxic metals in water released into the environment exceeded WHO limits	Tarimo and Hellar-Kihampa (2016)
Dares Salaam City	Ground water	Inorganic ions	Water quality influenced by seawater intrusion and anthropogenic inputs	Sappa et al. (2015)
Pangani River Basin	Surface water	Toxic metals	The presence of low levels of metal contaminants with concentration patterns indicating anthropogenic inputs.	Hellar-Kihampa et al. (2014)
Msimbazi River, Dares Salaam	Surface water	Industrial pollutants	Levels of Cr exceeding the Who and TBS standards.	Mwenda (2014)
Kinondoni District, Dares Salaam	Groundwater	fecal and total coliform bacteria	water samples from boreholes were contaminated with bacteria in quantities higher than the TBS limit	Kiangi (2014)
Pangani River Basin		Nutrients and inorganic ions	Inputs of nutrients (N-compounds) from human activities; levels of inorganic ions mostly indicate natural sources	Hellar-Kihampa et al. (2013a)
		Organic contaminants	Water samples contaminated by organochlorine pesticide residues from historical agricultural applications.	Hellar-Kihampa et al. (2013b)
South-eastern Tanzania	Surface water and groundwater	Isotopes and major ions	Elevated NO_3^- concentrations in a few shallow aquifer samples imply sewage infiltration from domestic wastewater.	Bakari et al. (2013)

Table 1. Cont.

Temeke District, Dares Salaam	Drinking water	Physico-chemical parameters	Significantly high levels of chloride exceeding the allowable WHO limit	Napacho and Manyele (2010)
Inter-tidal areas of Dares Salaam			Polycyclic aromatic hydrocarbon (PAH) contamination of surface sediments and oysters	Gaspare et al. (2009)
Mzinga Creek and Ras Dege, Dares Salaam	Mangrove ecosystem	Toxic metals	Low levels of Cd, Cr, Cu, Hg, Pb and Zn in water, suspended particulate matter and oysters. Contributed by industrial and agricultural activities and transportation activities in the nearby Dar es Salaam port	Mtanga and Machiwa (2007)

accumulation in the environment and long-term implication to the ecosystems (Minh et al., 2007).

Kiangi (2014) investigated the quality of domestic water obtained from boreholes in some wards of Kinondoni District in Dares Salaam, focusing on fecal and total coliform bacteria and some physic-chemical water quality parameters and compared them to the WHO guidelines and TBS standards. The obtained results indicated that the water samples from boreholes were contaminated with bacteria in population higher than the TBS and WHO limits. Napacho and Manyele (2010) investigated the quality of drinking water from different sources in Temeke District in Dares Salaam. The sources examined included tap water, river water and well water (deep and shallow wells). The study revealed that some of the physico-chemical parameters in water samples did not meet the permissible World Health Organization (WHO) and the Tanzania Bureau of Standards (TBS) levels. Chloride levels were found to be significantly higher than the allowable WHO limit.

CHALLENGES AND FUTURE PROSPECTS

Challenges

Analytical instruments

In water quality assessment studies, analytical chemistry plays a significant role especially in the analysis of samples; however, this often requires the use of expensive equipment. In most cases, sophisticated analytical research instruments and methods with very low detection limits are needed in order to detect most micro-contaminants in environmental samples. In recent decades, some robust and reliable methods that allow multiple analyses of samples have replaced the rudimentary, labour-intensive and time-consuming methods (Filella, 2013). Modern methods for measuring trace amounts of contaminants in the water are based on application of analytical techniques such as gas chromatography-mass spectrometry (GC-MS), high-performance liquid chromatography (HPLC), inductively coupled plasma-mass spectrometry (ICP-MS), ion chromatography (IC) and advanced liquid chromatography-tandem mass spectrometry (LC-MS^2), hydride generation atomic absorption spectrometry (HG-AAS) among others.

Other advanced tools for water quality studies include the use of remote sensing and real-time monitoring, for example, to assess the impacts of human activities, land-cover, water clarity, algal bloom, some optically related water quality characteristics and spatial and temporal information about fundamental environmental dynamics. There are also some advanced data-transfer technologies that allow continuous monitoring and capture changes as they occur. In terms of microbiological aspects, for example, authors in developed countries are now employing “Microbial Source Tracking” which is an advanced technology that identifies source-specific fecal pollution in environmental waters from different hosts such as humans, livestock, and wildlife (Younos and Parece, 2015).

In a developing country such as Tanzania, purchasing and maintaining analytical instruments is surrounded by many problems, including funding and expertise for operating and servicing the instruments. Without sufficient investment in scientific equipment, technical capacity becomes one of the major limiting factors for effective water quality assessment (Öman et al., 2006). For example, among the cited studies in Table 1 that employed such techniques, most were made possible by using resources from developed countries laboratories (Mataba et al., 2016; Mihale, 2015; Hellar-Kihampa et al., 2013a, b, 2014). With increased technological development and the introduction of new products for human, animal and agricultural use such as pharmaceuticals and personal care products, the range of chemical components that need to be sought in environmental samples at trace levels also increases. The lack of appropriate techniques for analysing such contaminants, whose numbers are constantly increasing, is of particular concern. Further to that, the analytical methods require solvents, reagents and standards such as certified reference materials and internal standards for quality control and assurance purposes.

Interpretation of results

Another challenge is the complexity of interpretation of the toxicological data. In most cases, data from the local environment are compared to regulation aspects or standards of other countries such as the European Union and the US EPA. However, studies suggest that there might be lots of differences between the local environment and the environments where the standards were first established. For example, the standard test species used to test toxicity may not be those existing in the local environment; the sizes of the water bodies assumed in the exposure modeling might be different due to climate, e.g. rainfalls in the tropical climate tend to be much heavier and thus runoffs become much heavier and more often. Other important considerations are estimates of sedimentation rates which are actually significantly higher in the tropical surface waters. As one step, the Tanzania Bureau of Standards has set quality standards for assessing the suitability of different categories of water. However, there is still a lack of national standards for some beneficial water uses such as agriculture, recreational and wildlife. Currently, researchers are using some international guidelines such as those of the WHO.

Most of the cited studies were concerned with establishing concentration levels of different micro-contaminants in a location and suggesting their possible sources. The spatial and temporal variations of water quality parameters were indicated to be influenced by multiple-factors, including several upstream stressors acting together. However, proving the cause-effect relationship or exact contributions of different diffuse sources to the overall contamination for regulation purposes has been a challenge, while aspects such as detection of long-term trends, effects of mixed toxicity of contaminants and assessment of exact risks to aquatic organisms were left to chance. The reasons for this scenario are reported to include inadequate analytical tools, funds, and human resources.

Data management

The government of Tanzania established a specific ministry responsible for water in the early 1970s. The ministry has contributed in management and development of water quality monitoring and assessment programs, although there has generally been more priority in monitoring water quantity as compared to water quality (Hawkins and Gillespie, 2010). Data that identify contaminants and characterize their sources are not readily available, while pollution control capacity is still inadequate. The only reliable source of primary data is from detailed periodic surveys of particular water bodies conducted by specialist programmes or donor-sponsored projects such as Pangani River Basin and Lake Victoria Environmental Management Project (Hawkins and Gillespie, 2010). In most other cases, monitoring data have been irregular and reports in the public domain on water quality difficult to get. Generally, a water quality database for the nation’s water is not available. Most of the cited studies were coordinated by individuals/ research groups in training and research institutions and are only published in research journals. Availability of useful and updated information of interest to professionals and stakeholders is still a challenge. The National Water Quality Management and Pollution Control Strategy document (Hawkins and Gillespie, 2010) gives some important recommendations for management of water quality data that if followed, will provide more focused and improved data management.

Future prospects

The observed trends in technological advancement, economic forces, population dynamics and climate change in the country are likely to introduce more significant and long-lasting environmental stressors that impact both quality and quantity of freshwaters. It is obvious that the coming decades will witness growing need for water quality assessment more than in the past. Such assessments will also require increased parameters than were considered in the past, and therefore a requirement for more advanced tools and techniques. There are almost no studies on emerging contaminants of concern such as pharmaceuticals and personal care products; although such contaminants are no longer termed as ‘contaminants of emerging concerns’ in developed countries because their determination in the environment is well published. Further to that, studies on persistent organic contaminants are relatively few, probably due to the challenge of analytical instruments, because generally studies that measured organic contaminants in environmental samples in the country are still rare.

Tanzania is a large country and rich in water resources, the documented studies only give a glimpse of their trends and status. The general knowledge in terms of quality of the large part of water resources in the country is highly spatial as there are still many important water resources that are yet to be systematically investigated. The baseline levels of micro-contaminants in most major

Tanzanian rivers are still unknown, and drainage basin-based studies on water and sediment chemistry are hardly available. The reviewed studies focused on water pollution with concern on concentration levels of contaminants, while aspects of ecosystem health; ecological risk evaluation and water ecology restoration were not well addressed. There were also fewer researches on groundwater quality. More studies on effects of climate changes will also be required because the subject is still not well addressed. Furthermore, according to the WHO, the greatest concerns in water for human consumption are a microbial risk. Current developments indicate that there might be some changes in assessment of biological water quality parameters. Traditionally, measuring of total coliforms and *Escherichia coli* bacterial has been the most common way of assessing biological quality of water for human consumption, however, of recent there have been some concerns by international water analysts on whether reliance on total coliforms and *E. coli* only as biological indicators is sufficient to ensure microbial water quality (Bari and Yeasmin, 2014). There are some considerations on the need to adopt a more holistic approach to assessing biological water quality. Future studies will, therefore, need to focus on these subjects, among others.

In this modern era, it is important to undertake sample pretreatment techniques which fulfill the requirements of environmental protection. It is also clearly necessary that water sampling and analysis is done by observing standard quality assurance and control protocols, including precision of analytical results and determination of baseline levels. Future needs, therefore, include the establishment of laboratories certified by the International Standards Organization (ISO) and training of staff to strengthen analytical and human resource capacity.

CONCLUSIONS AND RECOMMENDATIONS

Surface and ground water resources in Tanzania are major sources of supply for domestic, agricultural, industrial and hydropower generation. At the same time, there have been increased sources of stressors that threaten the water quality, where the main potential contamination hazards are well known. In the period between 2006 and 2016, significant research efforts have been devoted to water quality assessment in the country, with research aspects ranging from toxic metals, nutrients, pesticide residues, organic contaminants, organic matter, inorganic contaminants, isotopes, major ions and physico-chemical parameters and microbiological contaminants. Their concentration levels and distribution patterns vary widely from one area to another, depending on different factors such as types of the chemicals, input pathways, and climatic conditions. Generally, the reviewed studies indicate alteration of the natural characteristics of water due to natural and anthropogenic sources.

Monitoring and assessment of the quality of freshwater as a necessary resource is an important venture that requires significant research efforts to be deployed. Deliberate efforts should be made to enable availability of modern analytical tools; continuous measurement techniques that can enable testing when needed; event sampling that record impact of specific events such as floods and spills as they occur; automated sampling methods and analytical tools that may do a rapid assessment of water quality and detect any abrupt changes. It is important to have a special focus on groundwater since it is likely to be the key resource in Tanzania mainly due to the changing climate. There is a need of carefully managing it to make full benefit of its potential, including protecting its quality.

This study recommends the establishment of national water quality assessment program that will provide up to date water quality conditions for the large part of the national water recourses. This can be done through coordinated programs to collect data, interpret results and communicate findings to small teams of individuals/researchers familiar with the study area so as to make the best use of available resources. Other recommendations that this article puts forward are strict application of legal and administrative tools such as 'polluter-pays' principle; formation of networks for water quality monitoring and assessment to ensure that there is no duplication of work and efforts in collecting, analyzing, and storing water-quality data; commitment of financial resources by the Government for such efforts; establishment of reliable and accessible data base and communicating the water quality data to different stakeholders, including the general public, in a form that is accessible and suitable to needs of the different groups.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Electric energy generation from a floating dome type biogas plant at a ranch in the southeast of Mexico

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Ranches of Mexico's southeast region have an important energetic potential on their organic waste that remains unexploited. The objective of this work is to present the construction and operation of a floating dome "Biodigester" in a ranch located in Jalapa, Tabasco, Mexico, in addition to the analysis of produced biogas and its electric energy generation. The construction was based in the specifications of a Puxin® biogas plant. The biogas was analyzed using infra-red spectrometry with Fourier transforms. Electric energy was generated using an Energetic ® motor-generator. The methane and carbon dioxide percentage at 90 days of hydraulic retention time (HRT) was 51.51 and 29.05%, respectively. The electric energy generation was 3.58 kWhm^{-3}.

Key words: Biomass, floating dome, energy, biodigestate, biogas.

INTRODUCTION

In developing countries, particularly India and China, animal manure is used by farmers and the dairy industry to produce biogas, before manure is subject to other uses, such as fertilizers mostly. Anaerobic digestion is a biochemical process for organic matter degradation, by action of microorganisms under anaerobic conditions, resulting in products satisfying important needs of rural zones, such as biogas. Biogas for its heat potential and power generation, and digestate with a high content of nutrients applicable to crops (Asankulova, 2008; El-Mashad and Zhang, 2010; Fantozzi and Buratti, 2009; Fernández et al., 2010; Ferrer et al., 2011; Meng and Chung, 2010). In tropical zones, substrata with the highest potential for biogas production are water hyacinth (*Eichhornia crassipes*), manure (cattle, sheep, pork and poultry), cow gastric rumen content, yucca leaves, urban solid waste, agricultural wastes and residual water (Arthur et al., 2011; Krishna et al., 1991). Arthur et al. (2011) mention that sheep manure yield a return of 0.04 m^3 kg^{-1} manure. Akbulut (2012) reports the generation of

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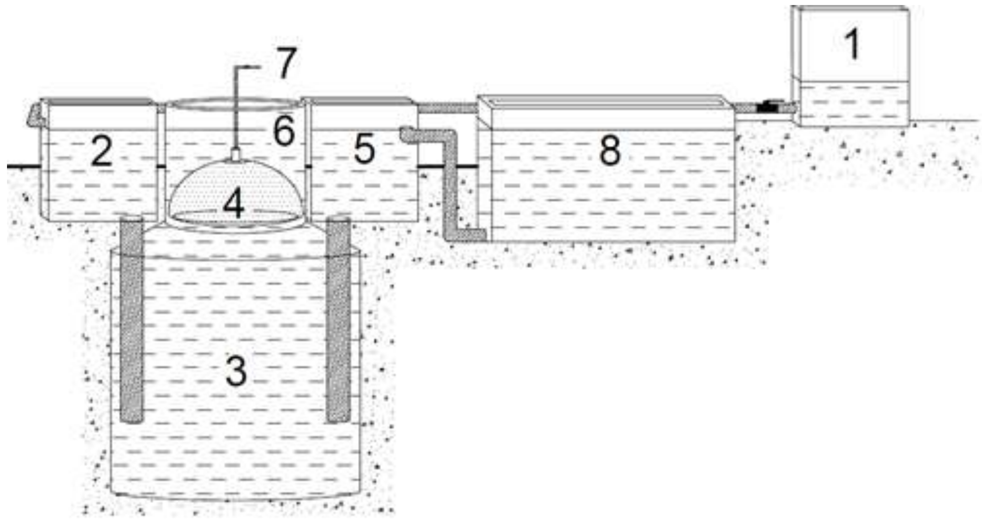

Figure 1. Adapted Puxin® biogas plant. (1) Mixer or Equalizer; (2) Inlet register; (3) Stomach or reactor; (4) Biogas reservoir; (5) Outlet register; (6) Neck; (7) Biogas outlet; (8) Biodigestate reception cell.

5.5 kWh m^{-3}, biogas quality was 55% of CH_4, yielding with cow manure in combination with sheep maure (93.9 and 6.01%, accordingly). Aburas et al. (1996) state that biogas plants are more feasible in agricultural farms or ranch, particularly for isolated rural zones, away from the commercial electric networks, since they supply power for activities such cooking, heating and power generation. The also mention that a regular farm of approximately 2.3 ha (170 dairy cows, 20 veils and 2 bulls) have a daily requirement for light and motors consumption (water and charge) of 32.73 kWh^{-1}, which may be supplied by 5 m^3 of biogas, with a 67% content of methane, in a 16 m^3 plant, and a production of 3.2 m^3 day^{-1} of biogas. Mohseni et al. (2012) report that biogas is considered as a first generation fuel, because of the simplicity of the process to producing it, without specific chemical processes. What makes it attractive to users of this type of technology is its easy operation and maintenance, because there are very expensive and complex biogas plants, which are being rejected in rural zones. Arthur et al. (2011) stated that Puxin® biogas plant is a pressure digester and hydraulic seal, build with concrete and used in rural regions of India, where it has been widely accepted. A common activity in Mexico's southeast ranches is to improperly dispose organic waste which causes water, soil and air pollution.

In Mexico's southeast, the construction of anaerobic biodigestor is a practice that is just beginning to be developed. This work presents the construction and operation of a floating dome "Biodigester" in a ranch located in Mexico's southeast, in addition to the analysis of produced biogas and its electric energy generation, which offers a sustainable option for farmers to dispose organic waste.

MATERIALS AND METHODS

Biodigester construction

Puxin® adapted biogas plant is described in Figure 1. To build the 10 m^3 Puxin® biogas plant, the following activities were performed:

Prospective view

A visit to "El Rodeo", a ranch located in the municipality of Jalapa, in Tabasco, Mexico, was made to define, based on the land topography project functionality, the area where the biogas plant was built.

Site suitability

Works of site cleaning, stroke and leveling were completed. Later on an excavation of 4.00 × 4.00 × 3.00 m was made.

Reactor construction

A simple concrete base was built to receive the Biodigester structure: Before starting with the construction of the biogas plan, a F´c = 100 kg cm^{-2} concrete base was built with the purpose of isolating the foundation area from mud and water puddles, which may contaminate concrete when pouring it for the biodigester base.

Pouring biodigester structure:

1. Lenticular slab: An important part of the structure. From this section depends the structure works as a whole in a stable form. It is circular, 3.00 m in diameter. It was made out of F´c = 250 $kgcm^{-2}$ concrete and reinforced with 6-6/4-4" electro-welded steel mesh.

Figure 2. Construction phase. (1) Lenticular slab; (2) Stomach and shoulder; (3) Neck.

Figure 3. Operation phase. (1) Feeding; (2) Placement of Dome; (3) Utilization of biogas.

3/8” steel bars were placed all around the perimeter, with 20 cm^2 separation with the “stomach and shoulder”. The purpose of the steel bar is to join monolithically the slab, stomach, and shoulder (Figure 1).
2. Stomach and shoulder: The wood frame was set to hand the “stomach and shoulder”. Vegetable oil was used to facilitate separation. Inside the “stomach” wood frame, 3/8” steel bars were placed every 20 cm on the perimeter of the slab, in square shape (90°), with the purpose of tying together both sides of the biodigester (slab and stomach). The stomach and shoulder structure was built with F’c = 250 $kgcm^{-2}$ concrete and reinforced with 6-6/ 4-4” electro-welded steel mesh. The final structure was built monolithically (Figure 2).
3. Neck: A wood frame was prepared to build the neck. F´c = 250 $kgcm^{-2}$ concrete and reinforced with 6-6/ 4-4” electro-welded steel mesh was used, and was monolithically poured. On the top section of this structure, a flange was made to receive the dome that shall be the biodigester cap. (Figure 3).
4. Input and output of registers: On the biodigester shoulder, two 6” PVC tubes were attached in symmetric line, which shall be used as structures for feeding and releasing the biodigestate. Input and output tubes were cut at a length of 1.50 m and were placed with a separation of 0.50 m from the bottom of the biodigester. The measures of the inlet and outlet are 1.00 × 0.80 m, block walls, matching its height at neck level.
5. Biogas plant finishing works: For internal finishing plaster of stomach and shoulder, a 1:12:1 mix (cement, sand and water respectively) was used. Once constructions activities of the biodigester were completed, soil from excavation was spread and flattened to field natural level.
6. Biodigestate reception cell: At output register, a pipe was adapted to lead “digestate” through a syphon to a digested liquids reception tank, with measurements 3.22 × 1.67 × 1.24 m and a volume of 5.31 m^3. This particular system automatically sends exceeding liquids to a reception cell by means of gravity.
7. Mixer: A devise measuring 1.00 × 1.00 × 1.00 m and a volume of 1 m^3 was built, with the purpose of mixing upstream substrata.

It is worth mentioning that structure reinforcement, implementation of the digestate reception tank and the uses of higher F’c were adaptations made during the construction of the biodigester.

Glass fiber dome: The dome used was fiber glass based with 6 mm thickness. It also counts with a 1” PVC biogas outlet. Three metal structures of a triangular shape were place in the basement, and triangular metal supports placed over the circumference of the dome base, in order to keep it suspended while gathering the biogas.

Figure 4. Motor-generator.

Biodegester operation

A total of 160 kg of substrata were introduced in the mixer (120 kg of sheep manure and 40 kg of aquatic fern (*Salvinia molesta*)). Forty liters of residual sludge from fish tanks as inoculum, plus more than 9800 L of water from a deep well (organic load rate of 11.14 kg SV m^{-3} day^{-1}) (Figure 1). This mix was sent by gravity to the input register, slowly filling the stomach and the neck. The biogas outlet was intentionally left open to avoid the formation of air bubbles under the dome (Figure 2). Hydraulic retention time (HRT) exceeded 90 days. The first time the dome was fully filled with biogas, it was used in a Puxin® stove (Figure 3).

Substrata analysis

Humidity was determined (SCFI, 1985); total solids were calculated from the difference of 100% humidity (Mahar et al., 2012), volatile solids (SCFI, 2015) and ashes (SCFI, 1984). Also, the elemental analysis of carbon, hydrogen, oxygen, nitrogen and sulfur (Analyzer Perkin Elmer® model: PE 2400). The chemical equation for sheep excreta and water fern was calculated.

Biogas analysis

From the start date of the project, an analysis of generated biogas was completed every week in a 5 cm length gas cell with KBr windows, using the "transmittance" technique, in a Thermo Nicolet (Nexus 670-FTIR) spectrometer, equipped with a Deuterated Triglycine Sulfate (DTGS) detector. Spectrums of 64 sweeps average were gathered for each sample, at a spectral resolution of 4 cm^{-1}, between 400 and 4000 cm^{-1}intervals.

Biodigestate analysis

For the biodigestate, a Hanna® 9828 equipment was used to measure oxygen dissolved, pH, temperature atmospheric pressure, resistivity, conductivity, true conductivity, total dissolved solids, salinity, oxide reduction potential (REDOX) and oxygen dissolved (% of saturation) in the field; and in the laboratory, nitrogen, phosphor and potassium were measure with a HANNA® HI83225 equipment, as well as the chemical oxygen demand (COD) from the beginning to the end, with a HANNA® C99 equipment.

Electric energy generation

The theoretical estimation of electric energy generated was calculated based on the amounts of biogas produced by each substrata used. For this purpose the Akbulut (2012) and Dach et al. (2014) equations were adapted as follows:

$$E_{Electric} = \left(total\ amount\ of\ biogas,\ m^3\right) * \left(\%\ Eficiency\right) * \left(Yield, \frac{kWh}{m^3}\right)$$

An Energetic® power generation equipment was used, with a generation capacity of 4.2 kWh m^{-3} (Figure 4). A theoretical efficiency of 42% was taken, as reported by Dach et al. (2014).

RESULTS

Table 1 shows the substrata analysis of sheep manure and aquatic fern used in the process. Table 2 shows the values for carbon, hydrogen, oxygen, nitrogen and sulfur, as well as it chemical formula, anaerobic reaction and energy potential for sheep manure and aquatic fern.

An estimate of the total biogas generation was made with both substrata, and results are described in Table 3.

Figure 5 shows infra-red spectrum of biogas from sheep manure, aquatic fern and residual sludge in fish tanks generated at the floating dome type plant located at "El Rodeo" ranch.

It also, shows the presence of two CH_4 narrow bands. One corresponds to an active IR signal of 3019 cm^{-1} assigned to a stretch (triple degeneration) and the other to an active IR signal of 1306 cm^{-1} assigned to strain (triple degeneration). Along with these bands, two groups of very fine signals between 2800 a 3200 cm^{-1} are found; they correspond to the vibrations assigned to NH_3. Another two bands also observe, which correspond to an active IR signal of 1391 cm^{-1} assigned to an asymmetric stretch (double degeneration) of NH_3 and the other, of 530 cm^{-1}, assigned to an asymmetric deformation (double degeneration). It can also be observed, a very small band all over spectrum 1A and 4A, corresponding to active IR signals of 450 cm^{-1} assigned to a symmetric deformation of NH_3. Other bands observed in the spectrum are the ones corresponding to active IR of CO_2 of 2349 cm^{-1}, assigned to asymmetric stretch, and the active IR signals

Table 1. Energy potential produced by sheep manure and aquatic fern.

Waste	Humidity (%)	ST (%)	SV (%)	Ashes (%)
Sheep manure	49.35	87.49	82.12	12.51
Aquatic Fern	79.16	69.91	57.24	30.09

Table 2. Determination of total theoretical Biogas

Sheep maure		Aquatic fern		Chemical formulas	Anaerobic reactions	Energy potential (m^3 kg^{-1} SV)		
C	37.05	C	32.03	Sheep manure			Sheep manure	Aquatic fern
H	5.32	H	4.27	$C_{183}H_{312}O_{155}N_{12}S$	$4C_{183}H_{312}O_{155}N_{12}S+148H_2O$	CH_4	0.399	0.514
O	41.79	O	31.34		$348CH_4+384CO_2+48NH_3+4H_2S$	CO_2	0.438	0.523
N	2.78	N	1.84	Aquatic fern		NH_3	0.060	0.056
S	0.54	S	0.43	$C_{201}H_{319}O148N_{10}S$	$4C_{201}H_{319}O_{148}N_{10}S+221H_2O$	H_2S	0.005	0.006
Total	87.49		69.91		$398CH_4+407CO_2+40NH_3+ 4H_2S$	Biogas	0.902	1.100

Table 3. Determination of total theoretical biogas.

Parameter	Amount	Parameter	Amount
Sheep manure (kg)	120.000	Aquatic plant (kg)	40.000
ST (kg)	60.760	ST (kg)	8.330
SV (kg)	49.860	SV (kg)	4.780
Biogas kg^{-1} SV (m^3)	0.902	Biogas kg^{-1} SV (m^3)	1.100
Biogas (m^3)	44.960	Biogas (m^3)	5.250
Biogas total (m^3)		44.960 +5.250 = 50.210	

Table 4. Group frequency for gases.

Gas	Group frequency (cm^{-1})	Assignment
CH_4	1306 / 3019	Deformation (triply degenerate) / Stretch (triply degenerate)[a]
CO_2	667 / 2349	In and Out-of-plane bend / Asymmetric stretch in plain[a]
NH_3	450 / 530 / 1200-1400 / 2800-3200	Symmetric deformation / Asymmetric deformation (doubly degenerate) / Asymmetric stretch (doubly degenerate) / Very Sharp[a,b]

[a]Housecroft and Sharpe (2008); [b]Stine (1975).

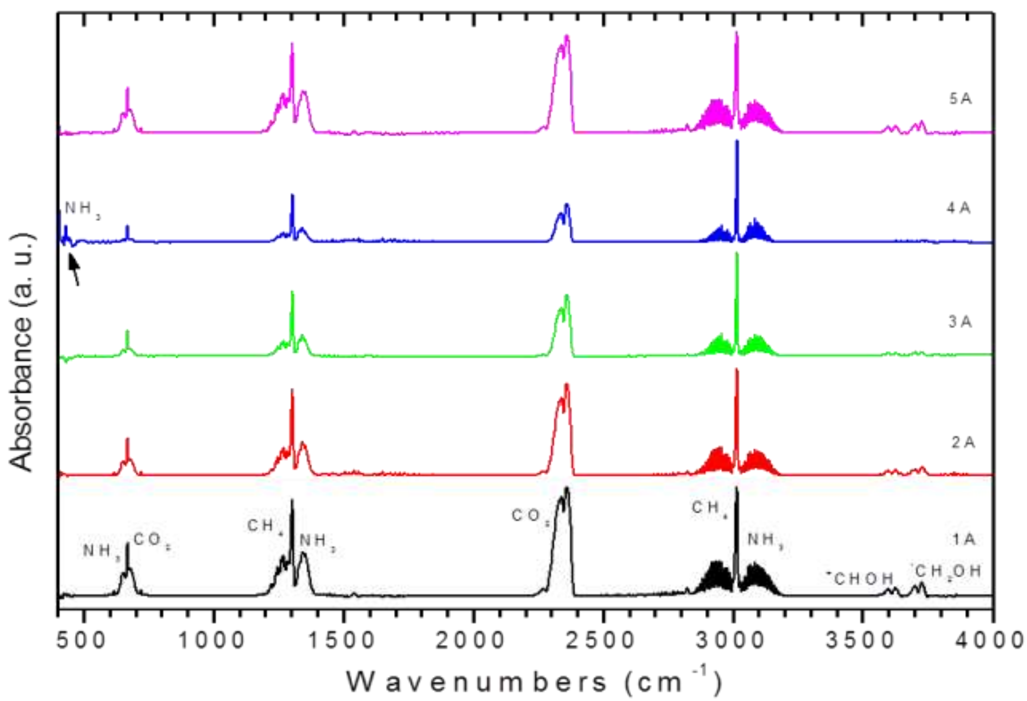

Figure 5. Infra-red spectrum of gases gathered by the reactor.

Table 5. Hydraulic retention time.

Gas	Hydraulic retention time (days)				
	30	45	60	75	90
CH_4	38.50	49.73	56.48	55.77	51.51
CO_2	41.77	29.84	25.68	20.13	29.05
NH_3	17.36	18.25	17.39	22.06	17.20
CHOH	1.03	0.92	0.00	0.94	0.86
CH_2OH	1.34	1.26	0.45	1.10	1.38

shown of 667 cm^{-1} assigned to a deformation out of the plane and deformation in the plane at the same frequency. It is also observed in the spectrums two double bands in the region of 3550 to 3750 cm^{-1} which correspond to primary alcohols -CH_2OH and secondary alcohols = CHOH.

In the Table 4, are shown group frequencies for principal gases in the biogas.

Table 5 shows the percent composition of CH_4, CO_2, NH_3, CHOH and CH_2OH calculated based on the intensities of the absorbance bands. Each percentage concentration resulted from the ratio of the absorbance of each band divided by the total absorbance of all interferogram bands. Figure 6 shows how the methane values increase as the hydraulic retention time increases and the carbon dioxide values decrease as time passes.

Table 6 shows average values with their corresponding standard deviation of physicochemical parameters of biodigestate, measured in field and in laboratory.

Electric generation was determined from the generated theoretical biogas total value, 1.00 m^3, applying the following equation:

$$E_{Electric} = \left(1.00\ m^3\right) * \left(0.42\right) * \left(4.2\,\frac{kWh}{m^3}\right) = 1.76\ kWh$$

After completing pilot tests using the electric generator, it was possible to achieve the generation of 110 and 220 V of energy, for 51.21 min, using 1 m^3 of biogas (Table 7). The total generation of electric power was 3.58 kWh. Figure 7 shows the use of energy to start a power drill.

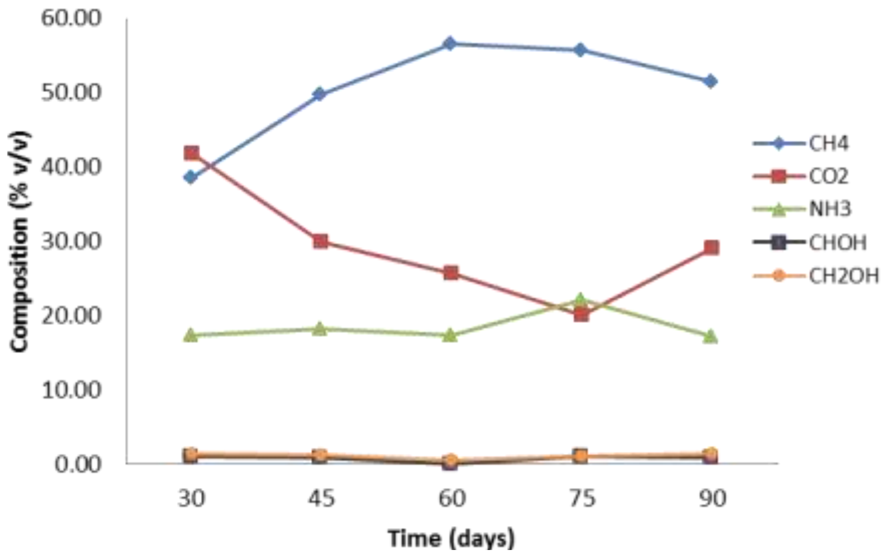

Figure 6. Composition of biogas trough time.

Table 6. Biodigestate physicochemical parameters.

Parameter	Average	DS
DO (ppm)	0.7750	0.5362
pH	7.2700	0.1906
pH (mV)	-26.3250	11.1674
Temperature (°C)	23.0300	8.5413
Atmospheric pressure (mBar)	1012.1500	9.1219
Resistivity (mΩcm)	0.0015	0.0002
Conductivity (µS/cm)	691.1250	90.3840
Conductivity (µS/cm^4)	703.7500	85.5299
Total dissolved solids (ppm)	345.6250	45.2609
Salinity (Sal)	0.3363	0.0457
Oxide reduction potential (mV)	-258.6875	62.1730
Dissolved oxygen (% of saturation)	9.6875	6.8620
Nitrates (NO_3^-) (mg/L)	2779.5238	2080.8267
Phosphor (mg/L)	662.9762	183.3848
Potassium (mg/L)	1830.7692	471.2496
COD initial (mg/L)	1649.000	463.3368
COD final (mg/L)	196.0714	122.4440

DISCUSSION

The organic load rate is much higher than the range reported by Álvarez and Lidén (2009) of 4 and 6 kg of SV m^{-3} day^{-1}, however, the methane yield of 0.399 is higher than the range of 0.7 to 0.14 m^3 kg^{-1} SV.

Regardless the season of the year, as Kalia and Kanwar (1998), Cantrell et al. (2008) mention, methanogen biogas production rate is sensitive to changes in influence material, pH, temperature, organic load velocity and hydraulic retention time (HRT), and they shall be controlled with the objective of maximizing the same biogas production.

Average temperature of the plant was always lower than environment temperature, as reported by Kalia and Kanwar (1998).

Mohammed et al. (2013) mention that organic compost from animals, is mostly treated by anaerobic digestion for

Table 7. Electric energy generation during a day.

Hour	Biogas volume (m^3)	Electric energy production time (min)	Yield (KWh/m^3)	Electric energy generation (KWh/m^3)
6:00 AM	1.00	51.21	4.2	3.58
12:00 PM	1.00	51.24	4.2	3.59
18:00 PM	1.00	52.16	4.2	3.65
12:00 AM	1.00	50.23	4.2	3.52
	Mean	51.21		3.58

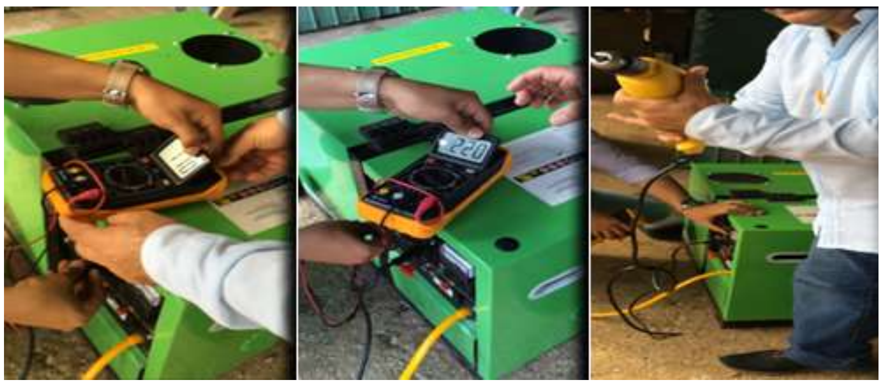

Figure 7. Generation of electric energy. (a) 110 V; (b) 220 V; (c) Using a power drill.

energy production, and it is a product that may benefit farmers in different manners.

The FTIR provided reasonable precision with a root mean square error of 10% using partial least squares analysis (Hepburn et al., 2015).

Conclusions

A Puxin® adapted biogas plant, floating dome type works for the southeast of Mexico. The mixes of substrata used represent a new opportunity for energy conversion when treating livestock wastes for a benefitted center (Cantrell et al., 2008). A floating dome has been redesigned and a new element has been included for biodigestate gathering (reception cell), along with the modification in material proportions. It is important to continue working in the reduction of the hydraulic retention time (HRT) as Cantrell et al. (2008) mentions. Other substrata generated in farms must be considered. And also assess the technology using for instance the analytical hierarchical process, appointed by Rao et al. (2014). Muller et al. (2007) which mentions that taking biofuel at a farm scale offers a great opportunity for the agricultural sector to reduce their dependency from imported fossil fuels, and at the same time, soil, water and air quality improve. According to Mohammed et al. (2013) the (%) of biomass contribution rate around the world for a final energy consumption, where Latin America is positioned in an intermediate place with a 18.20%, in comparison with Africa (60%) and the Middle East (0.30%), showing that agricultural biomass exploitation is not properly used and must be supported by government and other interested parties, through a pertinent program of support and incentive provisions specifically for transferring the focus on resources such as forestry for other bio-energy wastes. Our current study indicates that we can use the mix of substrata; however, improvement in biogas quality and production is highly desirable, therefore further studies about different mix of substrate will be made. In addition, longer-term examinations will be continued on the efficacy of the best process to enrich the biogas and to produce electric energy.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of aflatoxin B_1 (AFB_1) on follicle stimulating hormone, luteinizing hormone, testosterone, and estradiol hormone levels in reproductively mature male pigs

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Aflatoxin is a major food contaminant, with adverse effects on the physiology of both humans and animals. Exposure to aflatoxins has been known to pose a great threat to both humans and animals, particularly, in the tropics, with varied pathophysiological effects. This research focused on the effects of aflatoxin BI on the pituitary-gonadal axis of pigs, an area that has not fully been investigated since most studies have dwelt on other experimental animals. The aim of this study was to determine the effects of aflatoxin B1 on follicle stimulating hormone, luteinizing hormone, testosterone, and estradiol hormone levels in reproductively mature male pigs. This research adopted an experimental design using twelve reproductively mature Large White pigs aged 7 to 9 months and of average body weight of 54 kg. The pigs were allowed to acclimatize for a period of seven days. AFB_1 was obtained from Bora Biotechnology Company in Nairobi and the doses were given in three levels in the ratio of 1:2:3. The 1st treated group received 80 ppb per day, 2nd treated group received 160 ppb and the 3rd treated group received 240 ppb per day for 60 days. The control group received aflatoxin-free diet for the same study period. This was orally given as predetermined aflatoxin levels mixed with 150 g of pig finishers feed served to each pig in a separate aluminum feeding pot each in their specific experimental group. Each pig was thereafter served its daily 2 kg Unga feed in separate feeding pot. Water was also provided *ad libitum*. Five milliliters of blood samples were collected once every week from either the right or left ear of the pig in vacutainer tubes containing ethylenediamine tetraacetic acid (EDTA) which is an anticoagulant. Plasma samples were prepared by incubating the whole blood at room temperature for 10 to 20 min. The tubes were centrifugated for 20 min at 2,000 to 3,000 rpm. The supernatant was carefully collected and stored in a freezer at -21°C for hormonal assays. Consumption of increasingly higher doses of aflatoxin BI by pigs led to decreased levels of luteinizing hormone, testosterone and estradiol in a dose-dependent manner. The level of follicle stimulating hormone was however not significantly affected by consumption of aflatoxin BI dosages given.

Key words: Aflatoxin B_1, follicle stimulating hormone, luteinizing hormone, testosterone, estradiol hormone, pig.

INTRODUCTION

Aflatoxin (AF) is one of the contaminants in foods and feeds, with varying effects on the physiology of both animals and humans. It is a mycotoxin, a secondary metabolic by-product of the toxigenic fungi mainly *Aspergillus flavus* and *Aspergillus parasiticus* during their natural metabolic processes (Ahmed et al., 2012). The four major groups of aflatoxin that have been described based on their fluorescence at chromatography are aflatoxin B_1 (AFB_1), aflatoxin B_2 (AFB_2), aflatoxin G_1 (AFG_1) and aflatoxin G_2 (AFG_2).

The two main *Aspergillus* species yield different secondary metabolites such that AFB_1 and B_2 are produced by *A. flavus* and *A. parasiticus* while AFG_1 and G_2 are produced by *A. parasiticus*. In this classification, “B” and “G” stand for blue and green fluorescent colors, respectively (Ajani et al., 2014). The subscript numbers 1 and 2 indicate major and minor compounds, based on the degree of toxicity. AFB_1 is the most common, most toxic and a known carcinogen (Quintana et al., 2012).

Aflatoxins are not transmissible between animals, thus, the main cause of the toxicity in humans and animals is consumption of contaminated food and feed stuff. The toxigenic fungi can contaminate various feed components like maize, rice, wheat, peanuts, millet, oily feedstuffs, some of which form the majority of common food for both humans and animals. This contamination is dependent on the prevailing environmental conditions such as temperature range of between 28 and 33°C, water activity of about 0.83 to 0.97a_w and oxygen availability which favour production of aflatoxin in feeds (Bagheri et al., 2014). Contamination of animal feeds with aflatoxin can occur during the growth of the crop while in the field, at harvest and during postharvest operations as well as in storage. The task of preventing the occurrence of this toxins in swine feeds is therefore a very challenging one (Kanora and Maes, 2009).

Aflatoxins, particularly AFB_1, have been shown to impact on the endocrine glands and reproductive system at varying degrees, both in experimental animals and in humans. Hasanzadeh et al. (2011) did a study to determine the effects of aflatoxin B_1 on profiles of gonadotropic (follicle-stimulating hormone [FSH] and luteinizing hormone [LH]), steroid (testosterone and 17β-estradiol) and prolactin hormones in adult male rat. The results showed that the level of FSH significantly increased in all treatment groups fed on aflatoxin contaminated food. The levels of luteinizing hormone and testosterone were lower in all of the treated groups, while prolactin was significantly higher in the treated groups. The level of 17β-estradiol was significantly decreased only in the group that received higher concentration of aflatoxins in the diet. Their findings explain the hypophysotoxicity of aflatoxin and in particular on adenohypophysis. Effect of the toxin on the hypophysis could have led to the decreased level of the luteinizing hormone. The increased level of FSH in serum was attributed to the degeneration and desquamation of the epithelium, and a decrease in the size and thickness of the germinal layer in the seminiferous tubules. Damage to testes and a resulting reduction in circulating inhibin-B tend to elevate serum FSH levels. Serum testosterone levels were reduced mainly due to extreme damage to Leydig’s cells. The level of 17 ß-estradiol in the serum decreased only by administration of a relatively high dose of aflatoxin.

Clarke et al. (1987) investigated on endocrine and testicular related changes in male chicken fed on varying concentrations of dietary aflatoxin. Male chicken showed reduced plasma testosterone levels following the ingestion of aflatoxin contaminated diet, compared to the control group. Together with the reduced plasma testosterone concentrations were changes in testicular weight. Levels of plasma luteinizing hormone were significantly reduced in aflatoxin-fed males compared to the control group.

Ewuola et al. (2014) also reported lower levels of testosterone in aflatoxin-fed goats an effect that could be attributed to impairment of Leydig cells by the increased toxic levels. This may also explain the reduced spermatozoa production in the testis.

METHODOLOGY

This research adopted an experimental design using twelve reproductively mature Large White pigs aged 7 to 9 months and of average body weight of 54 kg. They were obtained from the University of Nairobi and housed in a pig pen at Karen in Nairobi. Completely randomized design was used in the allocation of the animals to the control group and to three treatment groups, each group comprising of three pigs. The pigs were allowed to acclimatize for a period of seven days. AFB_1 was obtained from Bora Biotechnology Company in Nairobi and the doses were given in three levels in the ratio of 1:2:3. The 1st treated group received 80 ppb per day, 2nd treated group received 160 ppb and the 3rd treated group received 240 ppb per day for 60 days. The control group received aflatoxin-free diet for the same study period. This was orally given as predetermined aflatoxin levels mixed with 150 g of pig finishers feed served to each pig in a separate aluminum feeding pot each in their specific experimental group. Each pig was thereafter served its daily 2 kg Unga feed in separate feeding pot.

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Table 1. Partial regression of FSH on dose, age, and weight.

Variable (FSH)	Slope and Intercept	Standard error	T-Statistic	P-value
Intercept	15.9924	2.90713	5.50111	0.0000
Weight	-0.20247	0.048384	-4.18463	0.0001
Age	0.009233	0.006579	1.40355	0.1645
Dose	-0.00137	0.00229	-0.5971	0.5522

FSH = 15.9924-0.20247×Wt + 0.00923347×Age-0.00137×Dose.

Table 2. Partial regression of LH on age, weight and toxin dosage.

Variable (LH)	Slope and Intercept	Standard error	T-Statistic	P-Value
Intercept	2.22118	3.80107	0.584357	0.5607
Weight	0.005879	0.063262	0.092927	0.9262
Age	0.009138	0.008602	1.06236	0.2914
Dose	-0.00617	0.002995	-2.06105	0.0427

LH= 2.22118+0.005879×Wt+0.009138×Age-0.00617×Dose.

Table 3. Partial regression of estradiol on age, weight and toxin dosage.

Variable (E2)	Slope and Intercept	Standard error	T- Statistic	P-Value
Intercept	102.143	38.2333	2.67157	0.0092
Weight	-0.72039	0.635806	-1.13303	0.2607
Age	0.014699	0.085704	0.171507	0.8643
Dose	-0.21256	0.030091	-7.0638	0.0000

Estradiol = 102.143-0.72039×Wt+0.014699×Age-0.21256×Dose.

Water was also provided *ad libitum*. Five milliliters of blood samples were collected once every week from either the right or left ear of the pig in vacutainer tubes containing ethylenediamine tetraacetic acid (EDTA) which is an anticoagulant. Plasma samples were prepared by incubating the whole blood at room temperature for 10 to 20 min. The tubes were centrifugated for 20 min at 2,000 to 3,000 rpm. The supernatant was carefully collected and stored in a freezer at -21°C for hormonal assays. Analysis of hormones was carried out at the University of Nairobi, Department of Clinical Studies. The reproductive hormones analyzed were the porcine FSH, porcine LH, porcine testosterone and porcine Estradiol (E2). Porcine ELISA kits for each specific hormone were obtained from *In-vitro* Diagnostics (EA) Limited, Nairobi. These kits were used in quantitative determination of the concentration of each specific hormone. Since the animals used were of different weight and age, these parameters were factored in as variables and statistical controls were used which gave the same results as experimental controls. The data was subjected to multiple regression analysis.

RESULTS

Porcine FSH

Table 1 shows the slopes of the partial relationship of FSH on dose, weight and age. Table 1 also shows that weight had a relationship with FSH. FSH decreased with increase in weight ($P<0.05$). However, FSH had no significant relationship with age and the toxin dosage.

Porcine LH

Table 2 shows the slopes of the partial relationship of luteinizing hormone on dose, weight and age. Weight and age had no relationship with luteinizing hormone concentration ($P>0.05$). Only aflatoxin dosage affected luteinizing hormone significantly ($P<0.05$) in which case luteinizing hormone decreased significantly with increased aflatoxin level.

Porcine estradiol (E2) hormone

Table 3 shows the slopes of the partial relationship of estradiol on dose, weight and age. Table 3 also shows that the aflatoxin dosage given had a highly significant effect on the level of estradiol hormone ($P<0.05$), while the age and weight of the pigs had no relationship with

Table 4. Partial regression of testosterone on age, weight and toxin dosage.

Variable (Testosterone)	Slope and Intercept	Standard error	T-Statistic	P-Value
Intercept	444.984	141.809	3.13791	0.0024
Weight	-5.53623	2.36016	-2.3457	0.0216
Age	0.13458	0.320905	0.419375	0.6761
Dose	-0.54583	0.11173	-4.88526	0.0000

Testosterone = 444.984-5.53623*Wt+0.13458*Age-0.54583*Dose.

estradiol hormone (P>0.05). Estradiol concentration decreased significantly with increased aflatoxin level.

Porcine testosterone hormone

Table 4 shows the slopes of the partial relationship of testosterone on dose, weight and age. Both weight and aflatoxin B_1 dosage had a significant impact on testosterone level (P<0.05). The relationship between the toxin dosage and testosterone was highly significant as shown in the table. Testosterone concentration decreased with increase in animal weight and with increase in aflatoxin dosage. However, age had no significant relationship with testosterone hormone (P>0.05).

DISCUSSION

The plasma levels of luteinizing hormone, testosterone and estradiol of the aflatoxin challenged groups were significantly reduced in a dose related manner compared to the control group. These findings agree with those of studies carried out on other experimental animals. The results in our study agree with those of Ewuola et al. (2014) who found out that goats fed higher aflatoxin levels had significantly lower testosterone levels compared to the control group. Clarke et al. (1987) had earlier found similar results in male chicken fed on varying levels of dietary aflatoxin. Their results showed reduced plasma testosterone levels, as well as reduced levels of plasma luteinizing hormone in the aflatoxin treated groups compared to the control group. Plasma testosterone levels have been shown to reduce in white leghorn male chicken and in birds fed varying levels of aflatoxin contaminated feed as described by Bbosa et al. (2013). The results of this study are also comparable to the findings of Hasanzadeh et al. (2011) who reported that aflatoxin B_1 causes reduction in the concentration of testosterone as well as 17β-estradiol in aflatoxin treated male rats. Our study findings of reduced levels of testosterone and estradiol may be attributed to reduction of Leydig cells as well as degeneration of Sertoli seen in examined testicular tissues of the studied pigs. Bbosa et al. (2013) suggested that one of the most common mechanisms for the action of AFB_1 is the binding of DNA to form complexes and inhibit nucleic acid synthesis. This mode of action may explain the direct effect of aflatoxin B_1 on Leydig cells and Sertoli cells in the testes, and consequently, the reduction of the gonadal hormones, namely, testosterone and estradiol. The aflatoxin dosages given to the pigs did not have any significant effect on the level of FSH. However, luteinizing hormone was significantly reduced by aflatoxin in a dose-related manner. These findings differ partly from the findings of Hasanzadeh et al. (2011) who reported a significant increase in the levels of FSH, but are in agreement regarding the reduced level of LH in aflatoxin fed male rats. The reduced luteinizing hormone levels can be explained by hypophysotoxic effects of aflatoxin especially on adenohypophysis (Hasanzadeh et al., 2011). Regulation of FSH is similar to that of LH except for the specific inhibitory effect of inhibin B on the production and secretion of FSH. In our larger study, testicular tissues of the AFB_1-treated pigs showed reduced number of Sertoli cells, an effect that would consequently translate to reduced levels of inhibin B. Decline in inhibin B level reduced its inhibitory effect on FSH. This mechanism is expected to cause an elevated FSH level. The FSH level in AFB_1-treated pigs did not differ significantly from the control group. This is explained by the hypophysotoxic effects of AFB_1 which is known to lower the FSH level (Mabeck et al., 2005). Weight as an extrenous variable was shown to have a significant effect on the levels of FSH and testosterone hormones a finding that may call for further investigation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Hydrogen sulfide and ammonia removal from biogas using water hyacinth-derived carbon nanomaterials

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The presence of hydrogen sulfide (H_2S) and ammonia (NH_3) in biogas pose serious human health and environmental challenges. In this study, H_2S and NH_3 were successfully removed from biogas using water hyacinth-derived carbon (WHC) nanomaterials. Carbonization temperature, biogas flow rate, mass of the adsorbent and activating agent (KOH/water hyacinth (WH)) ratio were found to greatly influence the efficiency of the H_2S and NH_3 removal. The adsorption capacity of both H_2S and NH_3 was found to increase with the carbonization temperature as carbon materials prepared at 450, 550, and 650°C afforded removal efficiencies of 22, 30, and 51% for H_2S and 42, 50, and 74% for NH_3, respectively, after contact time of 2 h. Similarly, the KOH/WHC ratio showed huge impact on the adsorptive removal of the two species. WH materials carbonized at 650°C and activated at 700°C using 1:4, 1:2, and 1:1 KOH/WHC ratios showed removal efficiencies of 80, 84, and 93% for H_2S and 100, 100, and 100% for NH_3, correspondingly after 2 h contact time. The adsorption capacity of NH_3 increased with the decrease in flow rate from 83 to 100% at flow rates of 0.11 and 0.024 m^3/h, respectively, while that of H_2S increased from 22 to 93% with flow rate 0.11 and 0.024 m^3/h, respectively. The removal of H_2S and NH_3 increased with adsorbent mass loading. With the 0.05, 0.1, 0.2, and 0.3 g of the adsorbent, the adsorption of H_2S after 1.5 h contact time was 63, 93, 93, and 95%, respectively while that of NH_3 was 100% for all the adsorbent masses.

Key words: Waste water, KOH, activation ratio, carbonization temperature, flow rate.

INTRODUCTION

The sustainability of fossil fuels is currently a growing concern as more countries strive for independence and security (Florin and Harris, 2008). In addition, global warming, that is strongly linked to the carbon dioxide from fossil fuels, is at the top of the rapidly growing list of global issues that require urgent and concerted efforts.

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In the light of these challenges, a number of clean and sustainable sources of energy, among them biogas, have attracted huge research interest that has already translated into tangible alternative energy technologies for power generation. Biogas technology represents one of a number of feasible village-scale alternative energy technologies with great promise in rural energy program in Africa. Unlike other renewable energy sources, biogas technology can be deployed at small and large scales in urban or very remote rural locations with little or no geographical limitations. Moreover, biogas has multi-pronged benefits since in addition to generating energy, the technology helps in waste management which turn mitigates public-health and environmental problems while the solid residue from biogas plants is used as fertilizer (Amigun and von Blottnitz, 2007).

Biogas comes from a variety of sources including waste from wastewater treatment facilities, slaughterhouses, and farms. By composition, biogas contains from 40 to 60% methane, 35 to 50% carbon dioxide, 0 to 20% nitrogen, 0 to 1% oxygen, and the remainder is a mixture of noxious compounds such as hydrogen sulfide, siloxanes, carbonyl sulfide, carbon disulfide, methyl and dimethyl sulfides and other halogenated compounds (Rasi et al., 2014). Due to its low caloric value and potentially harmful sulfur, nitrogen, halogen, and silicon-based fractions, biogas has to be cleaned before it is utilized in cooking and power generation.

Hydrogen sulfide is considered a broad-spectrum poison that poisons a number of systems in the body (Lindenmann et al., 2010). As such, there is need to remove it from biogas. In addition, combustion of unclean biogas as in cooking stoves and steam turbines generates pollutants such as SOx and NOx gases, which exceeds pollution limits in many parts of the world including Africa. SOx and NOx gases are very corrosive; as a result, they wear down the economy through frequent repairs of the infrastructure and expenditure on respiratory related illnesses. On the other hand, siloxanes in biogas leads to silicon dioxide (SiO_2) build up in stove burners and pipes. SiO_2 build up could potentially lead to blockage with further risks.

The current techniques for biogas upgrading involve desulfurization of biogases carried out with various physical, chemical, or biological processes. Conventional physico-chemical techniques such as LOC CAT process (wet scrubbing redox system that utilizes chelated iron to transform H_2S to elemental sulfur), and hydro-desulfurization that are often used for bulk.

H_2S removal from natural gas and biogas (Wachs, 2008) are costly and thus unviable for rural settings. Commercial activated carbon impregnated with potassium hydroxide has been reported for substantial removal of bulk H_2S from biogas (Choo et al., 2013; Sitthikhankaew et al., 2014). However, commercial activated carbon materials are expensive and are usually inefficient in removing organic sulfur compounds such as dimethyl sulfides (Cui et al., 2009). To significantly remove organic sulfur compounds with impregnated activated carbon, frequent recharge of the adsorbent materials is required which is costly. Some bacteria, for instance, *Azospirillum* and *Thiobacillus* are capable of oxidizing organic sulfur, however, they are usually slow and can only be active in liquid phase (da Silva et al., 2014). Moreover, single metal oxides such as ZnO and mixed metal oxide systems such as mixtures of vanadium, titanium, cerium or molybdenum oxides have been used for catalytic oxidative desulfurization (Sahle-Demessie and Devulapelli, 2009). This catalytic process is extremely costly not only because expensive metals are involved but also due to the fact that the oxidative reaction occurs at high temperatures. This represents a major setback to the use of this approach in decentralized small-scale biogas plants.

Scrubbers such as water and polyethylene glycol have been used in removing H_2S and NH_3 where the gas stream is passed through the scrubbing agent (Eze and Agbo, 2010). Since H_2S and NH_3 are soluble in water, their removal in aqueous chemical scrubbers becomes effective up to 99% (Munoz et al., 2013; Lien et al., 2014) but a large amount of scrubber is needed making it expensive for small scale application. Moreover chemicals such as chlorinated compounds leads to the production of secondary pollutants, which necessitates for treatment of the spent scrubbers before their disposal (Moussavi et al., 2008).

Biological methods have shown good efficiency to about 99% (Gadre, 1989; Zhao et al., 2010) as the bacteria in the biofilter biodegrade hydrogen sulfide to elemental sulphur. Despite of their efficiency, biological methods are very slow, sensitive to temperature, and need time to stabilize (Rattanapan and Ounsaneha, 2011; Soroushian et al., 2006; Seredych et al., 2008). As such, they are not suitable for large-scale purification and need considerable attention.

In addition, materials and chemicals such as ZnO, $FeCl_3$ and FeO have been used to reduce H_2S to elemental sulphur (Kapdi et al., 2005). The use of nanoZnO has achieved up to 100% catalysis (Sayyadnejad et al., 2008) but the reaction is water sensitive therefore the presence of water vapour in the biogas favour backward reaction (Novochinskii et al., 2004).

The use of AC impregnated with different chemical species such as hydroxides, carbonates and chlorides of earth and alkaline earth metals has afforded promising results on adsorption of H_2S and NH_3 (Gao et al., 2013).

Different carbon precursors have been utilized as source for AC; these include graphene, aerogel and agricultural waste such corncobs, coconut shells banana peels. The use of biomass is attractive because it is cheap and readily available and does not pose food security issues (Sodeinde, 2012; Sirichote et

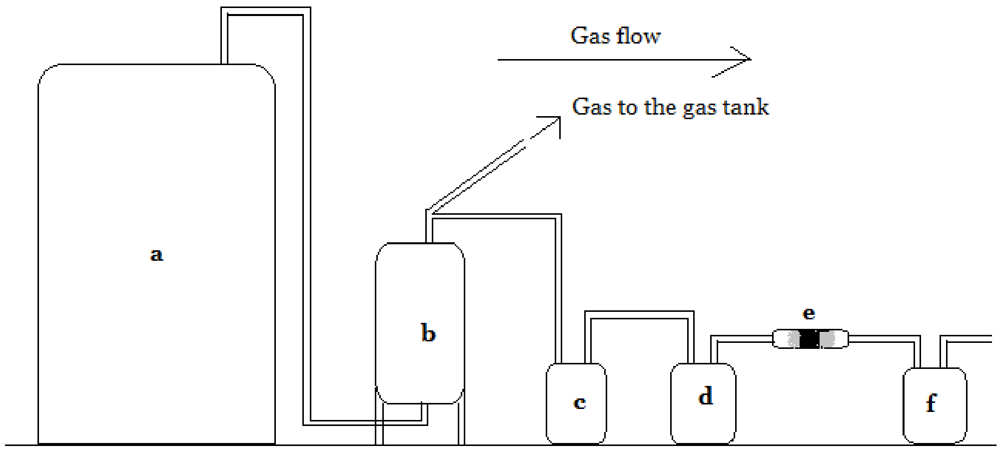

Figure 1. Experimental setup for the H_2S and NH_3 adsorption.

al., 2002; Alyani and Amin, 2008).

With the growing number of biogas plants, there is urgent need to develop cheap and effective materials for sulfur sequestration from biogas room temperature. In this study, water hyacinth derived carbon materials with very high sorption capacity for both hydrogen sulfide and ammonia were successfully prepared.

MATERIALS AND METHODS

Adsorbent preparation

Water hyacinth stems and leaves were collected from Lake Victoria Mwanza, Tanzania, washed, and dried in sunlight for one week. The dried precursor was then chipped into small pieces and powdered. Carbonization was then performed on the powdered samples at 450, 550 and 650°C in a carbolite horizontal tubular furnace (CTF 12/65/550) for 1 h under constant flow of nitrogen gas. The carbonized materials were activated at 700°C using KOH under inert nitrogen atmosphere. The activation was done by separately mixing 1 g of carbon samples suspended in 10 ml of distilled water with 1, 0.5, and 0.25 g of KOH getting 1:1, 1:2, and 1:4 KOH:WHC ratio. The KOH/carbon mixture was then stirred for 30 min at 80°C. The resultant homogenous mixture was dried in an oven at 100°C and then activated at 700ºC for 30 min in an inert atmosphere (constant flow of nitrogen gas). The heating rate for carbonization and activation was 10°C/min. The activated carbon materials were washed with 10 ml of 0.1 M HCl followed by distilled water till neutral pH was attained after which they were dried in an oven under 100°C for 12 h. The dried samples stored in a dry place before being tested for H_2S and NH_3 removal. The prepared samples were named as WHC-T and WHAC-X-T, where T represents carbonization temperature while X represents KOH/WHC ratio. X also s tands for flow rate or mass adsorbent during adsorption process.

Characterization

SEM

The morphology of the products was studied by field emission scanning electron microscopy (FESEM) using a Zeiss DSM 982 Gemini instrument equipped with a Schottky emitter at an accelerating voltage of 2.0 kV and a beam current of 1.0 mA. The FESEM samples were prepared by dispersing the powdered samples in absolute ethanol. The suspension was then sonicated for 35 min, and a drop was loaded on Au Pd-coated silicon glass chips mounted onto aluminum stubs with a two-sided carbon tape. The samples were dried by vacuum desiccation prior to SEM analysis.

H_2S and NH_3 adsorption set-up

The H_2S and NH_3 adsorption tests were carried out at Banana Investment Co. Ltd in Arusha, Tanzania where the biogas is produced from industrial waste. The company produces 60 m^3 of industrial waste water daily and the amount of biogas produced from the Up flow Anaerobic Sludge Blanket averages to about 100 m^3 daily. The composition of the gas produced is 84.3 to 89.8% CH_4, 12 to 14% CO_2, <1% O_2, 0.005 to 0.027 mg/g NH_3, and 0.02 to 0.056 mg/g H_2S as analyzed by the biogas 5000 gas analyzer.

Biogas was passed through a fixed bed column made of plastic tube, 5 cm long and 1 cm diameter, packed with the water hyacinth-derived carbon adsorbent. A given mass of adsorbent was placed in the tube and then supported by cotton wool on both sides of the tube. Then biogas was allowed to flow through the column with a flow rate 0.024, 0.04, 0.07 and 0.11 m^3/h at room temperature as illustrated in Figure 1. The flow rate of the biogas was monitored and controlled using flow meter, model JBD2.5-SA. The

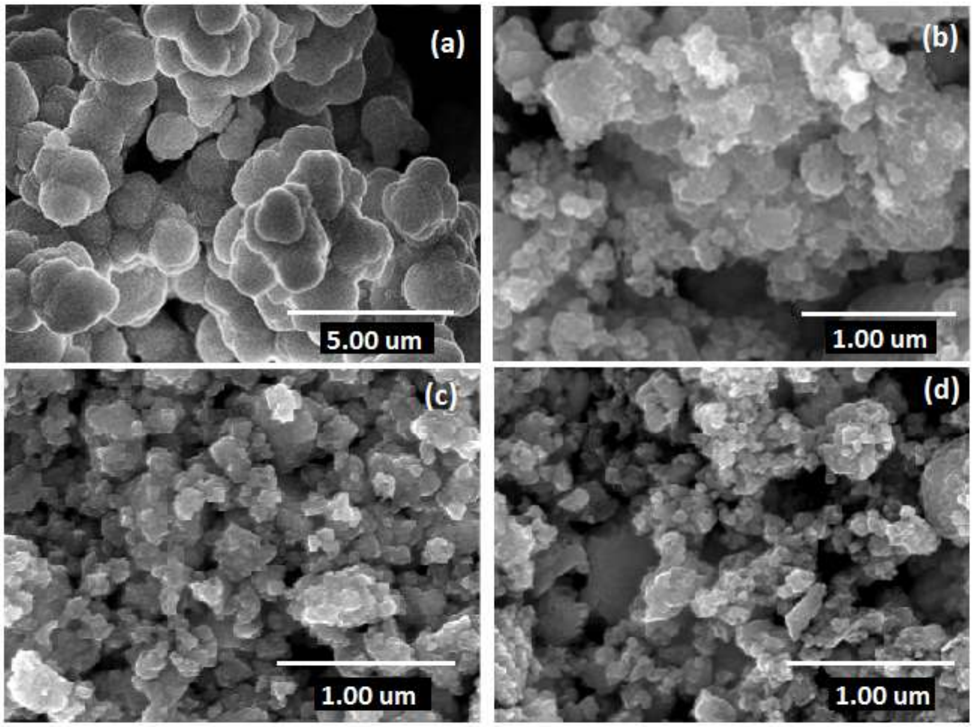

Figure 2. SEM images of WHC carbonized: (a) inactivated WHC, (b) WHC activated at 1:4, (c) WHC activated at 1:2, and (d) WHC activated at 1:1.

concentration of H_2S and NH_3 was recorded before and after the adsorption process. The measurements for both H_2S and NH_3 during the adsorption studies were taken at time interval of 5, 10, 20, 40, 60, 90, and 120 min. The breakthrough time was recorded when the outlet concentration of H_2S and NH_3 reached 40% of the incoming concentration. These adsorption tests were repeated three times for each sample tested.

RESULTS AND DISCUSSION

Morphological studies

The surface morphology of the water hyacinth-derived carbon materials obtained via carbonization at 650°C for 1 h and activated at 700°C for 30 min using different KOH to WHC ratios are shown in SEM images in Figure 2. The morphology of inactivated WHC is as shown in Figure 2a, while Figure 2b, c, and d are morphologies of WHAC activated at 1:4, 1:2, and 1:1 KOH to WHC ratios, respectively. The morphology of inactivated WHC shows microsphere-like clusters with smooth surfaces. The microsphere transformed into smaller irregular particles with rough surfaces upon activation with KOH, as indicated in SEM images in Figure 2b to d. This was due to the etching effect of the KOH, as a result, the surface area is increased (Tseng et al., 2006). This morphology is similar to that observed by Kurniawan et al. (2015) for carbon materials derived from water hyacinth.

H_2S and NH_3 adsorption studies

Effect of carbonization temperature

The water hyacinth derived carbons were tested on the removal of H_2S and NH_3 from biogas produced from winery effluent at Banana Investment Ltd. The performance of the materials was evaluated based on percentage removal. The percent removal was calculated using Equation 1:

$$\%\ \mathrm{Re}\,moval\ of\ H_2S\ or\ NH_3 = \frac{C_{in} - C_{out}}{C_{in}} \times 100 \quad (1)$$

For both gases, the adsorption capacity increased with carbonization temperature as shown in Figure 3a and b. WHC-650 sample afforded 51% removal after 2 h followed by WHC-550 and WHC-450 which removed 30 and 22% of the H_2S, respectively. The performance of these samples on NH_3 followed the same trend where 74, 50, and 42% of ammonia was adsorbed by the same adsorbents, respectively. The increase in adsorption capacity with temperature was due to the fact that at 650°C more organic matter volatilized from the water hyacinth compared to the low temperatures thus creating enough pores for adsorption of H_2S and NH_3 (Ioannidou

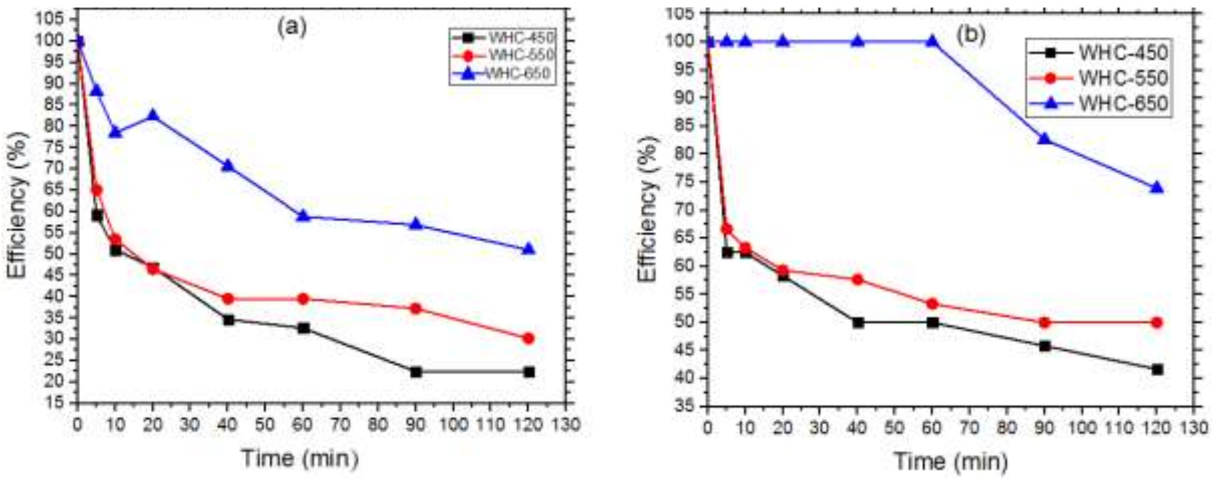

Figure 3. Effect of carbonization temperature on adsorptive removal of (a) H_2S and (b) NH_3.

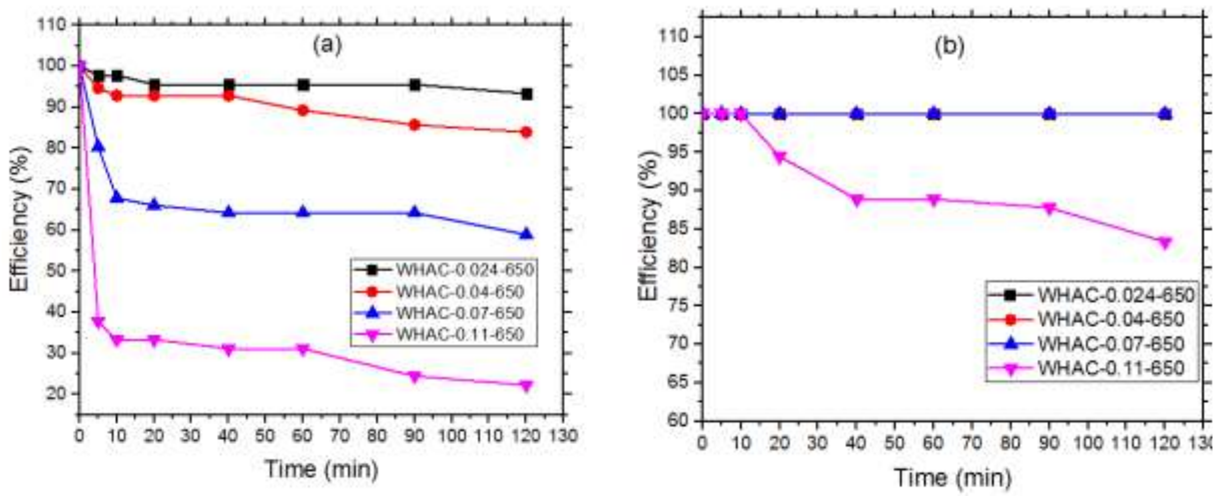

Figure 4. Effect of biogas flow rate on adsorptive removal of (a) H_2S and (b) NH_3.

and Zabaniotou, 2007).

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Effect of biogas flow rate

Figure 4 shows the effect of flow rate on H_2S and NH_3 adsorption. It was observed that the capacity of the materials in removing H_2S and NH_3 was different at different flow rates. With WHAC-1:1-650 at flow rates of 0.024, 0.04, 0.07, and 0.11 m^3/h, the adsorption of H_2S removing was 93, 93, 59, and 22%, respectively after 2 h. At the same flow rates and contact time, the efficiency of NH_3 removal was 100, 100,100 and 83.3%, respectively. This indicates the high effectiveness of the materials prepared for the ammonia removal. High adsorption of H_2S and NH_3 was observed at low flow rates since biogas had enough time to contact with the adsorbent. At high flow rates, the contact time between the gas stream and the adsorbent decreased and thus the amount of H_2S and NH_3 molecules passing through the adsorbent without being adsorbed increased.

Effect of adsorbent mass

The effect of the adsorbent mass on the adsorption of H_2S and NH_3 was studied using WHAC-1:1-650 sample and results given in Figure 5. The removal of H_2S was found to increase with increase in mass of adsorbent. When 0.05, 0.1, 0.2 and 0.3 g of adsorbent were used, 63, 93, 93, and 95% H_2S removal was obtained after 1.5 h contact time (Figure 5a). On the other hand, 100% NH_3 removal was obtained with all the adsorbent masses including 0.05 g (Figure 5b). The increase of adsorbent

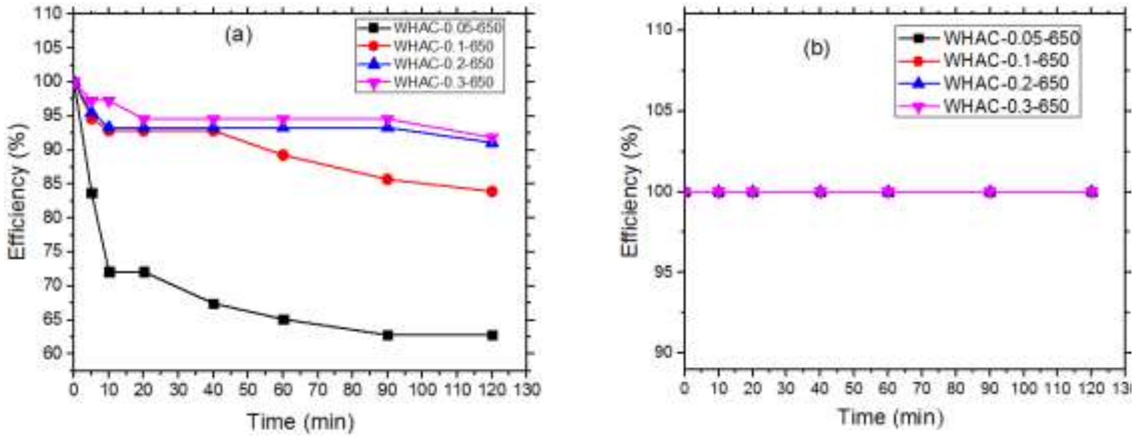

Figure 5. Effect of adsorbent mass (in grams) on adsorptive removal of (a) H_2S and (b) NH_3.

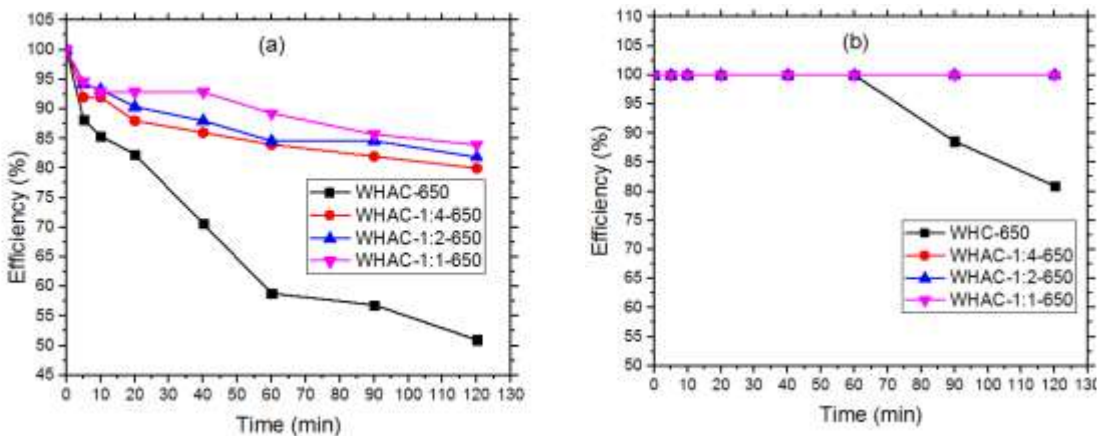

Figure 6. Effect of KOH to WHC ratio on the adsorptive removal of (a) H_2S and (b) NH_3.

mass increased the number of adsorption sites in WHAC materials and hence increased removal of H_2S and NH_3.

Effect of WHC to KOH ratio

The activation ratio has been reported as the most important observed parameter in synthesizing porous carbon. Figure 6 shows that the increase in KOH in impregnation increases the adsorption of H_2S and NH_3. The KOH assists in the formation and widening of the pores through arching (Lozano-Castello et al., 2001). At all ratios used for carbonization, the 1:1 KOH: WHC ratio had the best results for both NH_3 and H_2S removal. With NH_3, the adsorption is more efficient as it was at 100% with the ratio 1:2 and all ratios for 650°C activated samples. The highest adsorption of H_2S was 93% achieved by WHAC-1:1-650 samples after 2 h. Washing of the WHAC samples with HCl assisted the removal of the KOH used in impregnation process resulting in the increase of adsorption sites. The comparison of this technique with others is described in Table 1.

Sulphur sorption capacity

Sorption capacity (SC) of the WHC samples was determined using Equation 2, where *WHSV* is the space hourly velocity in $mLh^{-1}g^{-1}$, V_{mol} is the molar volume in $Lmol^{-1}$, *M* is the atomic weight of sulphur at standard conditions, C_{in} and C_{out} are the H_2S concentration before and after adsorption in ppm, respectively, and *t* is the breakthrough time (BT) (Garces, et al., 2012). BT was taken when the H_2S concentration of the treated gas was 40%.

$$SC\left[\frac{g\,sulphur}{100g\,sorbent}\right] = WHSV \times \left[\frac{M}{V_{mol}} \times \int_0^t \left(C_{in} - C_{out}\right)dt\right] \quad (2)$$

Table 1. Comparison of WHC adsorbent with other techniques reported in the literature.

Adsorbent	Mass	Biogas flow rate	Contact time	H_2S % removal	References
Fe/EDTA	-	265 ml/min	48 min	84.5	Frare et al. (2010)
AC-KOH	4 g	4.0- 4.5 L/min	10 h	73	Cui et al. (2009)
$AC-NaCO_3$	1 g	100 ml/min	100 min	33	Sitthikhankaew et al. (2014)
Water scrubber	70 cc	140 L/min	90 s	25.6	Lien et al. (2014)
WHAC-1:1-650	1 g	$0.024\ m^3/h$	2 h	93	This study

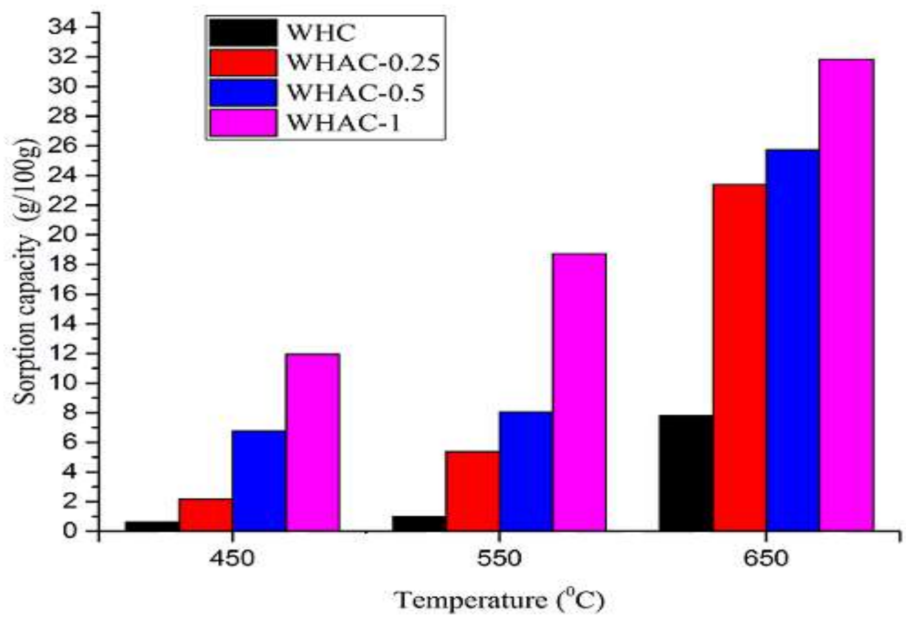

Figure 7. Hydrogen sulfide sorption capacity of WHC activated at 700°C and at different KOH/WHC ratios.

For this study, BT was defined as the time when the H_2S concentration adsorption decreased to 40% of the total. SC of the carbon samples increased with carbonization temperature and KOH/WHC ratio as shown in Figure 7. WHC-450, WHC-550 and WHC-650 gave SC of 0.63, 1, and 7.8 g/100 g, respectively, while WHAC-1:4-650, WHAC-1:2-650, and WHAC-1:1-650 gave SC of 23.4, 25.7, and 31.85 g/100 g, respectively. These results agreed with the percentage removal data where WHC-450, 550, and 650°C samples showed 22, 30, and 51% H_2S removal efficiencies, while WHAC-1:4-650, WHAC-1:2-650, and WHAC-1:1-650 samples showed 80, 84, and 93% H_2S removal efficiencies after 2 h, respectively. The breakthrough time (BT) increased as the carbonization temperature and the activation ratio increased. WHC-450, WHC-550 WHC-650 had a BT of 5, 10, and 60 min, respectively and WHAC-1:4-650, WHAC-1:2-650, and WHAC-1:1-650 had the BT of 180, 180, and 210 min, respectively as shown in Table 2.

Conclusion

In this study, water hyacinth-derived carbon materials were successfully synthesized and their performance in NH_3 and H_2S removal from biogas tested. Morphology studies showed a decrease in particle sizes of WHC with KOH amount. The WHAC samples prepared at 650°C and those activated at the highest ratio (1:1) showed superior hydrogen sulfide and ammonia removal capacity of 31.85 g/100 g and longer breakthrough time of 3.5 h. Furthermore, high hydrogen sulfide removal efficiencies of 95% were obtained with 0.3 g of the adsorbent. On the other hand, low biogas flow rate of $0.024\ m^3/h$ afforded 93% H_2S removal.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

Table 2. SC and BT for different carbon samples for H_2S.

Sample	SC	BT (min)
WHC-450	0.63	5
WHAC-0.25-450	0.52	5
WHAC-0.5-450	6.76	60
WHAC-1-450	11.96	120
WHC-550	1	10
WHAC-0.25-550	5.37	40
WHAC-0.5-550	8.06	60
WHAC-1-550	18.72	120
WHC-650	7.8	60
WHAC-0.25-650	23.4	180
WHAC-0.5-650	35.74	180
WHAC-1-650	31.85	210

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Effect of cement factory on land use-land cover in Obajana Lokoja Local Government Area, Kogi State, Nigeria

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Land use-land cover (LULC) is a vital phenomenon for the understanding interactions between the environment and human activities. In order to study and manage the resultant changes, it is pertinent to map different themes from time to time. The study focuses on the effect of the location of cement factory on land use-land cover in Obajana Community, Lokoja Local Government Area Kogi, Nigeria. The study employed supervised digital image classification method using Arc GIS 10.2 and ILWIS 3.3 Academic to classify the area into bare surface/degraded area, built-up area, vegetation and water body. The study revealed that changes have occurred within the period, 2005 to 2015; vegetal cover decreased by -19.2 km^2 (49.74%), built-up area has increased by 2.1 km^2 (5.44%). Bare surface/degraded area increased by 2.1 km^2 (5.44%). A decrease of -0.1 km^2 representing -0.26% was observed in the water body. It is therefore, recommended that land use land cover changes should be monitored at an interval of ten to fifteen years not only for urban planning purposes but to improve and manage land and land resources in a sustainable way.

Key words: Land use, land cover, change detection, image classification, urban growth.

INTRODUCTION

Cities are dynamic, this is because changes are inevitable. Kafi et al. (2014) stated that these changes can be attributed to one factor or the other depending on the socio economic, political and climatic condition of a given area. Due to physical development activities, the earth surface is being gradually altered in some manner and man's presence on the earth and his use of land has had a profound effect on the natural environment, thus resulting in an observable change in the land use-land cover (LULC) over time (Sreenivasulu et al., 2014).

Recent studies have shown that GIS and remote sensing have become very useful tools in research for trend analysis, change detection, monitoring and lots more, this is because data of any point of interest on the earth surface are available all year round, and so these data sets can be remotely acquired, analyzed and

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interpreted to extract needed information without any form of physical contact with the component under study.

Tripathi and Kumar (2012), in their study of Remote Sensing Based Analysis of Land use land cover Dynamics in Takula Block, Almora District India, employed Landsat- 5 TM (Thematic Mapper) and Landsat 7 ETM + (Enhanced Thematic Mapper Plus) data. These data sets were imported in ERDAS Imagine version 9.1. The dominant change which occurred in the study area is the croplands which were 13.48% in 1990 and increased to 21.47% in 2005. Analysis of their findings revealed a change of 7.99% in croplands which is attributed to increasing demand of cropland to fulfill the increasing need of foods in the study area.

Similarly, Manish and Ahmed (2010) worked on changes in land use pattern due to mining in Faridabad, using Landsat MSS of 1970 and IRS-P6 of 2006. Ancillary data such as Toposheet 1:50,000 were used for preparing base map and to create DEM. ArcGIS 9.2 and ERDAS 9.1 software were also used for geographical analysis, integration and presentation of the spatial and non-spatial data for change detection over a period of 35 years. It was found out that surface water bodies depleted at faster rate.

Sreenivasulu et al. (2014) carried out land use land cover analysis in and around Rajampet in Kadapa District, Andhra Pradesh, India using remote sensing and GIS. The study employed satellite images, ArcGIS 9.2, ERDAS IMAGINE 9.1, toposheets and satellite imageries. Analysis of the study reveals that there is a fast shrinkage of water bodies and marshy areas and the town is witnessing rapid transformation of land from agriculture to residential.

Also, Praveen and Jayarama, (2013) analyzed land used land cover changes using remote sensing data and GIS, the study was carried out using topographic map and remote sensing data. The study revealed that vegetation cover in the area has largely decreased from 68.23 km^2 in 1976 to 21.45 km^2 in 2003, with net decrease of 46.78 km^2. The area also witnessed agricultural land conversion to settlements and other urban development activities. Water spread area, both man-made and natural water features such as rivers/streams, tanks and reservoirs, also decreased from 12.09 km^2 in 1976 to 9.91 km^2 in 2003, with net decline of 2.18 km^2.

Rawat et al. (2015) used remote sensing and GIS to monitor land use-land cover change, using 30 m image resolution of Landsat Thematic Mapper of 1990 and 2010 for classification. The images were gotten from Global Land Cover Facility (GLCF) and earth explorer site and were imported in ERDAS Imagine version 9.3. Satellite image processing software was used to create a False Colour Composite (FCC). To work out the land use land cover classification, supervised classification method with maximum likelihood algorithm was applied in the ERDAS Imagine 9.3 Software. The result shows significant loose of forest and monumental increase in built up areas and a corresponding decrease in forestry and agricultural land.

A study by Duncan et al. (2009) on open pit gold mining and land use changes in Bogosu-Prestea area, South West Ghana due to mining over a twenty year period (1986 – 2006) was analyzed within the Golden Star Resources Bogoso Prestea Limited (GSRBPL) concession. The study revealed that mining in the area increased by 12.1% in land coverage with decrease in agricultural land use from 97.8% in 1986 to 82.7% in 2006. Settlements increased from 0.45% in 1986 to 4.95% in 2006 due to a rural-urban migration.

Similarly, Chitade (2010) carried out an impact analysis of open cast coal mines of Chandrapur district on LULC using remote sensing and GIS technique. The study was conducted using multi-temporal satellite data (IRS-P5 data of 2009 and 2010 and Landsat-5 data of 1990) to create a LULC mapping of the area; and reported a 67% increase in mine activities in the area. Daniel and Ayobami (2007) conducted Mapping and LULC change detection using remote sensing and GIS techniques in south west Nigeria. An area of 9558.58 km^2 was delineated on the Landsat scene covering the study area. The LULC mapping for the area was based primarily on Landsat 5 Thematic Mapper (TM) of December 1986 and Landsat 7 Enhanced Thematic Mapper (ETM) data of January 2002. The images were geometrically corrected to Universal Transverse Mercator (UTM) coordinate system. Their findings revealed that disturbed/degraded forest constituted the most extensive type of LULC in the study area. Accordingly, it accounted for about 49.6% of the total area in 1986, followed by high forest and derived savanna, occupying 30.6 and 12.6% of the total area, respectively. Between 1986 and 2002, the area witnessed significant settlement expansion and illegal logging, leading to further land use change.

Rawat, et al. (2013) carried out research on changes in LULC using geospatial techniques and supervised classification method. For better classification of results, some indices such as normalized difference vegetation index (NDVI), normalized difference water index (NDWI) and normalized difference built-up index (NDBI) were applied to classify the Landsat TM images at a resolution of 30 m of 15th November, 1990 and 2010. Five LULC types were identified and used in this study. They are built-up land, vegetation cover, agricultural land, water body and sand bar. Findings revealed that during the last two decades, the built-up area has increased from 1.25 km^2 in 1990 to 4.08 km^2 in 2010 which accounts for 8.88% of the total sprawl area. The vegetation cover has decreased from 10.29 km^2 in 1990 to 7.29 km^2 in 2010.

Kafi et al. (2014) analyzed LULC change detection using remotely sensed data in Bauchi city. They carried out the study grouping the various land use types into five: Wet land, farm land, shrub/grass, built up area and ditches/rocks. Image classification was done using supervised and unsupervised classification. Unsupervised classification was carried out using the 6 bands of multi date images in order to classify the image into clusters. Findings revealed that all the classes except farm land have increased over the years, with the built up area accounting for over 38% from 2003 to 2013. It was also found that the expansion of Bauchi city is more concentrated in the north eastern and South Western part of the city. This they attributed to the newly constructed estates that attracted other construction activities around the north eastern part, and also location of higher institutions around the south western part of the city.

Oluseyi (2006) performed urban land use change analysis of metropolitan city of Ibadan within the periods of 1972 and 2003 and discovered that the land use types that are subject to major changes are vegetal covers and sprawl development. It was also observed that development in Ibadan is similitude of the building types in the tradition core and the transition zones. Beside the city was growing at such an alarming rate using up the green and other forms of soft landscape in the city.

Ujoh et al. (2011) analyzed urban expansion and vegetal cover loss in and around Abuja with the use of Landsat imageries of 1987, 2001 and 2006. The study revealed that while built-up area increased, vegetation cover decreased at an alarming rate. Using population figures of the study area for 1987, 2001 and 2006, the land consumption rate (LCR) and land absorption coefficient (LAC) were determined. Increasing population and expansion in the Federal Capital City (FCC) resulted in land degradation including loss of vegetal cover, indiscriminate waste disposal and contamination of surface water.

Ekpenyong (2008) used the GIS database to model the LULC change between 1984 and 2003 for Akwa Ibom State. The result shows that some urban centres had expanded into farmlands/fallow lands and the surrounding secondary forest. Within that period, mangrove forest had reduced by 50%. Other forest covers in the area also changed, thereby threatening food security and climate among others.

Olokeogun et al .(2014) in their study on application of remote sensing and GIS in LULC mapping and change detection in Shasha forest reserve, Nigeria, used the Landsat 1986 and 2004 satellite images of the study area at 30 m resolution and a boundary map of Shasha Forest Reserve with scale 1:350, 000. The research found out that settlement expansion, subsistence farming and illegal logging are the major factors behind the LULC changes observed in the area. They however advised on the need for comprehensive assessment of human activities and adaptation of sustainable forest management.

Even though many researches have been carried out around the world on the use of remote sensing and GIS in monitoring and assessing the effect of mining activities of various environmental components within mining regions, reviewed literatures have shown that much emphasis has been laid generally on LULC changes as well as on the health challenges of people around mining areas.

This research therefore, assesses the effect of the location of cement factory on land use land cover in Obajana community, Lokoja Local Government Area Kogi, Nigeria. The objectives of this study include to:

1. Assess the land use land cover distribution in Obajana.
2. Assess the aerial extent of the land use land cover between 2000 and 2015.
3. Determine the magnitude of change in the land use land cover distribution.

Location of the study area

Obajana is a very small but very important community in Kogi State, north central Nigeria. It is part of Lokoja Local Government Area and is home to the famous Dangote cement factory, rated as the largest in Africa. Obajana can be assessed both by road and by air transport as it has two functional roads and a landing stip. Obajana lies within longitude 6°24'E to 6°27'E and latitude 7°54'N to 7°56'N. It has an undulating surface which gently slopes downward southwest-northeast trend (Figures 1 and 2).

MATERIALS AND METHODS

The research made use of the Integrated Land, Water Information System (ILWIS 3.3 Academic), ArcGIS 10.2 and the Statistical Package for Social Science (SPSS). ILWIS 3.3 academic was use for band combination, image classification and to calculate the normalize differential vegetation index (NDVI) of Obajana. ArcGIS 10.2 was used to clip the boundary of the study area and calculate the area in square kilometer of the resulting land use land cover classes for each study year. The comparison of the land use land cover statistics assisted in identifying the percentage change, trend and rate of change between 2000 and 2015.

Three bands were used to form the false colour composite for this study. These bands are 4, 3 and 2. The bands were combined in ILWIS 3.3 academic using the "New Map List" tool found on the operation list.

On each of the satellite images in question (2000, 2005 and 2015), the area of interest that is the study area, were "Clipped out" using the X,Y coordinates of a point on the right upper corner and the X,Y, coordinates of another point on the left Lower corner. This task was also performed on ILWIS 3.3 academic. Sample sets were then created for all the images; built-up area, degraded land, vegetation and water body.

The images were subjected to a supervised classification using the maximum likelihood. This task was performed using the classifier tool on the operation list of ILWIS 3.3 academic. The area of each sample set was determined in square kilometers. The classified images were exported to ArcGIS 10.2 software where the boundary area of Obajana was "Clipped".

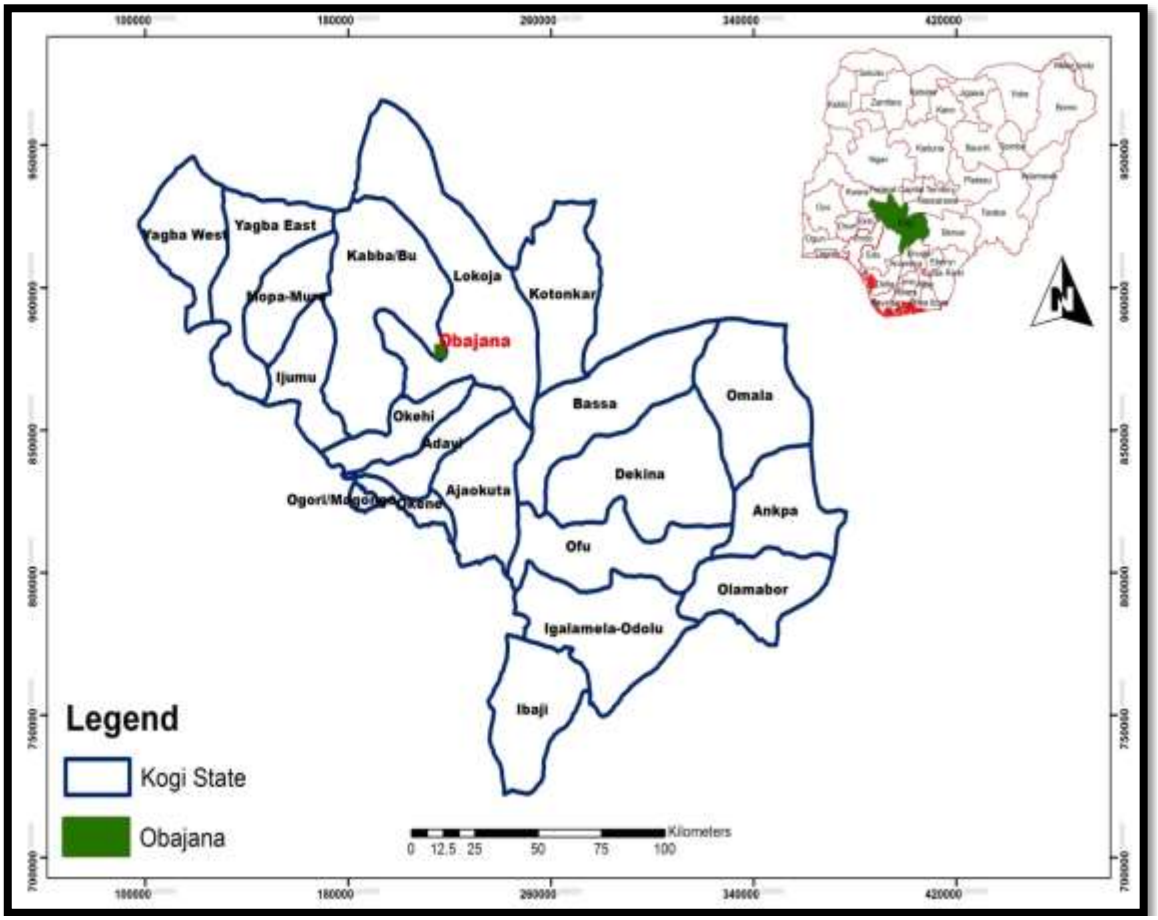

Figure 1. Kogi State depicting the study area. Sources: Fieldwork, 2016.

RESULTS AND DISCUSSION

Land use land cover change distribution of Obajana (2000-2015)

In line with the objectives of the study, geographic information system techniques were employed to identify and map the land use land coverof Obajana over a period of 15 years. The LULC maps are presented in Figures 3, 4 and 5 for 2000, 2005 and 2015, respectively. They show the extent of the land use land cover change. Aerial extents measured in kilometer square (km^2) and the corresponding percentages of coverage are presented in Tables 3 and 4 for 2000, 2005 and 2015 respectively. The classes of land use land cover identified are:

i. Bare surface/degraded land
ii. Built-up area
iii. Water body
iv. Vegetation

Land use land cover distribution of Obajana 2000

Result presented in Figure 3 reveals that in 2000, greater part of the study area was made up of vast vegetation with scanty built up area and degraded land/bare surface. Table 1 shows that vegetation accounted for 157.8 km^2 (97.7%), whereas built up area and bare surface/degraded land covered 3.0 (1.9%) and 0.7 km^2 (0.4%), respectively. It has been observed that there was no visible sign of water bodies in the study area. The dominance of vegetal cover could be attributed to wide spread of agricultural practice in the study area before the discovery of limestone deposit and subsequent establishment of the cement industry.

Land use land cover distribution of Obajana 2005

The five year period between 2000 and 2005 witnessed increases in activities both in the basic and non-basic sectors due to proposed establishment of the cement

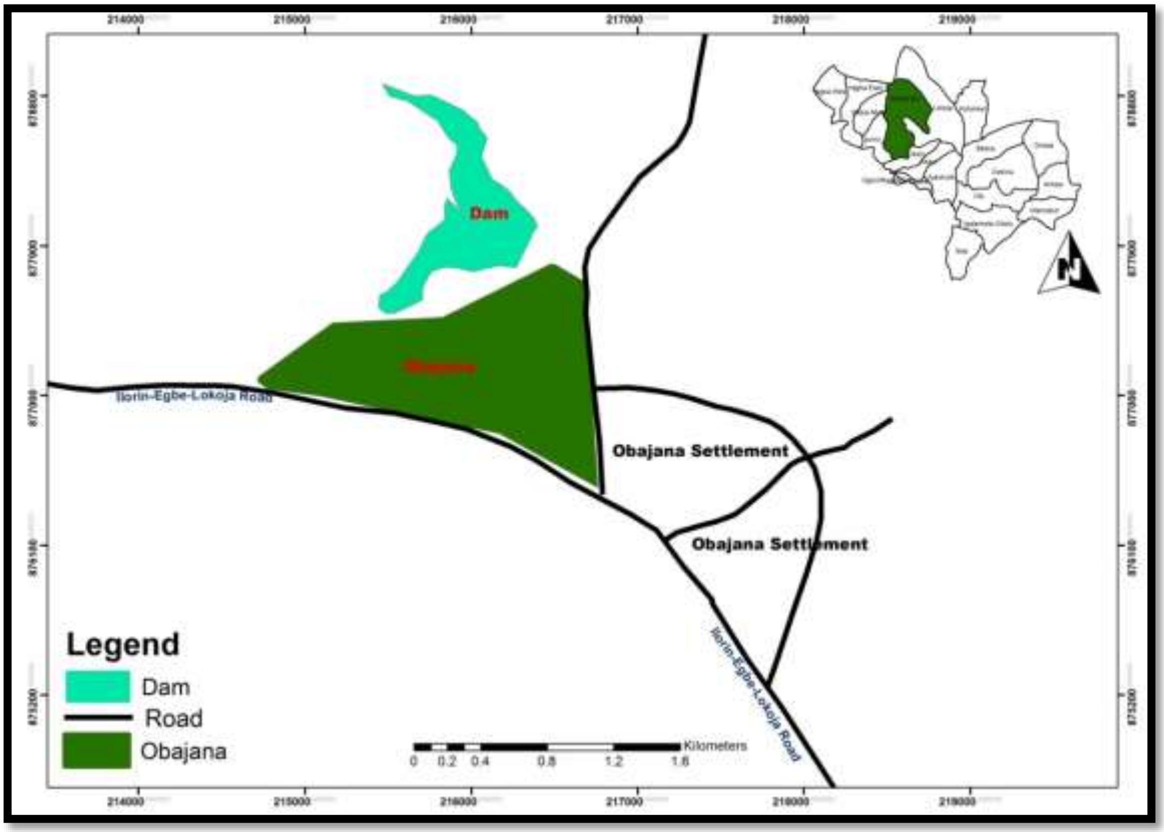

Figure 2. Obajana the study area. Sources: Fieldwork, 2016.

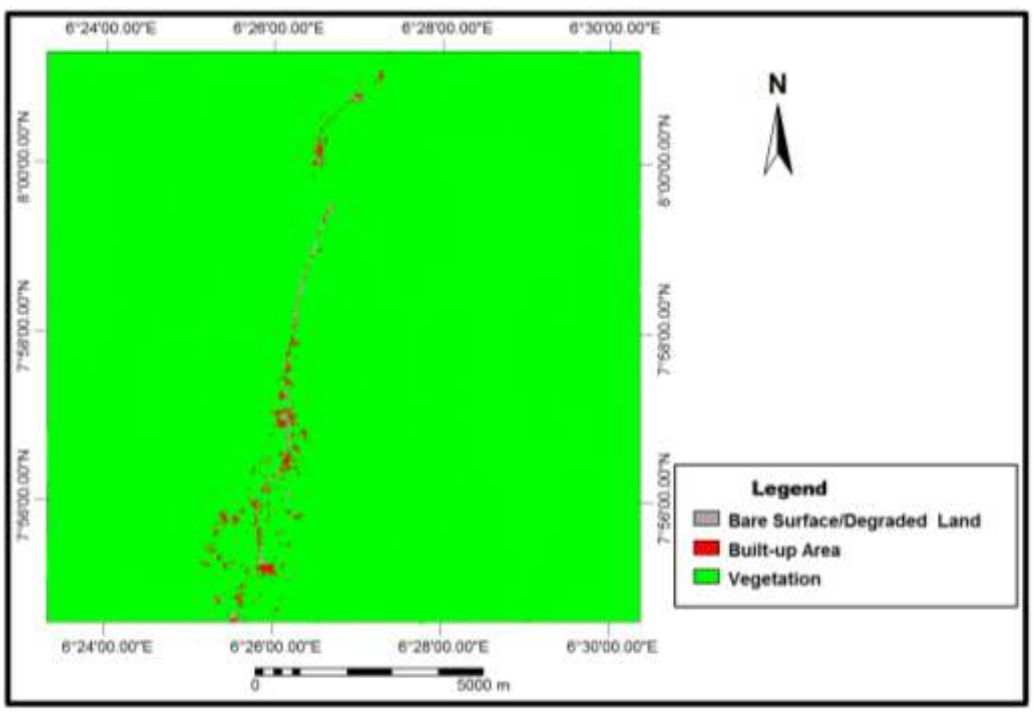

Figure 3. Land-Cover Classification of Obajana in 2000. Source: Fieldwork, 2016.

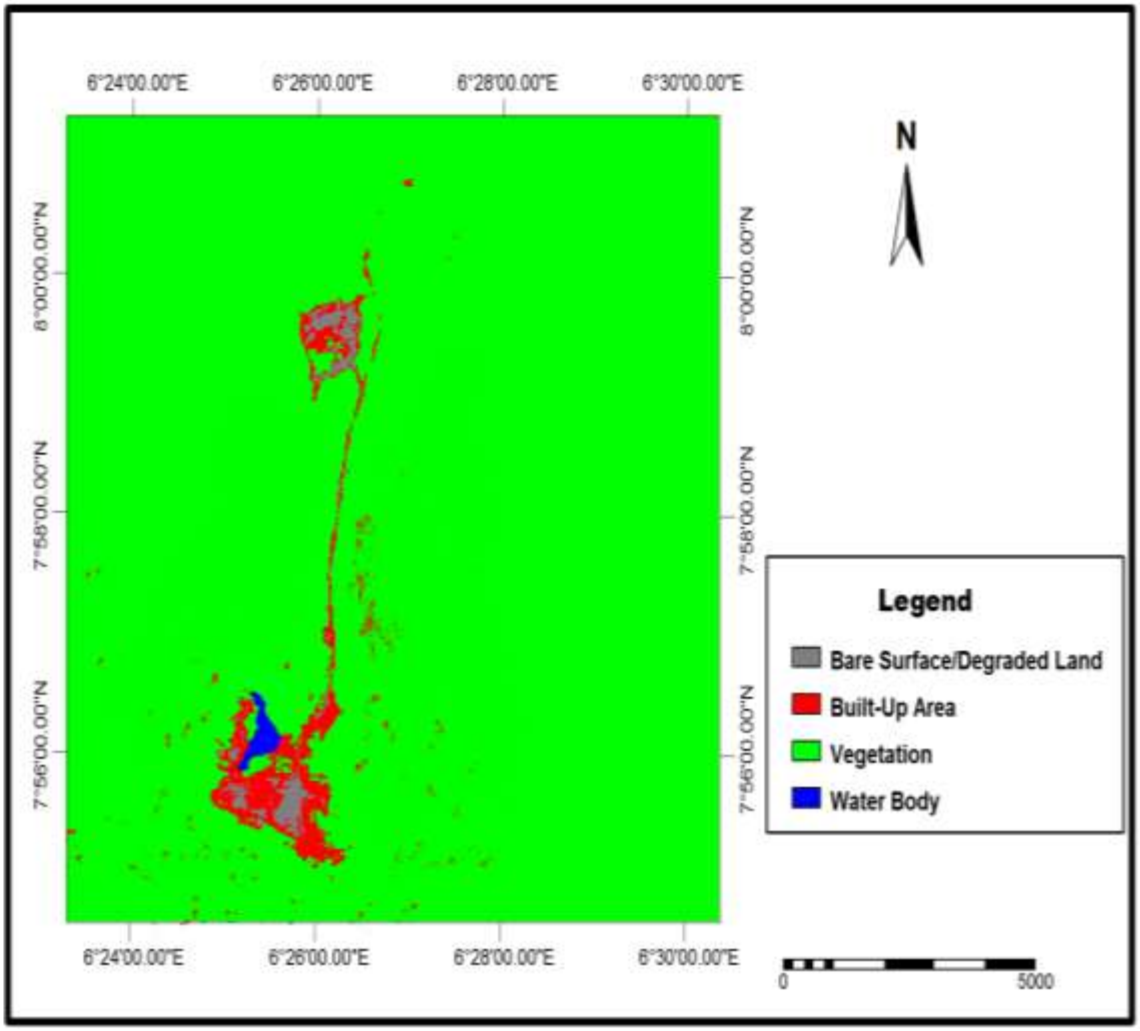

Figure 4. Land-Cover Classification of Obajana in 2005. Source: Fieldwork, 2016.

industry in the study area. This therefore, resulted in an increase in the built up area from 3.0 km^2 (1.9%) in 2000 to 5.4 km^2 (3.3%) in 2005. However, the period experienced a decrease in the size of vegetation from158 km^2 (97.7%) in the year 2000 to 154 km^2 (95.7%) in 2005. Besides, the degraded area/bare surface increased from 0.7 km^2 (0.4%) in 2000 to 1.2 km^2 (0.7%) in 2005. It has been observed that within the five year period, water body has emerged occupying 0.4 km^2 (0.3%) in form of a dam constructed to serve the cement industry (Table 2).

Land use land cover distribution of Obajana 2015

Upon completion of the largest cement factory, the settlement of Obajana had transformed from a small rural agrarian based community into a cement manufacturing destination rated as the largest in Africa. Results presented in Figure 5 and Table 3 therefore, showed that built up area increased from 5.4 km^2 (5.4%) in 2005 to 22.6 km^2 (14%) in 2015. As a result of the increase in socio economic development, the vegetation steadily declined from 154.7 km^2 (95.7%) in 2005 to 135.5 km^2 (83.8%) in 2015. There is also an increase observed in Bare surfaces/degraded area from 1.2 km^2 (0.7%) in 2005 to 3.3 km^2 (2.0%) in 2015. However, water body reduced from 0.4 km^2 (0.3%) in 2005 to 0.3 km^2 (0.2 %) in 2015.

Magnitude of change in land use land cover of Obajana 2005-2015

It has been observed that significant changes have occurred in the land use land cover classes within the 10 year period manifested in the form of increase or decrease in sizes. Result presented in Table 4 shows

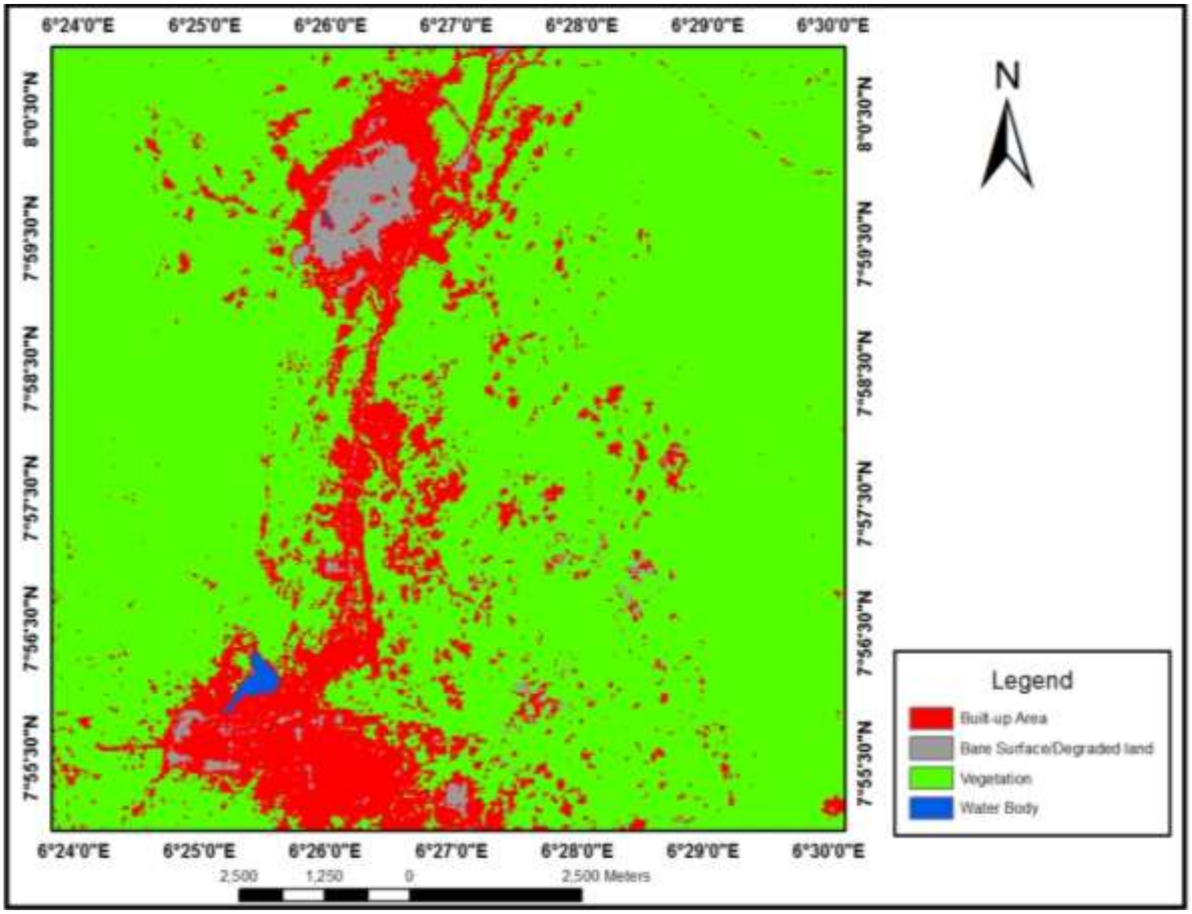

Figure 5. Land-cover classification of Obajana 2015. Source: Fieldwork, 2016.

Table 1. Land use land cover distribution of Obajana 2000.

Training set (class)	Area (km^2)	Percentage
Bare surface/degraded land	0.7	0.4
Built-up area	3.0	1.9
Vegetation	158	97.7
Water body	--	--
Total	161.7	100

Source: Fieldwork, 2016.

Table 2. Land use land cover distribution of Obajana 2005.

Training set	Area (km^2)	Percentage
Bare surface/degraded land	1.2	0.7
Built-up area	5.4	3.3
Vegetation	154.7	95.7
Water body	0.4	0.3
Total	161.7	100

Source: Fieldwork, 2016.

Table 3. Land use land cover distribution of Obajana 2015.

Training set (class)	Area (km^2)	Percentage
Bare surface/degraded land	3.3	2.0
Built-up area	22.6	14
Vegetation	135.5	83.8
Water body	0.3	0.2
Total	161.7	100

Source: Fieldwork, 2016.

magnitude of change that have occurred in the classes in terms of aerial extent measured in kilometer square (km^2) with corresponding percentages of coverage.

Built- up area

It has been observed that the built -up area covering 5.4 km^2 (3.3%) in 2005 has increased to 22.6 km^2 (14%) in

Table 4. Magnitude of change in land use land cover of Obajana 2005-2015.

Land use land cover	2005 A		2015 B		(B-A) Magnitude of change		
	Area (km^2)	%	Area (km^2)	%	Area (Km^2)	%	Remark
Bare surface/ degraded land	1.2	0.7	3.3	2.0	2.1	5.44	Increased
Built – up area	5.4	3.3	22.6	14	17.2	44.56	Increased
Vegetation	154.7	95.7	135.5	83.8	-19.2	-49.74	Decreased
Water body	0.4	0.3	0.3	0.2	-0.1	-0.26	Decreased
Total	161.7	100	161.7	100	38.6	100	

Source: Fieldwork, 2016.

2015, thereby recording a total increase of 2.1 km^2 (5.44%). The observed change implies that physical development has taken place as a result of socio economic changes brought about by the operation of the cement factory.

Bare surface/degraded area

This class recorded an increase of 2.1 km^2 (5.44%) within the 10 year period. In 2005, it occupied 1.2 km^2 (0.7%) and further increased to 3.3 km^2 (2.0%). The observed increase can be attributed to socio-economic growth and development witnessed in the study area.

Vegetation

The vegetal cover has indicated a significant change of the highest among all other categories with a decrease of -19.2 km^2 (-49.74%). Vegetation occupied 154.7 km^2 (95.7%) in 2005 and further decreased to 135.5 km^2 (83.8%) in 2015. Site clearing for construction purposes to soothe socio-economic development can be attributed to the observed decrease.

Water body

It has also been noticed that the only water body in form of a dam in the area occupying 0.4 km^2 (0.3%) in 2005 decreased by -0.1 km^2 (0.26%), following a decrease of 0.3 km^2 (0.2%) in 2015. The observed decreased can be attributed to natural dry up, thereby forming suitable sites for appropriate development purposes.

CONCLUSION AND RECOMMENDATIONS

The research has shown that the major land use land cover classes in Obajana; bare surface/degraded land, built-up area, vegetation and water body have witnessed changes within the ten years period studied. The research has demonstrated that remote sensing and geographic information system (GIS) can be very good tool for mapping, tracking urban expansion and detecting land use land cover changes. Settlement expansion due to operational activities of the cement industry is the major factor behind the land use land cover changes observed in the area. In order to achieve sustainability in growth and development of the land use land cover of Obajana, the following recommendations are made:

1. Environmental impact assessment (EIA) study should be carried out on the cement industry in Obajana, to have firsthand information on the impact of the plant on the host community's land use land land cover. Once the EIA is done and areas of impact identified, then a comprehensive master plan or development plan should be developed based on the environmental management plan (EMP) of the EIA to guide pattern and direction of future development.
2. Land use land cover changes should be monitored at an interval of ten to fifteen years not only for urban planning purposes, but for improving and managing land use and land resources in a sustainable way.
3. Adaptation of sustainable vegetal cover management practices such as close supervision of agricultural and forest reserves and making more arable lands available through restoration of already degraded and improvised lands.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests.

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