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Full Length Research Paper

Climate change adaptation strategies by small-scale farmers in Yatta District, Kenya

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Climate change is a great environmental challenge facing humanity today. In Yatta District, residents report frequent crop failures, water shortages and relief food has become a frequent feature of their life. This study examines the adaptation strategies to climate change adopted by the dry-land farming communities in Yatta District. Study participants included 510 randomly sampled small-scale farmers. Key informants were district departmental heads from the Ministries of Water, Agriculture and Environment. Questionnaires, interviews, Focus Group Discussions and field observations were used to generate the data. Quantitative data was analysed using Statistical Package for Social Sciences (SPSS) whereas qualitative data was analysed through establishing the categories and themes, relationships/patterns and conclusions drawn in line with the study objectives. Findings indicate that most farmers adopted autonomous adaptation strategies that included planting drought tolerant crops (76.5%), charcoal burning (52.9%) and rainwater harvesting (20.2%) among others. Chi square results indicated that age, level of education and knowledge of climate change had significant influences on adaptation strategies. Some of these strategies had serious adverse environmental impacts on social, economic and biophysical domains of the environment like putting future agricultural production at risk since farms have been converted into sand mining fields. Major limitations to climate change adaptation were financial constraints (93.4%), lack of relevant skills (74.5%) and lack of scientific and technical knowledge (71.6%). The study concludes that farmers are engaging in adaptation strategies that are fundamentally changes in livelihoods and mainly unsustainable. Livelihood activities such as charcoal burning and sand harvesting in their fragile arid and semi-arid lands ecosystem are destructive and thus, not sustainable. These livelihood changes are significantly influenced by levels of education and climate change knowledge. The study recommends that agricultural extension services be enhanced to sensitize the farmers about climate change thus improving their perception and adaptation strategies.

Key words: Climate change, small-scale farmers, adaptation strategies.

INTRODUCTION

Climate change refers to a change in the state of the climate that can be identified by changes that persists for an extended period, usually decades or longer (IPCC, 2007). The United Nations Framework Convention on Climate Change (UNFCCC, 2007) have argued that climate change may have a permanent negative impact on the natural resource base upon which agriculture thrives especially considering that it is happening at a time of growing demand for basic human requirements such as food, fibre and fuel. Agriculture on the other hand is highly dependent on the climate and human dependence on agricultural livelihoods particularly the poor is high (Slater et al., 2007).

In Kenya, climate change has had far reaching effects since majority of the country's population depend on rain-fed agriculture. Seventy five per cent of Kenya's population depends on agriculture for food and income and the sector contributes 26% to the Gross Domestic Product and 60% to foreign exchange earnings (Perret, 2006). Over the past decade, the incidence and intensity of hunger and malnutrition has increased significantly and food availability has not kept pace with the rapidly growing population in Kenya (Shori, 2000).

The regions that are associated with hunger are mainly the arid and semi-arid lands. Decreased food production and famine are very regular in these areas despite the involvement of the largest proportion of population in agriculture. Increasing temperatures and frequent droughts have worsened the already fragile situation of the small-scale farmers who rely on rain-fed agriculture for survival. Indeed droughts have been a regular occurrence in the past in many parts of the world with grave consequences on food security and malnutrition (FAO, 2011). With climate change, severe droughts are likely to occur more often and to affect larger areas (FAO, 2011). Yatta District lies in these arid and semi-arid areas characterized by frequent droughts and food insecurity. Agriculture is the most important sector in this district contributing 70% of the district's household income (Republic of Kenya, 2009). However, inadequate and unreliable rainfall, environmental degradation, low investment in irrigation infrastructure, high post-harvest losses and poor farming methods in the district leads to food insecurity.

Presently in Yatta area, seasons that were predictable are no longer predictable. Season rains are erratic and droughts have become more frequent and severe (Mburu et al., 2014). The change of weather has brought many pests and diseases to the plants and animals. Rivers such as Ngomola, Kamanguli, Mukengesya, Iuuma and Inyanzaa have dried up as a result of climate change. Many plant species of social importance have also become rare over the years. Overall, climate change has brought poverty to the people of Yatta and relief food has become a permanent feature in their lives. To cope with these changes small-scale farmers have devised their own adaptation strategies.

According to UNDP (2004), adaptation is a process by which strategies to moderate and cope with the consequences of climate change can be enhanced, developed and implemented. Adaptation to climate change involves changes in agricultural management practices in response to changes in climate conditions and often involves a combination of various individual responses at the farm-level (Shashidahra and Reddy, 2012).

The objective of this study was to examine the adaptation strategies to climate change adopted by the dry-land small-scale farming communities in Yatta District. The study also assessed the environmental impacts of such adaptation strategies.

METHODOLOGY

Study area

The study was carried out in Yatta District in Kenya (Figure 1). Yatta is situated between longitudes 37^0 20' and 37^0 55' East and between latitude 0^0 50' and 1^0 30' South. Part of the district falls on Yatta Plateau, which is a long, flat-topped ridge formed by a stream of lava flow from OlDonyoSabuk Mountain. It covers a total area of 2,469 Km^2 and has a population of 299,435 inhabitants (Republic of Kenya, 2009). The main soil types are Acrisols, Luvisols, Ferralsols, Alfisols, Ultisols, Oxisols and Lithisols (Lezberg, 1988; Barber et al., 1981; Scott, 1963). These soils are all generally of low fertility and many are highly erodible. The dominant vegetation is dry bush (Lerberg, 1988). The district receives about 450-800 mm of rainfall per year and average temperatures range from 25 to 29°C (Republic of Kenya, 2009). The population density is influenced by land productivity and water availability.

Sampling and sample size

A representative sample size for the survey was determined by using Krejcieand Morgan's (1970) formula commonly used to calculate a sample size from a given finite population (P) such that the sample size will be within plus or minus 0.05 of the population proportion with a 95% level of confidence (Equation 1: sample size determination).

$$s = \frac{X^2NP(1-P)}{d^2(N-1)+X^2P(1-P)} \quad (1)$$

Where: X^2 = table value of Chi-Square for 1 degree of freedom at the desired confidence level (in this case 3.84), N = the population size, in this case 299,435, P = the population proportion (assumed to be 0.5 since this would provide the maximum sample size), d = the degree of accuracy expressed as a proportion (0.05). This formula gave 384 as the minimum sample size for the study. However, a larger sample size was considered to account for non-responses. Since sampling was farm based, to cover as much study area as possible, one sub-location was randomly selected in each of the 17 administrative locations. From each of the sub-location, 30 farmers were randomly selected, giving a sample size of 510 farmers in total. District heads of agriculture, environment

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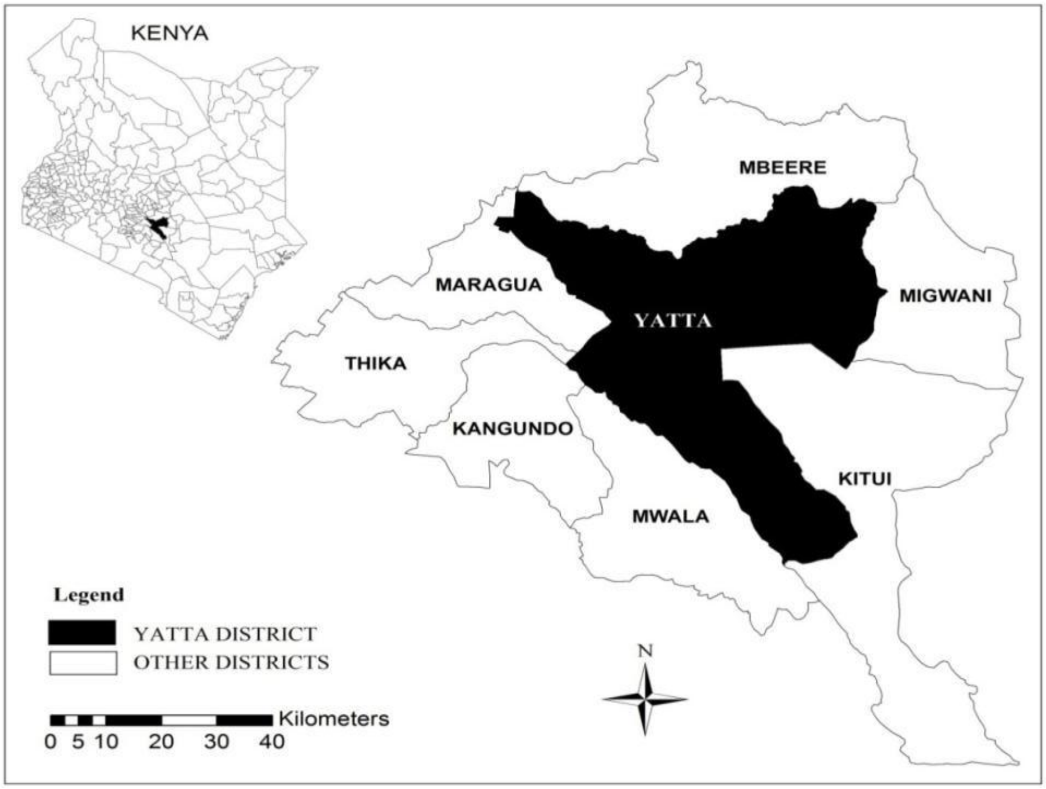

Figure 1. Study area location. Source (GoK, 2009).

and water departments were also interviewed. Four single sex Focus Group Discussions (FGDs) comprising of eight to twelve farmers were conducted.

Data collection and processing

The study being primarily a survey research employed several methods for data collection including the use of questionnaires, interviews schedules, FGDs, desk research and observations from the field. The study adopted the Participatory Vulnerability Profiles (PVP) approach as used by Haan et al. (2001). The PVP focused on current vulnerability, risk of present and future climatic variations and responses to reduce present vulnerability and improve resiliency to future risks. This approach placed the stakeholder at the centre of the research, which is important because the people in the region have developed indigenous knowledge systems that have enabled them to cope so far with the climate change phenomenon.

Data analysis methods

The collected data was analysed using both quantitative and qualitative techniques. Frequency counts, means and percentages were computed for all quantitative data and results presented using frequency distributed tables. Chi-square test was used to determine relationships between adaptation strategies and background variables like age, level of education and knowledge of climate change. FGDs results were transcribed and translated and then analysed qualitatively which basically involved establishing the categories and themes, relationships/patterns and conclusions drawn in line with the study objectives (Gray, 2004).

RESULTS AND DISCUSSION

Farmers in Yatta district were engaging in various strategies to adapt to climate change (Table 1). Such adaptation strategies included planting drought tolerant crops, charcoal burning, rainwater harvesting and joining community based organizations (CBOs) addressing climate change challenges among others (Table 1). These adaptation strategies were mainly autonomous adaptations where farmers changed their livelihoods in response to changing climate. These kinds of adaptations are based on accumulated knowledge and experiences over the years by the residents.

These results corroborate findings by Boko et al. (2007) who noted that strategies of adaptation already observed in Africa include diversification of livelihood activities, adjustments in farming operations and selling of labour. According to Benedicta et al. (2010), the main adaptation strategies of farmers in Sekyedumase District in Ghana include change in crop types, planting short season varieties, changing planting dates and crop diversification.

According to Sekaleli and Sebusi (2013), some of the farmers' adaptation strategies in Lesotho include water harvesting technologies, conservation tillage, use of

Table 1. Adaptation strategies to climate change.

Adaptation strategies	Frequency	%
Planting drought tolerant crops	372	76.5
Charcoal burning	257	52.9
Joining CBOs addressing climate change challenges	100	20.6
Rainwater harvesting	98	20.2
Apiculture (honey production)	96	19.8
Sand scooping	91	18.7
Hunting	73	15.0
Irrigation agriculture	64	13.2
Migration to other areas	37	7.6
Greenhouse farming	5	1.0
Fishing	15	3.1

keyhole and trench gardens, agro-forestry and application of traditional medicine to control pests and diseases. Women farmers in Peru take advantage of the knowledge inherited from ancient Peruvian culture. They adapt though postponing planting season when the rains delay, crop rotation, production diversification, production of native crops and migration to look for jobs among others (Abeka et al., 2012).

In china, farmers have implemented their own adaptation strategies, such as changing cropping patterns, increasing investment in irrigation infrastructure, using water saving technologies and planting new crop varieties to increase resistance to climatic shocks (Wang et al., 2010). In the USA farmers adapt to the changing climate by choosing crops resilient to drought and pest risk, plant different crops according to slope, aspect and other highly site-specific conditions. They also apply different practices such as tillage, technological advances including information to manage market risk (Antle, 2009). Farmers in Europe adapt to climate change through infrastructural measures such as on-farm harvesting and storage of rainwater, management measures and technical measures (Iglesias et al., 2007). The main adaptation strategies in Yatta District are discussed below.

Planting drought tolerant crops

The results of this study show that most farmers (76.5%) (Table 1) planted drought tolerant crops such as *Sorghum bicolor*, *Cajanus cajan, Vigna unguiculata, Vigna radiata, Dolichos lablab* and *Manihot esculentum* among others. Chi square results indicated that age had a significant influence on planting drought tolerant crops (X^2=9.259, df=3, p<0.05) whereby the elderly farmers are more likely to plant drought tolerant crops. This can be explained by the farming experience gained over the years by the older farmers. Periodical droughts are part of the climate system in Yatta district and due to this the older farmers have learnt to plant drought tolerant crops. Maddison (2006) argued that, if farmers learn gradually about the change in climate they would also learn gradually about the best techniques and adaptation options available. According to Shongwe et al. (2014) in a study in Swaziland, the choice of adaptation strategies by households was significantly influenced by age of household head. The age of the household head represents experience in farming. Experienced farmers perceive climate change better as they are exposed to past and present climatic conditions over their life span and hence the higher chance of planting drought tolerant crops. Additionally, the level of education had a significant influence on planting drought tolerant crops also (X^2=12.87, df=3, p<0.05). The higher the farmers' level of education, they are more likely to plant drought tolerant crops. Knowledge gained through education exposes the farmers to the advantages of drought tolerant crops hence planting them. Looking at the combined factors of education and age, the latter is more significant in Yatta since most of the educated people prefer seeking employment in urban areas to farming.

The characteristics of drought tolerant crops such as withstanding low water and high heat conditions (Borel, 2009) leads to reasonable harvests even with low rainfall. These characteristics lead to reasonable harvests even with low rainfall. The crops offer an alternative to suffering from hunger through seasons due to crop failure.

However, during FGDs farmers observed that planting *Sorghum bicolour*is unpopular since they have to wake up very early in the morning to drive the birds away. According to the District Crops Production Officer, farmers in this region are faced with perennial famine because they rely on maize and other crops that need plenty of rain. There is need to diversify the varieties of drought tolerant crops they plant in order to alleviate poverty.

Charcoal burning

The study established that 52.9% of the farmers burn charcoal mainly for commercial purposes in order to meet their domestic needs. Chi-square test results showed that knowledge of climate change had a significant influence on charcoal burning (X^2=18.405, df=2, p<0.05) whereby the higher the knowledge level, the less likely they are to burn charcoal. The level of education also had a significant influence on charcoal burning (X^2=11.207, df=3, p<0.05) in that the less educated the farmersare, the more likely they are to burn charcoal. Education exposes the farmers to the role played by trees in mitigating climate change and as such the more educated the farmers are, the less likely to burn charcoal. As verified by the results, those farmers with a good knowledge about climate change would not cut down trees for charcoal burning. This is because they understand the consequences of cutting down trees on the climate of the area. Indeed Tadesse (2010) observed that knowledge and access to information are essential for effective environmental management and have significant impacts on the economy and the livelihood choices people make.

The farmers pointed out that they use species such as *Terminali abrownii* (*Fresen*)**,** *Dalbergia melanoxylon* (Guill.&Perr)*, Acacia tortilis* (Forssk.)*, Acacia Senegal* (*L.*) *Willd, Melia volkensii, Albizia anthelmintica* (Brongn)and *Acacia mellifera* (*Vahl*) *Benth* among others for charcoal making. All these are trees of significant ecological importance in the dry lands. From field observations and farmers' responses regarding species that used to be common in Yatta area but are now very difficult to find, it was evident that charcoal burning has contributed to the disappearance of some of these species. Species such as *Dalbergia melanoxylon* and *Albizia anthelmintica* are quite rare in Yatta district. Indeed *Dalbergia melanoxylon* is listed in the IUCN Red List (2010) as a near threatened species.

Sand harvesting

The results show that 18.7% (Table 1) of the respondents were involved in sand harvesting as a form of adapting to climate change. Sand is harvested on the farms and in the rivers both seasonal and permanent. Harvesting is also carried out along the road sides and wherever sand is available. It is a business that has attracted many young men in this region. The National Environmental Management Authority (NEMA) has tried to regulate this business through issuance of national sand harvesting guidelines (NEMA, 2007). However, this has been without much success in Yatta District mainly due to lack of personnel to enforce the guidelines and also the fact that the government is yet to gazette them. The county government also encourages sand business as a source of revenue. The District Environment Officer concedes that issues of illegal sand harvesters are a serious problem especially in Thika River and in areas around Kamburu and Masinga dams.

Rainwater harvesting

The study reveals that only 20.2% of the respondents were involved in rainwater harvesting both in their homesteads and on farms (Table 1). This is dismal bearing in mind that Yatta is a semi-arid area where droughts are becoming more frequent and rains more erratic and unreliable. According to Ngigi (2009), farmers in Ethiopia and other parts of Kenya have shown high adoption rates for farm ponds and other rainwater harvesting technologies. Indeed rainwater harvesting can offer a partial solution to the issue of climate change. Majority (93.4%) of the respondents attributed their lack of harnessing rainwater to inadequate finances. Among these 20.2% of the respondents harvesting rainwater, majority were using small containers such as drums, buckets and jerry cans. Very few had water tanks. Other homesteads had grass thatched rooftops which are not suitable for rainwater harvesting.

Less than 2% of the respondents practised road runoff water harvesting on the farms. Respondents attributed this deficit to lack of finances to dig retention ditches that are necessary for storing the storm water and allowing a slow seepage into the farm. Road runoff water provides additional environmental flows and additional water for food production and it is possible to double or triple crop yields through this technique (Ibraimo and Munguambe, 2007). Respondent farmers practising this technique reported improved food security in their households. These findings agree with the results of an evaluation of rainwater harvesting techniques conducted in Laikipia District that showed road runoff water utilization for crop production is already improving yields (Kihara, 2002). Responding to water scarcity stress and the threat of declines in crop yields require farm level intervention such as rainwater harvesting and establishing small-scale water reservoirs on farmlands (Osman-Elasha, 2010).

Other adaptation strategies

Other adaptation strategies devised by farmers in Yatta district included greenhouse farming (1%), apiculture (19.8%), hunting (15%), irrigation agriculture (13.2%), joining CBOs addressing climate change challenges (20.6%), fishing (3.1%) and migration to other places in search of casual labour (7.6%) (Table 1). Those who had joined CBOs consisted of 22% of all male respondents and 17.8% of all female respondents. During FGDs, respondents also reported that they are nowadays doing family planning, rationing food in their homes, forming self-help groups, establishing kitchen gardens, storing fodder and turning to goat milk as ways of adapting to climate change. Chi-square test revealed significant relationship existed between joining CBOs and planting drought resistant crops (X^2=23.88, df=1, p<0.05). Significantly more of those farmers who had joined CBOs

Table 2. Environmental impacts of farmers' adaptation strategies in Yatta district.

Impacts of sand harvesting N = 91	F	%	Impacts of greenhouse N = 5	F	%
School drop out	60	65.9	Improved harvest	5	100.0
Drug and alcohol abuse	85	93.4	Controlled plant diseases and pest	4	80.0
Insecurity	90	98.9	Improved export market	2	40.0
Sexual immorality	75	82.4	Efficient water utilization	4	80.0
STDs and early pregnancies	35	38.5	Altered land aesthetics	1	20.0
Divorce	15	16.5	**Impacts of joining CBOs N = 100**	**F**	**%**
Rivers drying increasing water distance	72	79.1	Sharing of knowledge and skills	65	65.0
Source of livelihood	90	98.9	Acquiring scientific and technical knowledge	12	12.0
Aquatic life poisoning by oil/fuel spills	3	3.3	Environmental conservation skills and knowledge	9	9.0
Derelict land	1	1.1	Tree planting	88	88.0
Vegetation destruction	8	8.8	**Impacts of rainwater harvesting N = 98**	**F**	**%**
Accidents	5	5.5	Clean water availability	90	91.8
Impacts of charcoal burning N = 257	**F**	**%**	Improved yields	30	30.6
Air pollution	103	40.1	Better sanitation at home	76	75.6
Low rainfall	7	2.7	More time to do other chores	90	91.8
Soil erosion and degradation	187	72.8	**Impacts of fishing N = 15**	**F**	**%**
Deforestation	111	43.2	Food	5	33.3
Biodiversity loss	8	3.1	Income	15	100.0
Health problems	134	52.1	Accidents	2	13.3
Source of livelihood	120	46.7	**Impacts of migration N = 37**	**F**	%
Impacts of planting drought tolerant crops N = 372	**F**	**%**	Family separation	25	67.6
Source of food	268	72.0	School drop out	18	48.6
Soil structures protection	7	1.9	Land left idle	7	18.9
Improved harvests	300	80.6	**Apiculture N = 96**	**F**	**%**
Loss of income	272	73.1	Income	13	13.5
Interference with following season planting	8	2.2	Food	17	17.7
Small scale irrigation N = 64	**F**	**%**	Bush fires	7	7.3
Food	22	34.4			
Income	21	32.8			
Water borne diseases	3	0.6			

(95.0%) were planting drought resistant crops as compared to 71.8% of those who had not joined CBOs.However, membership in CBOs had no significant effect on rain water harvesting.

Environmental impacts of adaptation strategies employed by farmers

To counter the effects of climate change, farmers adopted various strategies ranging from changes in livelihood to new farming strategies. These changes in agricultural management practices and livelihoods by the farmers in response to changes in climate often result into positive or negative effects to the land and ecosystems. The respondents were aware of both negative and positive environmental impacts of their adaptation strategies. It was quite evident that some adaptation strategies had serious adverse impacts on both social and biophysical domains of the environment. More so the future of agriculture is put at risk by some of these strategies. The impacts range from biophysical, social to economic impacts (Table 2).

Environmental impacts of sand harvesting

The findings showed that sand harvesting is one of the adaptation strategies with serious negative impacts on both social and biophysical domains. Many social problems were associated with sand harvesting activities. Issues of early pregnancies (38.5%), children dropping out of school (65.9%), prostitution (82.4%), drug and alcohol abuse (93.4%) and insecurity (98.9%), sexually

Figure 2. Impacts of sand harvesting on the farms at Manaja area.

transmitted diseases such as AIDS (38.5%) and divorce (16.5%) among others were reported (Table 2).

In Manaja area, this strategy has put future agricultural production at risk since farms have been converted into sand mining fields. As observed during transect walks in the area, many farms have been dug up destroying most of the land that can be cultivated for growing crops. Some farms have been dug beyond two meters deep leaving behind derelict land (Figure 2). This further exacerbates the food security situation in Yatta District.

Sand harvesting has destroyed vegetation including cash crops such as mangoes and even encroached homesteads (Figure 2). Respondents observed that instream sand harvesting has led to drying of rivers further complicating the issue of water scarcity in Yatta area. In Kithyoko Location, respondents noted that sand harvesting has increased their average walking distance to fetch domestic water to three kilometres one way. Rivers like Mukengesya, Iyuuma, Inyanzaa and Kamanguli have dried up due to excessive and uncontrolled sand harvesting. However, economically the adaptation had positive impacts as a source of livelihood through the provision of employment opportunities.

In other areas such as India, fifteen adverse consequences of sand mining have been identified. They include depletion of groundwater; lesser availability of water for industrial, agricultural and drinking purposes; destruction of agricultural land; loss of employment to farm workers; threat to livelihoods; human rights violations and damage to roads and bridges (Saviour, 2012).

Environmental impacts of charcoal burning

The environmental impacts associated with charcoal burning in the study included air pollution (40.1%), low rainfall (2.7%), soil erosion and degradation (72.8%), deforestation (43.2%), biodiversity loss (3.1%), health problems (52.1%) and source of livelihood (46.7%). Some of the tree species preferred for charcoal burning by the respondents have become very rare in the area. Indeed the Environment Officer confirmed that charcoal burning has seriously affected tree species such as *A. senegal, D. melanoxylon* and *A. tortilis*.

Elsewhere, charcoal burning has been reported to result into loss of biodiversity, soil erosion, recurrent droughts, migration to urban centers, decline of wildlife, scarcity of woody resource and watershed degradation (MoPD&E& CLHE, 2004). Charcoal burning also negatively affects the environment through the emission of high levels of carbon dioxide, which is one of the major greenhouse gases that contribute to global warming and climate change (Wario and Bowa, 2011).

Environmental impacts of planting drought tolerant crops

Planting drought tolerant crops was reported by the respondents to have both positive and negative environmental impacts. These included alternative source of food (72.0%), soil structure protection (1.9%), improvement of harvest stability (80.6%), loss of income (73.1%) and interference with the following season's planting (2.2%). The respondent farmers observed that, even though they mostly focus on growing marketable crops like maize, they also grow some drought tolerant crops such as *Sorghum bicolor*, *C cajan, V. unguiculata, V. radiata, Dolichos lablab* and *M. esculentum* for their household consumption (Figure 3). These drought tolerant crops provide an alternative source of food in seasons where maize fail and improve harvest stability.

Drought tolerant crops such as *S. bicolor*, *C. cajan, V. unguiculata, V. radiata,* and *Dolichos lablab* among others lend greater resilience to agricultural production

Figure 3. Intercropping of *Vigna radiata*, *Zea mays* and *Cajanus cajan* in alley farming

under water stress conditions and may also reduce a farm's water requirements (FAO, 2012; CGIAR, 2012). Early maturing varieties of these crops such as *V. radiata* have proved especially useful for helping dry land communities get through the "hungry season"- period before harvest when the previous year's grain supplies have been exhausted. The successful harvests that farmers have had after sowing the drought tolerant crops suggest that food security could be better achieved if more farmers grew adapted crops which survive dry spells and erratic rainfall (ICRISAT, 2011).

The major negative impact reported by the respondents was loss of income since these drought tolerant crops are not in high demand in the market. This was found to be a major drawback to the acceptance of these drought tolerant crops. To improve on this the government supported by World Bank is running an Orphaned Crops Programme to sensitize the farmers in Yatta district to increase the acreage of these traditional high value crops (MoA, 2007). Other private organizations such as Kenya Breweries are promoting planting of Sorghum through distribution of free seeds and offering market. Another negative impact reported was that the tap roots of cow peas left behind after harvesting were affecting next season's planting. The respondents observed that as soon as the rain fell, these tap roots sprout and spread fast interfering with the germination of planted seeds.

Environmental impacts of greenhouse farming

Greenhouse farming was found to be undertaken by very few respondents in the study area basically due to the capital outlay involved. Several environmental impacts were associated with greenhouse farming. These included improved harvests (100%), controlled plant diseases and pests (80%), improved export market (40%), efficient water utilization (80%) and altered aesthetics of the land (20%). It was evident that the five respondents with greenhouses were economically better off than the rest. Crops grown in the greenhousesincluded vegetables such as tomatoes, onions and flowers for export.

Greenhouse farming is a very effective way to deal with the increasing rainfall unreliability in Yatta area since it is practised all year round and the water saving achieved by greenhouse production is impressive (Boulard et al., 2011). Four out of the five farmers with greenhouses reported efficient water utilization as a positive impact (Table 2). Greenhouse farming has the potential to feed the population and also generate income thus improving their economic status. The farmer just has to know when to plant and harvest his crops for maximum gains. The altered aesthetics of the land can be compensated by planting more trees in the area.

Greenhouse crops fetch higher remunerative prices due to their quality as a result of better controlled plant diseases and pest (Table 2). On the other hand, studies conducted in India indicated that the socio-economic impacts of the greenhouse farming are enormous (Government of India, 2009). However, according to Boulard et al. (2013), greenhouse farming can also have negative impacts such as ecotoxicology or human toxicology impacts.

Environmental impacts of joining CBOs addressing climate change challenges

Joining CBOs provided a forum for the farmers to interact and share adaptation knowledge and skills (65%). These communities based organizations helped farmers in

Table 3. Limiting factors to devising adaptation strategies by small-scale farmers in Yatta District.

Limiting factors	Yes		No	
	F	%	F	%
Financial constraints	454	93.4	32	6.6
Lack of relevant skills	362	74.5	124	25.5
Lack of scientific and technical knowledge	348	71.6	138	28.4
Lack of information	330	67.9	156	32.1
Lack of infrastructure/inputs	300	61.7	186	38.3
Reliance on relief food	192	39.5	294	60.5

acquiring some technical and scientific knowledge pertaining to climate change (12%). Respondents also reported gaining skills and knowledge of environmental conservation (9%) such as controlling water run-off and ultimately adjusting to climate change. Examples of these CBOs are the Water Resource Users Associations formed by the farmers in an attempt to conserve the water resources. Farmers in these groups engage in activities like tree planting and digging bench terraces. Others run community tree nurseries. Since these organizations have a core function of addressing themselves to the challenges of climate change, their environmental impacts were generally positive.

Environmental impacts of rainwater harvesting

The environmental impacts associated with rainwater harvesting in the study included availability of clean water (91.8%), improved yields (30.6%), better sanitation at home (75.6%) and availability of time to do other house chores (91.8%). Harvested rainwater provides clean water supply to the households at close proximity whereas harvested runoff water improves yield (Kihara, 2002). In a case study of rainwater harvesting for domestic, livestock, environmental and agricultural use in Kusa, Kenya, Orodi et al. (2005) found the impacts to be immediately noticed on the improved health of the residents and time saved. There was assured supply of domestic water at the homesteads and improved yields (Ibid).

In a study conducted by Aroka (2010) in Mwingi, Kenya the time spent for collecting water was found to have decreased while the general health of the community is thought to have improved as a result of water harvesting. Rainwater harvesting schemes have also made more water available closer to communities, meaning less time and energy spent on gathering water from distant and possibly unsafe water sources (Aroka, 2010). According to Malesu et al. (2006), water harvesting in Lare Division, Kenya has improved access to clean water and consequently improved health status of the local community. It has also increased agribusiness activities in the area that include the production and sale of livestock and farm products. Women are spending more time on their farms and are seeing their incomes from farming rise as their water-related workload decreases. There is also increased crop diversity resulting in improved food security and better nutrition in the area (Ibid)

In Yatta District, rainwater harvesting may not provide relief to the farmers since the low rainfall during droughts is unlikely to be sufficient for rainwater storage. Furthermore, climate change may exacerbate this problem in future. However, this notwithstanding, in areas where women walk for about six kilometres daily to fetch water for domestic use and spend some time queuing at the water points, rainwater harvesting can have some socio-economic benefits.

Limitations to adaptation strategies

It emerged from the study that Yatta small-scale farmers faced a host of challenges that limited their capacity to devise effective adaptation strategies. As shown in Table 3, the farmers in Yatta District experienced challenges such as financial constraints (93.4%), lack of relevant skills (74.5%), lack of scientific and technical knowledge (71.6%), lack of information (67.9%) and lack of infrastructure and inputs (61.7%) among others.

During the FGDs, it also emerged that finances are critical to rain water harvesting and adaptation to climate change in general. The farmers observed that, even with basic skills and knowledge of adaptation, they are just helpless due to poverty. This is clearly demonstrated by the words of one middle aged farmer from Eendei sub-location that;

"We just let the rain go because we do not have finances. We have the basic skills of knowing what to do but we do not apply those skills because we cannot harvest water. We know that we are supposed to have big tanks for storage and we also know about kitchen gardens and how to maintain them. However majority of us have no finances and we just let the water go to waste. Poverty has crept in because of the recurrent droughts. We don't have tanks. Also some of us don't have donkeys to fetch water for kitchen gardens. We know what needs to be done but have no resources to do so."

Lack of scientific and technical knowledge among the farmers can be attributed to the wide-ranging low levels of education in the district whereas lack of information can be attributed to the poor infrastructure in the district: there are no farmers' training facilities in the district and the road network is generally sparse and most of the rural population is not well connected (Republic of Kenya, 2009).

Reliance on relief food could be a limitation to adaptation in the sense that it can lead to the dependency syndrome. In a research study conducted by Harvey and Lind (2005) in Kenya and Ethiopia, a significant percentage of people interviewed (45%) reported that relief assistance has made some people lazy. Men in one remote village complained of an 'eat and wait' attitude among some community members. The existence of such views in remote communities suggests the power of the dependency syndrome argument where relief undermines initiative (Harvey and Lind, 2005).

The findings of this study corroborate an earlier research by Bryan et al. (2011), whose Kenyan study results revealed that lack of money or access to credit (63%) was a significant barrier to adaptation. Other findings by Bryan et al. (2011) corroborate the outcomes of this research, that lack of access to water (26%), in the case of irrigation and lack of money/credit (55%), lack of access to land (6%) and water (20%), lack of inputs (10%) and lack of information (5%) in the case of agroforestry, are significant impediments to adaptation to climate change.

These findings also corroborate the results of a study conducted by Gbetibouo (2009) in the Limpopo River Basin, South Africa where more than 53 percent of farmers cited lack of access to credit, poverty and lack of savings as the main barriers to adaptation. However, according to Gbetibouo (2009), few farmers designated lack of information or knowledge of appropriate adaptation measures as barriers to adaptations. On the other hand, lack of knowledge on climate change is considered by Nzeadibe et al. (2011) to be one of the major constraints to climate change adaptation by farmers in the Niger Delta.

Conclusion and recommendations

The study concludes that, small-scale farmers in Yatta District are engaging in various adaptation strategies to climate change that are not guided by any policy. These are fundamentally changes in livelihoods such as charcoal burning, sand harvesting, fishing and apiculture, rainwater harvesting and planting drought tolerant crops. They also join CBOs addressing climate change challenges among others.

Education levels and knowledge of climate change significantly influenced a number of these adaptation strategies. The adaptation strategies adopted have both positive and negative environmental impacts. Sand harvesting have serious ecological and social impacts ranging from crop land destruction, drying river beds and land degradation to prostitution and drug abuse. Charcoal burning has led to significant decrease of some plant species due to overexploitation. Conversely, planting of drought tolerant crops and joining CBOs addressing climate change issues have had positive environmental impacts. The main constraints to devising effective adaptation strategies were lack of finances, lack of skills and inadequate information on climate change and scientific knowledge.

Considering the importance of rain-fed agriculture in Yatta and Kenya in general and the fact that ambitious mitigation efforts can only lessen but not prevent future climate change, the study recommends that the Ministry of Agriculture formulates policies specifically focused on small-scale farmers' adaptation to climate change so as to improve food security. To improve food production and avert crop land destruction in Yatta district, rain-fed agriculture needs to be complemented with the development of small scale irrigation schemes and greenhouses. Water harvesting needs to be enhanced and promoted. This is because climate change is expected to have serious environmental, economic and social impacts on small-scale farmers whose livelihoods depend on rain-fed agriculture. Small-scale farmers should also be capacitated by the Ministry of Agriculture in terms of climate change knowledge and skills to avert further risks in agricultural production in the area. Further research should be conducted to establish the likely costs and effectiveness of these adaptation strategies in the small-scale dry land agriculture.

Conflict of interests

The authors did not declare any conflict of interest.

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Full Length Research

Investigation of groundwater flow potential in Makurdi, North Central Nigeria, using surficial electrical resistivity method

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Vertical electrical sounding (VES) employing Schlumberger electrode configuration was carried out in order to study the groundwater flow potential in Makurdi, north central Nigeria. This was done in thirty locations to determine the aquifer resistivity, thickness, longitudinal conductance, hydraulic conductivity and transmissivity. From the result, the averages and ranges of these parameters were determined. 2D contour maps of aquifer resistivity, aquifer thickness, longitudinal conductance, hydraulic conductivity and transmissivity were drawn. The distribution of thickness and transmissivity maps provided a means of identifying areas where aquiferous zone is prolific. The classification of the groundwater potential shows 3.3% very low, 26.7% low, 66.7% moderate and 3.3% high potentials. Knowledge of hydraulic conductivity and transmissivity is necessary for the determination of groundwater flow potential through an aquifer.

Key words: Aquifer resistivity, hydraulic conductivity, transmissivity, longitudinal conductance, vertical electrical sounding, thickness, Makurdi.

INTRODUCTION

Groundwater is that water found within the saturated voids beneath the ground. It is the major source of potable water supply in the Makurdi area. Groundwater is the subsurface water which fully saturates the pores and behaves in response to gravitational force (Straher, 1973). Water is an indispensable resource and the concern of many earth scientists and researchers have been on the acquisition of a reliable source of drinking water (Akinbinu, 2015). Surface and groundwater resources are abundant in Nigeria. The water resources master plan for Nigeria which was prepared by the Japan International Co-operation Agency (JICA) in 2006 indicates an estimated surface water resource of about $2.67 \times 10^{11} m^3/year$ and groundwater storage of about $0.52 \times 10^{11} m^2/year$ (Oteze, 2006). These figures greatly outweigh the country's total water demand of about $0.40 \times 10^{11} m^3/year$ (Oteze, 2006). Surface water is frequently found to be grossly degraded in quality because of its exposure to physical, biological or chemical contaminants (Edet, 2004). Groundwater on its

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own has less of a degree of contamination when compared with surface water and this has contributed to an increase in the number of boreholes drilled by the government, non-governmental organizations and individuals in Nigeria.

The availability and quality of groundwater in Makurdi, the capital town of Benue State, North Central Nigeria, are determined from a number of composite factors such as porosity and permeability. The Public Water Works which supplied water to all parts of the town has become dysfunctional and moribund. Most residents of the town have adjusted to providing their own domestic supplies by use of shallow hand dug wells (approximately 10 m deep) which are often poorly completed. The Makurdi Sandstone which is the main aquifer that supplies water into wells for abstraction is frequently indurated to the extent that well failure is always recorded when it is encountered using manual digging as is the case with all shallow boreholes. The wells are neither cased nor are they properly capped after completion. The immediate surroundings of the wells are inadequately sequestered from unsanitary conditions. Since there was no professional prospecting for the location of water bearing sediments, some of the boreholes have either failed entirely or partially because of uncoordinated drillings. When the rate at which a well is discharge is greater than the rate at which it is recharge, then the well may fail (Davison et al., 1997). The nature of the aquifer is a function of subsurface geological composition that play an important role in determining the circulation of water from the surface (infiltration) to subsurface water through recharge processes (Bashir et al., 2014).

It is believed that the thickness and the other properties of the aquifers where the water is tapped from are very important and can only be made known through geophysical surveys. According to Makinde (2002), groundwater is related to the nature of earth rocks. Information on these rocks can be provided by a number of physical techniques which includes: seismic reflection and refraction, electrical resistivity techniques, well-logging etc. The vertical electrical sounding (VES) method is a depth sounding galvanic method and has proved very useful in groundwater studies due to simplicity and reliability of the method. The electrical resistivity of rock is a property which depends on lithology and fluid contents.

The basement complex terrain has many challenges as regards to groundwater potential evaluation and it explains why yield in basement complex is lower than well yield in sedimentary terrain. Groundwater usually occurs in discontinuous aquifers in basement complex area. Using electrical resistivity method and borehole lithologic logs, Dan-Hasssan (2001) depicted that the aquifers of the basement complex rocks of north central Nigeria are predominantly weathered overburden aquifers. As the resistivity of sediments and rocks are controlled by the amount of water present and the salinity (electrolytic conduction), clay mineral, fine grained or increasing silt or clay content in poorly sorted rocks or sediments will reduce resistivity (Burger,1992). Resistivity imaging method has improved the chance of drilling successfully by identifying the fractured and weathered zones in hard and compacted terrain (Loke, 2001). The flow potential of groundwater is a measure of the transmissivity of the aquifer, which is the product of the aquifer thickness and hydraulic conductivity. The knowledge of aquifer characteristics is important in determining the natural flow of water through an aquifer, it response to withdrawal of fluid, the availability, quantity and quality of the groundwater. Hydraulic conductivity (k) is a measure of the ease with which a fluid will pass through a medium (Heigold et al., 1979). By definition, hydraulic conductivity depends not only upon the medium but also on the fluid (Heigold et al., 1979).

Geophysical site investigations for groundwater exploration are scanty and inadequate in the study area and the hydrogeology is not well developed. The present study is therefore aimed at evaluating the groundwater condition and the nature of the subsurface layers, which will constitute the baseline information about the hydrogeology of the area.

Location and geology of the study area

The study area is Makurdi, the Benue State Capital, North central, Nigeria (Figure 1). It lies between latitudes 7°40'N and 7°50'N of the Equator and between longitude 8°20'E and 8°40'E of the Greenwich Meridian, covering a total area of about 670 km². Makurdi lies within the Guinea savannah vegetation zone with a few patches of forests. The annual rainfall ranges between 1,500 to 2,000 mm with its peak rainfall in the month of July. Temperatures in March and April are about 38 and 48°C, respectively, while in December/January, the temperature is 27°C (Benue State Water Supply and Sanitation Agency, 2008). Makurdi belongs to the Makurdi Formation which overlies the Albian Shale. It consists of thick current bedded coarse grained deposits. The Makurdi sandstone has a thickness of about 900 m (Offodile, 1976). The southern part of the Benue valley is generally gently undulating and punctuated by a few low hills. But toward the northeast, the relief is exaggerated by hills like the Lammuder and Ligri hills, which rise up to 600 m above sea level. The drainage consists of rivers which meander into the River Benue from the north and south directions.

Geologically, the Benue valley consists of a linear stretch of sedimentary basin running from about the present confluence of the Niger and the Benue rivers to the north east, and is bounded roughly by the Basement Complex areas in the north and south of the River Benue. The elongated trough-like basin is continuous with the coastal basin, and in fact, has been correctly described as the longest arm of the Nigerian coastal basin (Offodile,

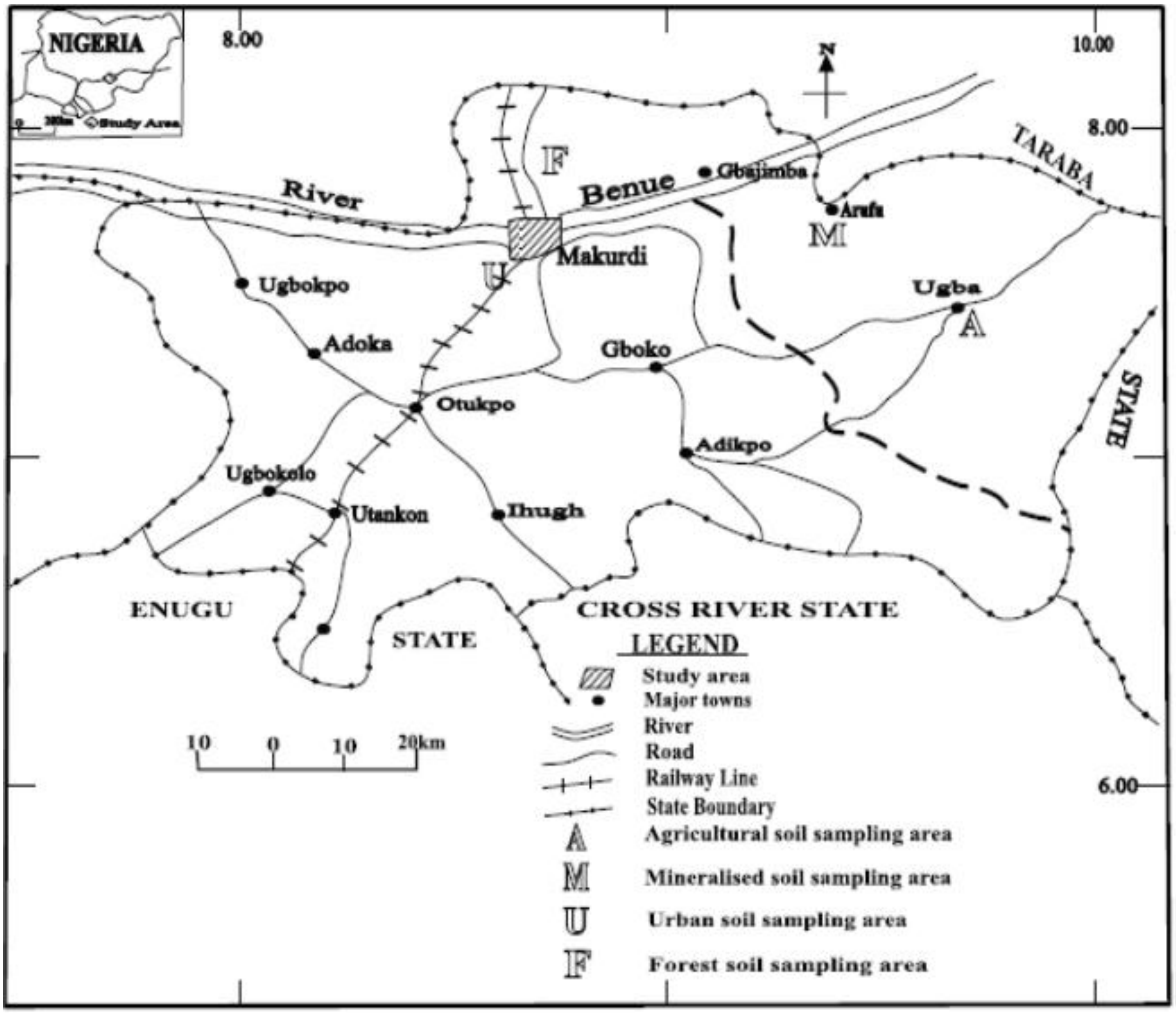

Figure 1. Map of Benue state showing Makurdi (Adamu and Nganje, 2010).

2002) (Figure 1).

MATERIALS AND METHODS

Different types of geological, geotechnical and environmental problems have been studied using surface electrical resistivity methods. The resistivity survey in the study area was completed with thirty Schlumberger electrical sounding (VES) (Figure 2). PZ-02 resistivity meter was used with maximum current electrodes spacing $\left(\frac{AB}{2}\right)$ of 100.0 m, $\left(\frac{MN}{2}\right)$ of 15.0 m. The resistances of the subsurface were measured and recorded against the appropriate potential and current electrodes separation. The depth of penetration is proportional to the separation between the electrodes in homogeneous ground, and varying the electrodes separation provides information about the stratification of the ground (Dahlin, 2001). This method can be used in groundwater to determine depth, thickness and boundary of an aquifer (Zohdy, 1969). The Schlumberger electrode configuration was performed using the vertical electrical sounding field procedure to assess the electrical resistivity of the subsurface and the thickness of the aquifer. The apparent resistivity (ρ_a) was determined using

$$\rho_a = \pi.\left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right].R_a \qquad (1)$$

Where, AB is the distance between the two current electrodes, MN is the distance between the potential electrodes, and R_a is the apparent electrical resistance measured from the equipment. The equation can be simplified to

$$\rho_a = K.R_a \qquad (2)$$

Where, K is the geometric factor given by $\pi.\left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right]$

Figure 2. Google Earth map of the study area showing VES stations.

Using the conventional partial curve matching technique with two-layer master curves in conjunction with auxiliary point diagrams (Orellana and Mooney, 1966), the initial estimates of VES data was achieved. From this, estimates of layer resistivities and thicknesses were obtained which served as starting points for computer-assisted interpretation. The conventional curves and auxiliary point diagrams (theoretical curves) used in the interpretation helped in obtaining a good fit between the observed field curves and the theoretical curves during total and partial matching. The computer software program WINRESIST was used and the data sets obtained from the manual interpretation stage were keyed as inputs into the computer modeling software (WINRESIST) to generate data for the estimated model (Figures 3 to 6). According to Heigold et al. (1979), hydraulic conductivity can be determined using:

$$K = 386.40 R_{rw}^{\ -.93283} \quad (3)$$

Where, K is the hydraulic conductivity and R_{rw} is the aquifer resistivity.
The transmissivity values were calculated using (Todd, 1980):

$$T = Kh \quad (4)$$

Where, T is transmissivity, K is hydraulic conductivity and h is aquifer thickness. This provides a general idea of the water-producing capabilities of aquifer from surficial electrical methods.

The longitudinal conductance (S) was calculated thus:

$$S = \frac{h}{\rho} \quad (5)$$

Where, h is layer thickness and ρ is layer resistivity.

RESULTS AND DISCUSSION

The field results obtained within the survey area is presented in Table 1. The interpretation of the data identified aquifer layers at various sounding points showing the variation of aquifer resistivity and thickness due to lithologic composition, from which the longitudinal conductance, hydraulic conductivity and transmissivity were computed. The aquifer resistivity in the study area ranges from 10 to 702 Ωm with an average value of 190.4 Ωm. From the results obtained, aquifer thickness ranges from 5 to 65 m having an average value of 27.37 m. The high thickness values at some VES points makes it prolific and desirable. The VES with the greatest thickness of 65 m was observed at Nyiman layout while VES at Owner's occupier, North Bank (INEC) and New

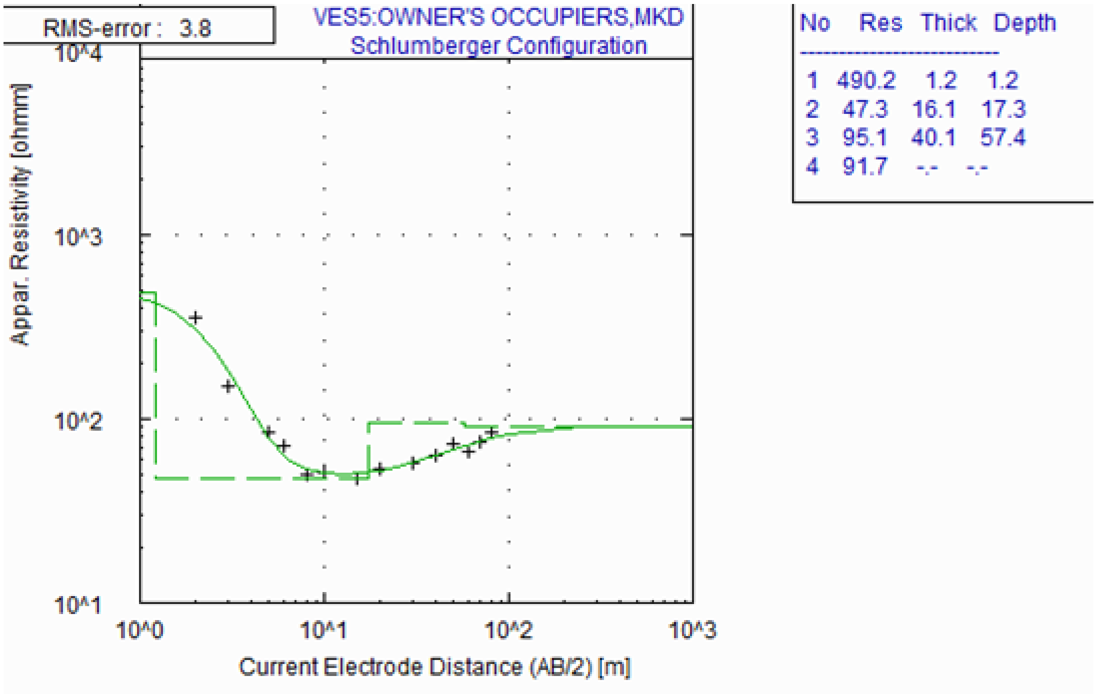

Figure 3. VES 5 geoelectric curve.

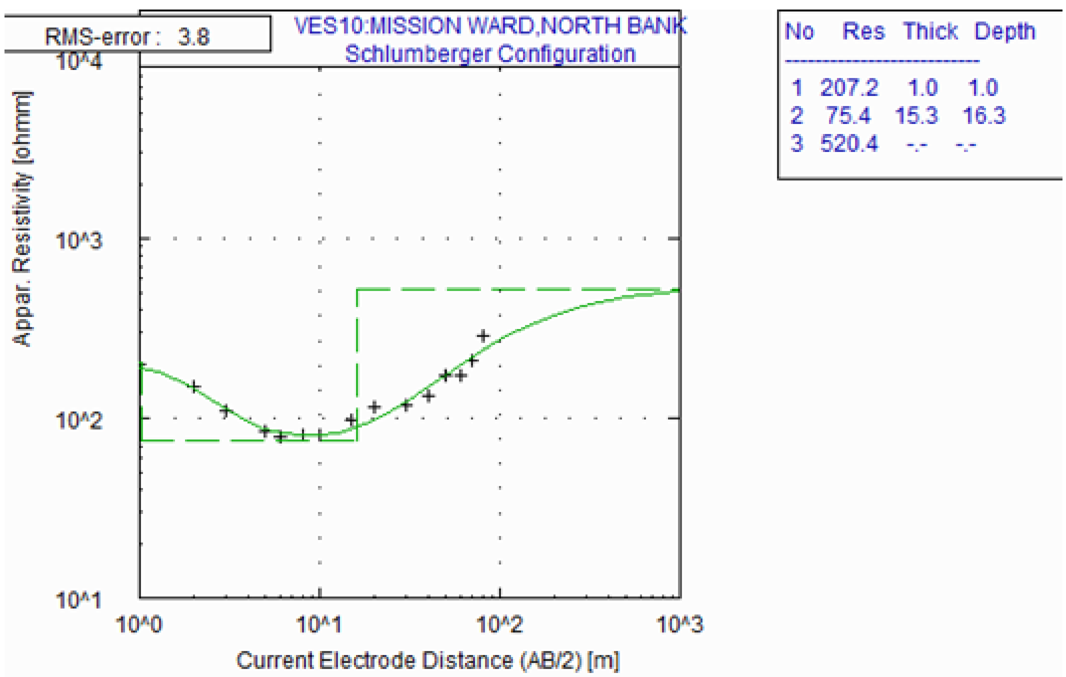

Figure 4. VES 10 geoelectric curve

G.R.A. have the thinnest of 5m. Table 1 also gives the result of hydraulic conductivity (K), transmissivity (T_r) and Longitudinal conductance (S). It gives the range of longitudinal conductance from 0.01 to 0.97 Ω^{-1}, the average value been 0.33 Ω^{-1}. Most of the VES points in the study area have values less than the good protective

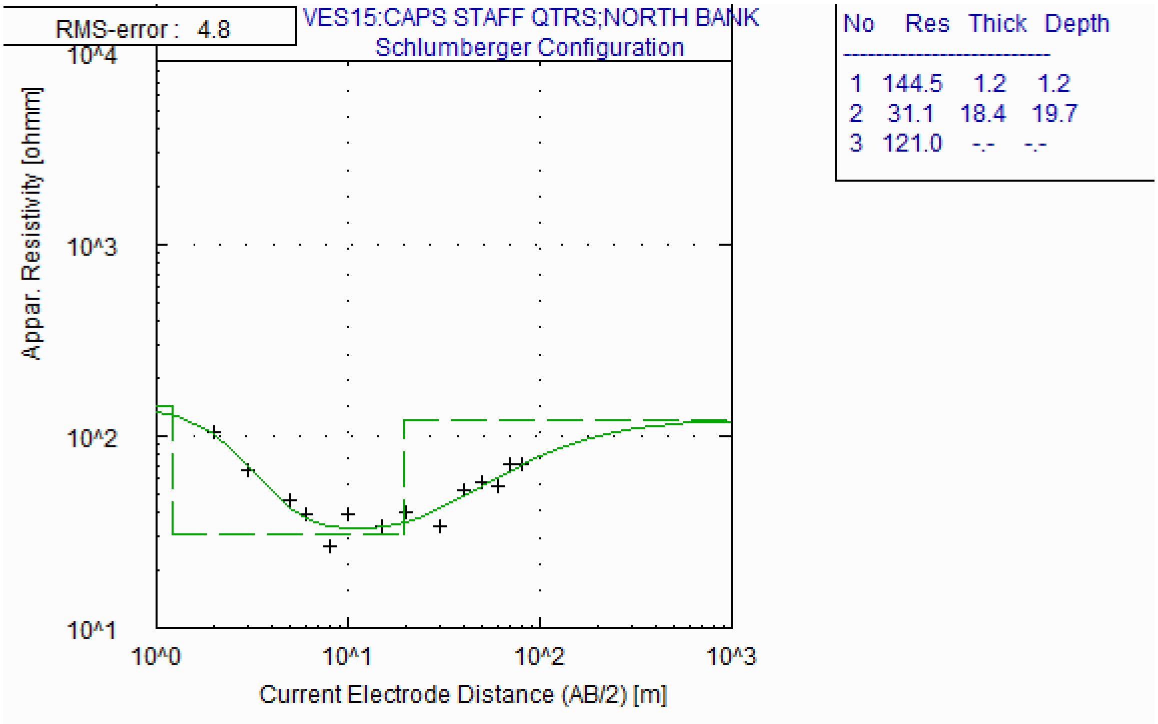

Figure 5. VES 15 geoelectric curve.

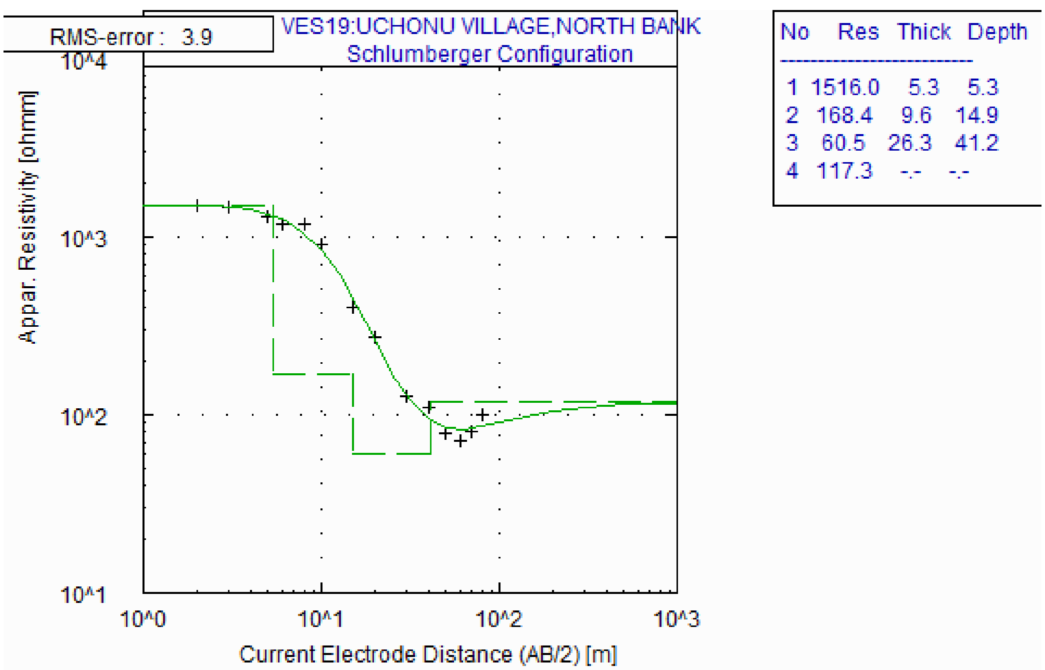

Figure 6. VES 19 geoelectric curve

aquifer range of $0.7 < S < 5.0$, thus indicating that the aquifers are unprotected. The result gives the hydraulic conductivity ranging from 0.85 to 45.10 m/day with an average value of 7.05 m/day. The average theoretical value of hydraulic conductivity given by Niwas and Singhal (1981) is 8.64m/day for pure sand and gravel,

Table 1. Summary of aquifer geo-electric parameters.

VES Station	Location Name	Aquifer resistivity (ρ)	Aquifer Thickness(h) (m)	Longitudinal conductance (S)	Hydraulic Conductivity (K) m/day	Transmissivity Tr (m^2/day)	Latitude(°N)	Longitude (°E)	Groundwater Potential
1	Judges' Qtrs	82	62	0.76	6.34	393.08	08.57804	07.71225	Moderate
2	Judges' Qtrs	109	45	0.41	4.86	218.70	08.58002	07.71121	Moderate
3	Owner's occupier	135	22	0.16	3.98	87.56	08.54855	07.69639	Moderate
4	Owner's occupier	296	5	0.02	1.91	9.55	08.56032	07.69639	Low
5	Nyiman Layout	72	5	0.07	7.15	35.75	08.54484	07.69633	Low
6	Nyiman Layout	333	65	0.20	1.71	111.15	08.51637	07.70640	Moderate
7	Nyiman Layout	273	3	0.01	2.06	6.18	08.51527	07.70531	Low
8	High level	219	17	0.08	2.53	43.01	08.51964	07.71994	Low
9	High level	131	35	0.27	4.09	143.15	08.52250	07.71837	Moderate
10	Mission ward	117	30	0.26	4,55	136.50	08.54739	07.75541	Moderate
11	Industrial Estate	10	6	0.60	45.10	270.60	08.49008	07.70197	Moderate
12	Lafia road	84	52	0.62	6.20	322.40	08.56592	07.79809	Moderate
13	UniAgric road	31	30	0.97	15.70	471.00	08.57532	07.76310	Moderate
14	72 Battalon barrack	218	15	0.07	2.55	38.25	08.54099	07.78555	Low
15	CAPS Staff Qtrs	58	17	0.29	8.75	148.75	08.59575	07.77264	Moderate
16	CAPS Boys' hostel	24	5	0.21	19.93	99.65	08.59867	07.77159	Moderate
17	Shamija Village	304	10	0.03	1.87	18.70	08.61812	07.76231	Low
18	North bank (INEC)	583	5	0.01	1.02	5.10	08.56564	07.98390	Low
19	Uchonu Village	271	33	0.12	2.08	68.64	08.55995	07.77061	Moderate
20	Mission ward	183	30	0.16	3.00	90.00	08.55364	07.76229	Moderate
21	Wadata	39	54	1.39	12.67	684.18	08.51550	07.74444	High
22	Naval School	60	18	0.30	8.48	152.64	08.54222	07.71837	Moderate
23	Ankpa Qtrs	48	45	0.94	10.44	469.80	08.50399	07.70963	Moderate
24	New G.R.A	184	44	0.24	2.98	131.12	08.53838	07.68977	Moderate
25	New G.R.A	702	5	0.01	0.85	4.25	08.53881	07.68717	Very low
26	Naka road	26	20	0.77	18.50	370.00	08.48886	07.68336	Moderate
27	Kanshio	150	50	0.33	3.61	180.50	08.53665	07.68336	Moderate
28	Wurukum	124	23	0.19	4.31	99.13	08.53853	07.72420	Moderate
29	Lower staff Qtrs	160	30	0.19	3.40	102.00	08.55924	07.66061	Moderate
30	Kanshio	686	40	0.06	0.87	34.80	08.53820	07.68476	Low
	Average	190.4	27.37	0.33	7.05	164.87			

Vertical electrical sounding (VES).

hence our value falls below this value, indicating that the study area is fraught with argillaceous bands of clay. Transmissivity values and its variation within the geologic formation was calculated and is also presented in Table 1, and interpreted using Table 2 (Offodile, 1983) for classification of well potential.

The transmissivity values range from 4.25 to 684.18 m^2/day, the average value been 164.87 m^2/day. The areas with high transmissivity can be attributed to having thick aquifer sand. The aquifer in the study area can be delineated as unconfined

Table 2. Well classification based on transmissivity values (Offodile, 1983)

Transmissivity (m^2/day)	Classification of well
>500	High potential
50 - 500	Moderate potential
5 - 50	Low potential
0.5 - 5	Very low potential
< 0.5	Negligible potential

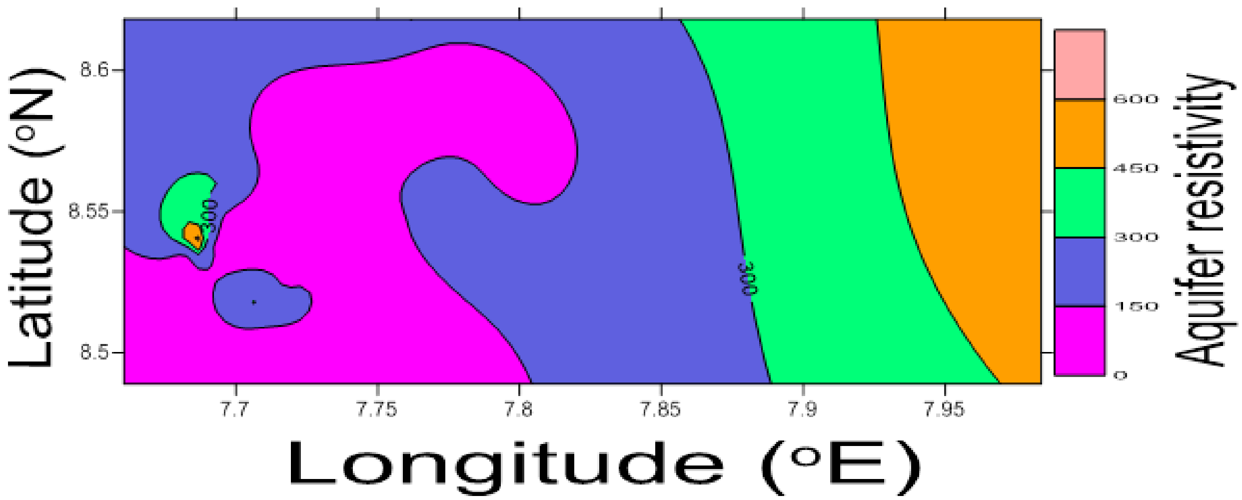

Figure 7. Contour map showing the distribution of aquifer resistivity.

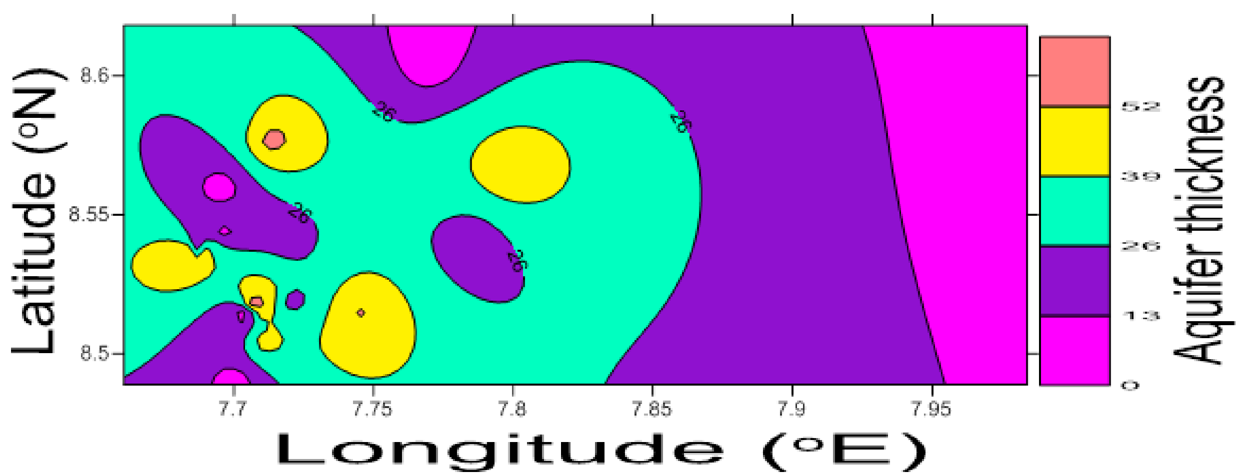

Figure 8. Contour map showing distribution of aquifer thickness.

since it has non-porous layers above and below the aquifer zone. From the results of geoelectric parameters, the 2D contour maps were drawn to show the variation of the geoelectric parameters. Figure 7 is a contour map showing the distribution of aquifer resistivity as it decreases from east to west. This suggest that zones with low resistivity values will have high conductive geomaterials, as such poor groundwater quality. Figure 8 shows the distribution of aquifer thickness across the study area. It is oberved that the eastern part of the study

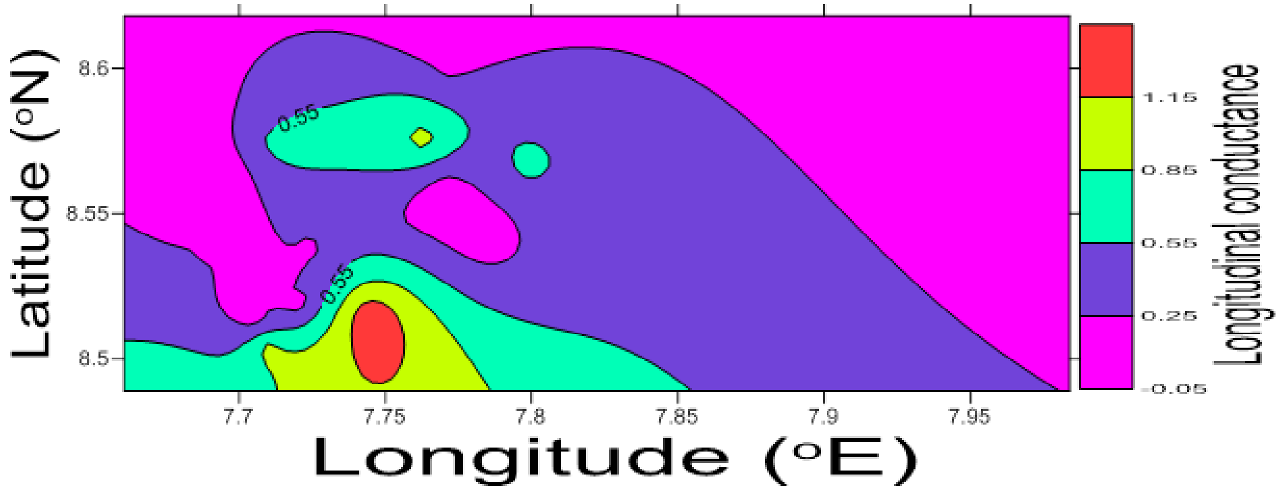

Figure 9. Contour map showing the protective capacity of the study area.

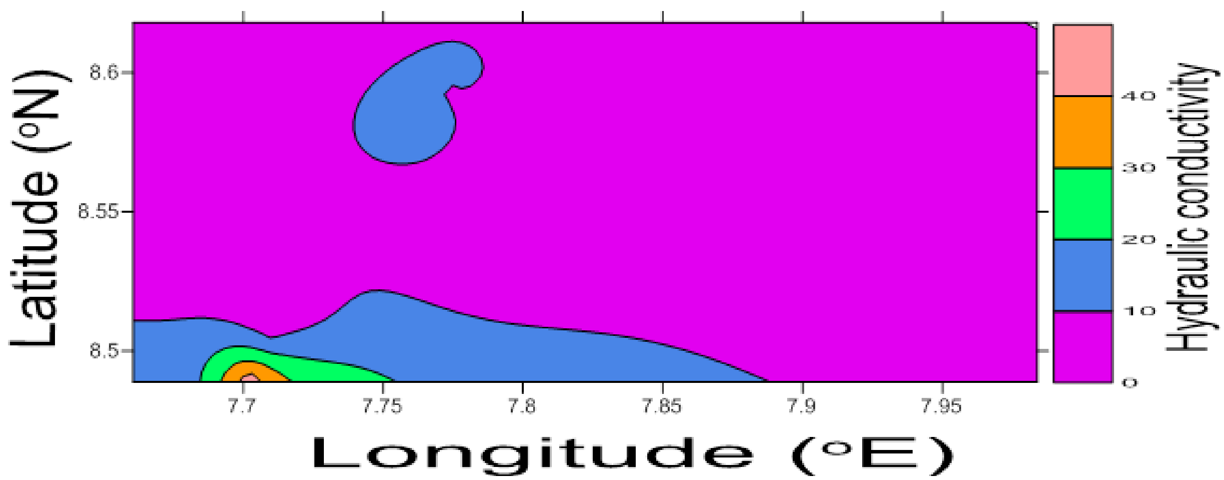

Figure 10. Contour map of aquifer hydraulic conductivity.

area have low aquifer thickness which extends northwards and can also be observed in parts of the western zone, thus indicating that thickness is not a major determining factor for resistivity. The longitudinal conductance map (Figure 9) shows a decrease of longitudinal conductance from south across the northwest through the northeast and southeast. It can be inferred that the zones with low longitudinal conductance values are vulnerable to contamination and thus are highly conductive as a result of seepage of contaminant fluid into the groundwater system. Hydraulic conductivity is proportional to permeability. High permeability will be observed in aquifer zone with high hydraulic conductivity and also contaminants will be easily circulated. The contour map, Figure 10, shows low hydraulic conductivity observed in most parts of the study area and high values of hydraulic conductivity observed in the extreme southwest, it can be inferred that low permeability is dominant in the study area. For characterization of rocks as a water conducting media, transmissivity is a major property (Fatoba et al., 2014). The contour map, Figure 11, shows that high transmissivity is obtainable in the southwest and decreases northwards across the eastern part of the study area. It can be inferred that aquifer productivity will be high in the southwestern part of the study area. Groundwater potential is a function of complex inter-relationship between geology, physiography, groundwater flow pattern, recharge and discharge processes (Ezeh, 2002). It is also deduced that groundwater flow potential increases as transmissivity and longitudinal conductance increases.

The study area is characterised by very low, low, moderate and high groundwater flow potential. The high groundwater potential is observed at VES 21 (Wadata).

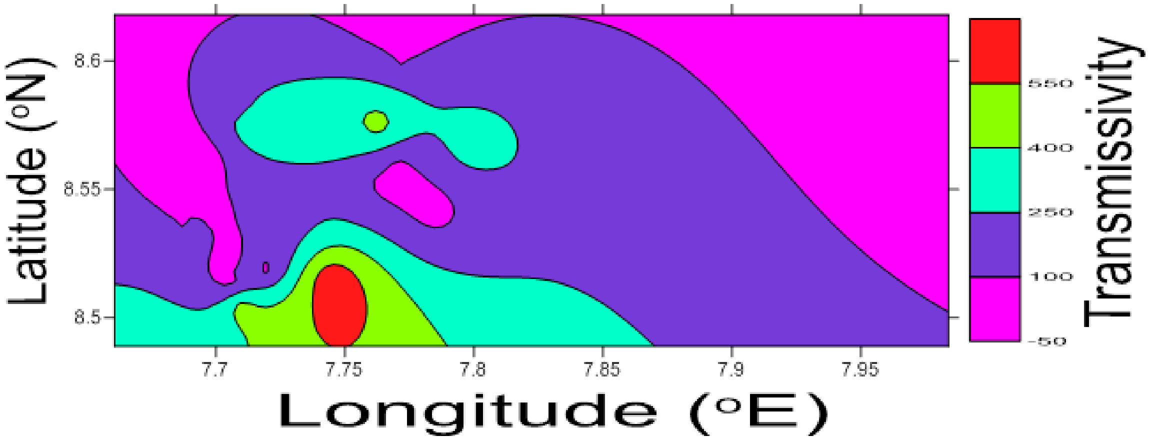

Figure 11. Contour map showing the variation of aquifer transmissivity.

The high groundwater flow potential is favourable for sustainable groundwater development.

Conclusion

Thirty (30) VES have been used to evaluate the subsurface hydrogeological conditions in Makurdi, Benue state, using geoelectric parameters to characterise the groundwater conditions of the region. From the interpreted results, longitudinal conductance, hydraulic conductivity and transmissivity were calculated. These parameters were mapped to show lateral and longitudinal distributions of thicknesses, hydraulic conductivity and transmissivity within the water bearing geomaterials. The groundwater flow potential is affected by aquifer thickness and hydraulic conductivity. The flow potential shows the study area to have 3.3% very low potential, 26.7% low potential, 66.7% moderate potential and 3.3% high potential. The transmissivity increases towards the southwestern part of the study area, thus, the southwestern part have high groundwater flow potential. The point with the lowest hydraulic conductivity (0.85 m/day) has the lowest transmissivity (4.25 m^2/day) which gives the lowest well potential. Transmissivity values are suitable for sustainable groundwater development and zones with high yield have been determined for future development and for choosing the drilling sites.

Conflicts of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Groundwater quality degradation due to salt water intrusion in Zanzibar Municipality

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Saltwater intrusion problems are widespread where there are over pumping of groundwater from coastal aquifers. Water samples were collected from production boreholes in Zanzibar municipality and analyzed for salinity indication parameters comprising of chloride, electrical conductivity, total dissolved salts and percentage salinity levels. Historical water quality data of boreholes were also collected and used to establish trends. The water quality results indicated that the groundwater from the boreholes is progressively becoming more saline against the pumping age. The increase in salinity indicates progressive saltwater ingress in the aquifers. These trends show that saltwater intrusion is still limited around the shoreline areas especially Beit-el-Ras and Mbweni. The aquifer under the historic Stone Town area is also showing high potential for saltwater intrusion for which increased pumping of groundwater may render it saline. To curb this problem, controlled groundwater pumping and establishment of a long-term monitoring programme have been recommended.

Key words: Zanzibar, groundwater, saltwater intrusion, water quality, Tanzania, stalinization

INTRODUCTION

Saltwater intrusion is a common problem in coastal areas where over-pumping of groundwater occurs. It results in salinization of fresh groundwater tapped in wells and boreholes and therefore rendering it unsuitable for domestic supplies and other uses. Saltwater intrusion is not reversible, once it happens, the wells will be abandoned and the aquifer cannot readily be used (Black, 1977). This is a waste of resource that leads to scarcity of water for the people and increased costs for water. For municipalities in developing countries, like Zanzibar, provision of alternative water source could take many years due to inadequate financial resource. This could mean suffering on part of the communities and other water related health problems arising from using water sources of inferior quality. The normal control mechanism for saltwater intrusion problem is to maintain the proper balance between pumping rates and aquifer recharging capacity. This works only where groundwater monitoring is practiced, otherwise in its absence, the intrusion could happen without notice.

The Zanzibar Municipality relies on groundwater as a sole source of water supplies. The public water authority meets only about 62% of the water demand which is estimated at 45,000 m^3/day, the remainder being sourced from private boreholes and shallow wells (Revolutionary Government of Zanzibar, 2004). About 30% of the water is lost in the distribution system before reaching the consumers. The State of Environment Report

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Table 1. Existing boreholes serving Zanzibar Municipality (Zanzibar Water Authority, 2009).

Water source	Water production (m³/day)
Springs	
Mwanyanya/Bububu	5,000
Mtoni	5,000
Boreholes	
Chunga 1	1,800
Chunga 2	1,800
Chunga 3	1,800
Kaburikikombe 1	2,300
Kaburikikombe 2	2,300
Kianga	2,300
Mbweni	400
Mwembemchomeke 1	2,300
Mwembemchomeke 2	2,300
Mfenesini	1,000
Cave	
Dimani	100
Total production	**28,400.00**

(Revolutionary Government of Zanzibar, 2004) mentions availability of water among the priority issues of Zanzibar. Since 1950s, the government of Zanzibar has progressively developed systems for groundwater abstraction. There are currently 11 production boreholes with a total water pumping rate of 18,300 m^3/day (Zanzibar Water Authority, 2009). The boreholes are located within the urban area and many are close to the Indian Ocean coast. There are also springs and caves providing 10,100 m^3/day (Table 1). A thorough assessment to balance pumping rate with aquifer capacity was not conducted. The present increase in population and drive for enhanced tourism on the island is forcing more water production from the boreholes hence posing a potential threat to sea water intrusion in the aquifers. This assessment was conducted to investigate the extent of sea water intrusion in the existing boreholes.

MATERIALS AND METHODS

Description of the study area

This research was conducted in Zanzibar Municipality, Tanzania Islands. Zanzibar is part of the United Republic of Tanzania, East Africa, located within the Indian Ocean and is composed of two major islands of Unguja and Pemba. Zanzibar Municipality is the headquarters of Zanzibar and lies on the Unguja Island (Figure 1). The islands are located between latitude 4°50' and 6°30' South, and longitude 39°10' and 39°50'. Unguja is the largest island occurring at approximate 40 km off the coast of Tanzania mainland. The island is 86 km long and 39 km wide, with an area of 3,354 km^2 and population density of 460 persons per square kilometer. Pemba is situated about 40 km to the north east of Unguja, and is 68km long and 23 km wide, with an area of 1,537 km^2 (Revolutionary Government of Zanzibar, 2004).

According to the 2012 national census, Zanzibar (Unguja and Pemba islands) has a population of 1,303,569 growing at 2.8% per annum (United Republic of Tanzania, 2013). Unguja island had 896,761 and Pemba 406,848 being 68.8 and 31.2% of the population of Zanzibar respectively. The Zanzibar town has a population of 223,000, which is about 24.9 and 17% of the total population of the Unguja Island and entire Zanzibar respectively. Zanzibar islands are bestowed with magnificent coastal areas offering diverse potentials for tourism development. As a result, coastal areas are becoming more populated with intensified socio-economic activities (especially tourism based activities) thus greatly impacting on the natural resources base among of which is the groundwater.

The geological and hydrogeological setting of Zanzibar is characterized by lower Miocene rocks consisting of deltaic sandstones associated with marls and minor reef limestone (Sikat, 2011). The major aquifers occur in the Quaternary limestone (Q2), Quaternary sand (Q3), Miocene limestone (M1) and Miocene sand (M3) (Kent et al., 1971; Sikat, 2011; Vuai, 2012).

Methodology

The study was carried out for six months from January to June 2004. Further updates were conducted between January and June 2009 (Sheha, 2009). A total of 154 boreholes in Zanzibar Municipality were investigated. Water samples were collected from the boreholes and analyzed for salinity linked parameters including electrical conductivity, chlorides, total dissolved solids (TDS) and salinity percentage. Other parameters like nitrogen nitrate and faecal coliforms were also determined. Samples analysis was done in the Environmental Engineering Laboratory, Ardhi University, Dar es Salaam. Historical water quality data of the boreholes were collected from the Zanzibar Water Authority (ZAWA) records. Borehole positions were determined by a hand held GPS. Spatial analysis was done to determine areal extent of the sea water intrusion and to enable determination of longitudinal water quality variation across the municipality. Four longitudinal profiles were used, namely, Beit-el-Ras to Amani (3800 m), Stone Town to Amani (4500 m), Stone Town to Mombasa (4800 m) and Chukwani to Mombasa (1620 m).

RESULTS AND DISCUSSION

Groundwater abstraction

Sustainability of the present water sources for the Zanzibar municipality is not quite understood. Groundwater is the sole source of water supply, abstracted through boreholes, springs and caves. There are 13 water sources of which 30% are located within the urbanized area. Although more than 70% of the municipality residents are connected to public water system, it does not meet the demand (Table 1) and as such there are many private operated boreholes. There are observed water decline from the spring sources (Table 2) signaling further water scarcity and more private borehole drilling. There is no registration or monitoring of boreholes drilling and/or operation (control

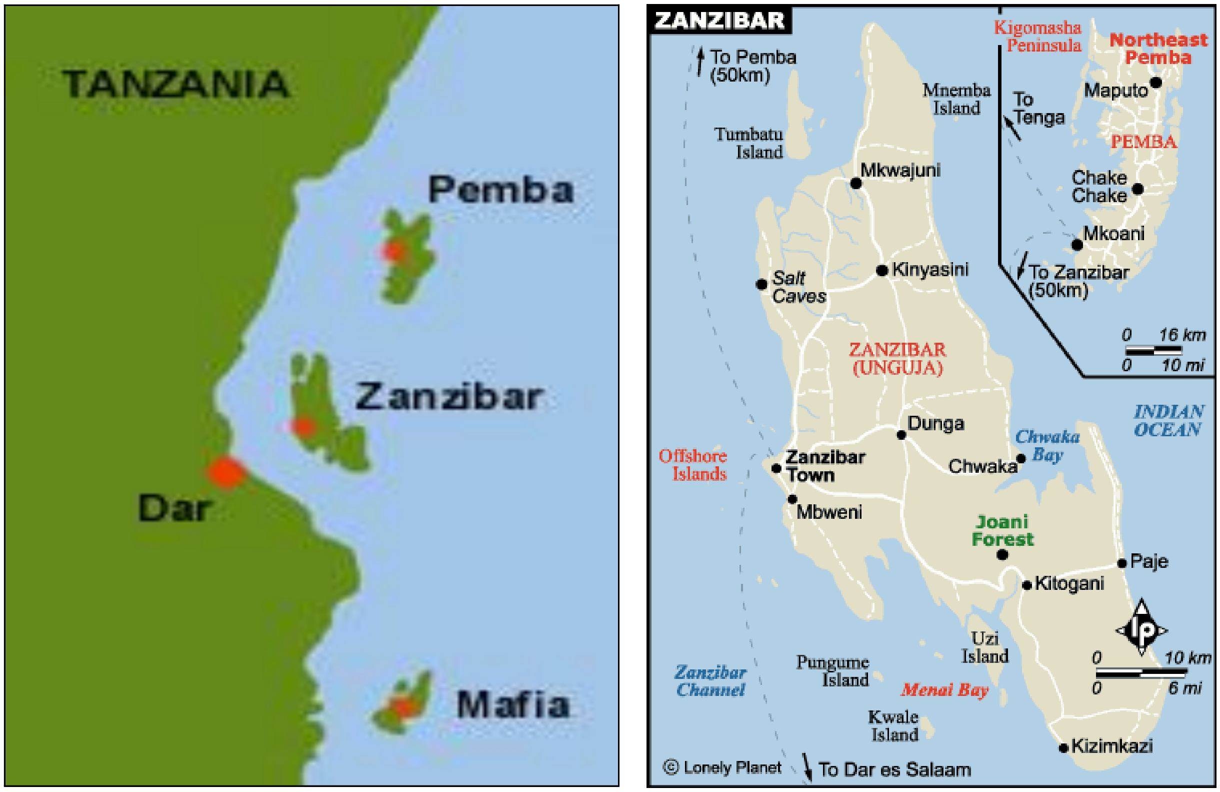

Figure 1. Location map of Zanzibar (Department of Survey and Urban Planning-Zanzibar, 2007, cited in Sheha, 2009).

Table 2. Average daily water production from spring sources in Zanzibar Municipality (Source: Zanzibar Water Authority, 2009)

Year	Mwanyanya or Bububu springs (m^3/d)	Mtoni springs (m^3/d)
1993	4,820	5,327
1994	5,010	4,900
1995	4,700	5,300
1996	4,500	4,300
1997	4,200	4,000
1998	4,200	4,000
1999	4,000	3,500
2000	4,000	3,400
2001	4,000	3,400
2002	3,700	3,400
2003	3,400	3,100
2004	3,400	3,100
2005	3,400	3,100
2006	3,400	3,100
2007	3,000	2,980
2008	3,000	2,980

of pumped water) and hence groundwater withdrawal rates are not known. Many surveyed boreholes in this study are privately owned located at business premises or institutions. Boreholes have been drilled from a distance of less than 70 m from the Indian Ocean shoreline (Beit-el-Ras) to more than 3 km (Kaburikikombe) within the municipality boundaries. Coast areas like Stone Town (the historical town), Beit-el-Ras, Mtoni and Mbweni have many shallow and boreholes apart from being connected to central water articulation system. Continued unregulated boreholes drilling and groundwater abstraction in the municipality thus threatens the seawater/freshwater balance in the underneath aquifers with consequential seawater intrusion. With the advent of present drive towards tourism sector expansion and rapid population increase in Zanzibar more stress on the aquifer is anticipated that may result into complete aquifer degradation from saltwater intrusion if groundwater abstraction will not be checked.

Water quality changes indicating saltwater intrusion

The results of laboratory analysis and historical water quality data of the boreholes in Zanzibar Municipality are shown in Tables 3 and 4, respectively. Available water quality data obtained at Kaburikikombe boreholes span from 1988 and was used to track saltwater intrusion trend. About 97% of boreholes analyzed show a positive trend in conductivity, salinity, TDS, and chloride levels.

Table 3. Representative analyses for groundwater from boreholes in Zanzibar Municipality.

Borehole details						Conductivity	Salinity	[a]TDS	Chloride	[b]N-Nitrate	[c]FC
Number	Name	Drilling date	Diameter mm	Depth (m)	Yield (m^3/h)	µs/cm	ppm	mg/L	mg/L	mg/L	No./100 mL
BH1	Kaburikikombe	1996	254.0	50.00	126	1044	500	520	284	3.41	0
BH2	Kaburikikombe	1988	250.0	42.00	120	1056	500	528	324	4.23	0
BH3	BOT	2000	152.4	29.50	13	444	200	222	64	1.38	0
BH4	Zainab bottler	2203	150.0	10.00	15	720	200	365	130	1.66	0
BH5	M.matrecta	1990	130.0	22.00	12	679	300	340	140	3.57	0
BH6	Ngozi	2003	101.0	20.00	5	368	200	183.8	176	1.65	0
BH7	Gongoni	1996	143.0	17.00	29	2080	1100	1039	1040	4.92	5
BH8	Soda	2001	101.6	18.00	4	1054	500	527	204	2.45	0
BH9	S.S.beit-el ras	2002	150.0	19.00	5	8360	5607	4880	4460	4.4	0
BH10	S.R. mombsa	2000	145.0	20.00	8	525	59.01	304	227	1.3	0
BH11	N.S. kilimani	2000	101.0	19.00	5	672	200	390	304	1.6	2
BH12	M.I.barastekipande	1999	150.0	18.00	6	1320	1050	691	512	3.2	4
BH13	H.K.M.Makumbi	2002	101.0	17.00	7	1650	813	604	512	1.5	5
BH14	Migombani	2002	165.0	38.40	2	982	494	532	256	1.6	0
BH15	Amani	2000	105.0	52.97	20	951	215	347	120	2.5	0
BH116	Mpendae	1992	250.0	32.00	7	560	141	450	56.3	2.6	0
BH17	Magomeni	1999	120.0	24.00	10	841	455	287	300	4.1	0
BH18	Kwakhani	1992	135.0	18.00	7	942	420	540	411	2.5	0
BH19	Malindi	1994	101.0	17.00	5	1520	641	754	500	2.8	00
BH20	Baghani	2000	100.0	18..55	7	1447	350	584	600	5.6	0

[a]TDS - Total dissolved salts, [b]N - nitrate – nitrogen nitrate, [c]FC - faecal coliform.

Examples of the positive trends are shown in Figure 2 for Kaburikikombe boreholes which are located about 3 km from the shoreline. The data indicate remarkable changes in groundwater quality, especially salinity variations. Increased salinity in groundwater coupled with elevated abstraction rates commonly leads to saltwater intrusion. Unregulated groundwater extraction and increased water demand related to population increase and tourism investment in Zanzibar has been assumed to have triggered salt water intrusion which is reflected by elevated salinity in boreholes. In this case there are some evidences that the increased salinity may be due to saltwater intrusion. For instance there was a marked chloride changes for BH1 (Kaburikikombe) from 110 mg/l in 1993 to 284 mg/l in 2004 (60% increase) while the nitrate-nitrogen levels remained very low (less than 4 mg/l). Should the sewage disposal in the municipality have an impact on the chloride levels in the water from the boreholes it was expected to have elevated levels of nitrate-nitrogen or at least a positive trend.

Longitudinal variation in water quality was noted from the sea shore along the four profiles (Figure 3). Generally, boreholes located close to the coastline showed relatively higher salinity, TDS, conductivity and chloride levels than inland boreholes. Chloride concentration of 2000-6500 mg/l and 1000-2000 mg/l were observed in some boreholes located 0- 100m and 100-1000m from the sea line. A steep longitudinal gradient was observed along the Beit-el-Ras to Amani profile where chloride dropped from 4500 mg/l to less than 300 mg/l. The other profiles had a rather flatter concentration gradients in all the four

Table 4. Examples of historical water quality data for the boreholes in Zanzibar Municipality (Source: Zanzibar Water Authority, 2004[a]).

BH No.	Location	Sampling date	Conductivity (µs/cm)	Salinity (ppm)	TDS (mg/L)	Chloride (mg/L)	NO3-N (mg/L)	FC (No./100 mL)
BH1	Kaburikikombe	2/11/1998	944	195	472	111	4.1	0
		30/12/99	956	215	600	160	3.87	0
		2/6/2000	966	230	580	167	2.9	0
		5/9/2001	877	224	430	130	2.6	0
		4/9/2002	981	290	504	230	1.2	0
		7/8/2003	965	467	542	222	3.2	0
		11/3/2004	1044	500	520	284	3.41	0
BH7	Gongoni	1/10/2000	1432	751	634	470	4.7	1
		30/6/01	1556	701	624	441	2.8	3
		23/12/02	2001	982	851	842	1.6	1
		2/6/2003	1975	932	823	843	1.4	3
		12/3/2004	2080	1100	1039	1040	4.92	5
BH8	Soda	1/2/2000	611	153.2	301	87.2	4.14	0
		26/1/01	692	193	309	123	1.3	0
		30/7/02	712	209	336	197	3.6	0
		15/6/03	791	307	349	192	1.2	0
		12/3/2004	1054	500	527	204	2.45	0

[a]Data extracted from working files, Zanzibar Water Authority (2004)

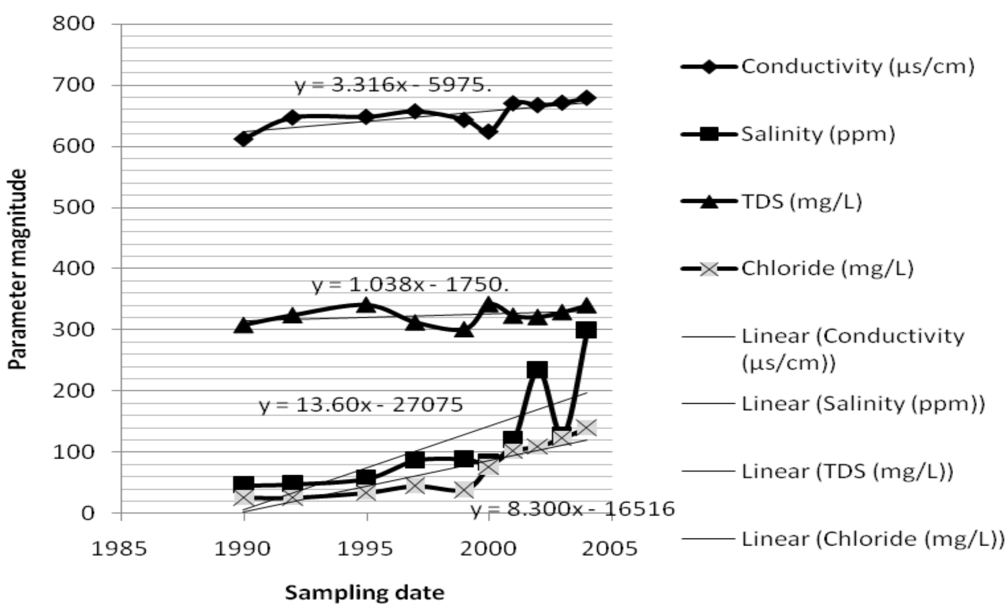

Figure 2. Example of salinity parameters trends in the Kaburikikombe boreholes, Zanzibar Municipality in 2004.

parameters measured.

Generally the water quality data indicate that Beit-el-Ras and Mbweni areas are more threatened with saltwater intrusion problems than the rest of the municipality beach areas of Chukwani, Mbweni, Kilimani and Stone Town due to more number of boreholes showing progressive increases in salinity levels, many of which exceeded 2000 ppm. These levels are early

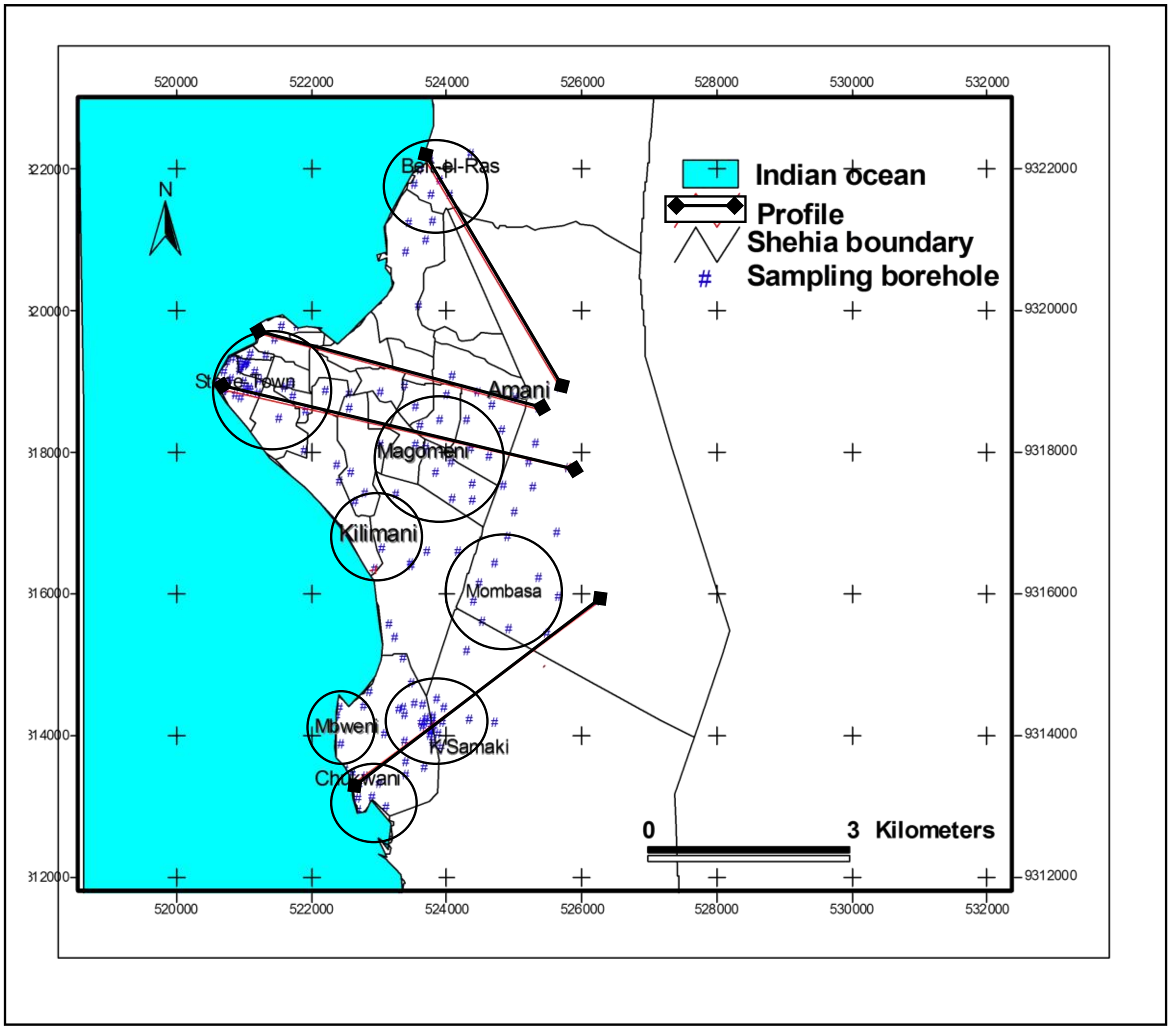

Figure 3. Map of Zanzibar municipality showing locations of some boreholes sampled and longitudinal profiles considered in the study.

indicators of major salt water intrusion problems that could occur should the present uncontrolled groundwater pumping practices continue.

Conclusion

It is quite evident from the study that there are evident signs of saltwater intrusion in the coastal aquifers underneath the Zanzibar municipality. The groundwater salinity increase trend is exacerbated by increased water demand arising from the high population density and expansion in the tourism industry on the island. Uncontrolled groundwater pumping presents a real water resources management problem that could easily deplete the only freshwater resource sustaining the island. Occurrence of saltwater intrusion will increase water scarcity on the island and literally adding more poverty to the people apart from causing more health related problems. The water resources authorities in Zanzibar should therefore take proactive steps towards curbing the saltwater intrusion threats by controlling the groundwater withdrawal and putting in place long-term monitoring system.

Conflict of interest

The authors did not declare any conflict of interest.

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Full Length Research

Estimation of methane generation based on anaerobic digestion and mass balance at Kiteezi Landfill, Kampala, Uganda

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Kiteezi landfill site is the main solid waste dumping site in Kampala City (Uganda). In this study, the generation of methane from waste at Kiteezi landfill was measured using laboratory-scale anaerobic digestion experiment and estimated using the Mass balance model. The samples were collected in the wet and dry seasons, with five replicates for each season which were processed for further experiments focused on moisture content analysis and anaerobic digestion. The moisture content analysis results showed a significant change ($P < 0.05$) between wet season and dry season. Also, the anaerobic digestion revealed that moisture content was a determining factor in gas generation. The average monthly methane production estimate from the mass balance model was 1.63 Gg methane/month and was comparable (within 14%) to the amount estimated by laboratory-scale anaerobic digestion experiment (1.43 Gg methane/month). It is a worthwhile undertaking to further investigate the potential of commercially producing methane from Kiteezi landfill as an alternative source of green and clean energy for urban masses.

Key words: Solid waste management, methane generation, anaerobic digestion and mass balance model.

INTRODUCTION

Kampala Capital City Authority (KCCA) is in charge of solid waste (SW) management. Kampala is approximately 199 km^2 with a population of over 2 million at a population growth of 3.9% (UBOS, 2012). About 28,000 tons of the waste is delivered monthly to Kiteezi landfill, but this is only 40% of the overall waste generated in Kampala (Komakech et al., 2014). The uncollected garbage is dumped on the streets, drainage and water channels and unoccupied land causing environmental and health challenges (Komakech, 2014). KCCA is in charge of collection, transportation and disposal of municipal waste to the landfill. The landfill is situated on 29 acres in Kiteezi. However KCCA still faces a challenge on how to manage the waste effectively and appropriately. This is due to inadequate data such as; estimated amount of refuse projected to be generated and collected per day, the average composition of solid waste and number of households within Kampala (Anon,

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2010; Anesa et al., 2006). Other challenges KCCA faces include; inadequate sorting of waste, poor sensitization of the public, poor urban planning, few sites for dumping, lack protective gears when sorting and collecting the waste. This leads to the preparation of work plans and budgets that do not adequately address the challenges in solid waste collection, transportation and disposal (Anon, 2010; Anesa et al., 2006). The amount of waste and its composition received at the landfill varies quite often due to the seasonal variations, weather, cultural practices, methods and frequency of waste collection, food habits, waste burning and the scavenger's activity. However, at the landfill the SW vehicles are no longer weighed but quantities are estimated on the basis of the number of disposals made by the SW vehicles, this is not at all reliable since there are changes in the compactness of the SW. Hence, it is problematic to estimate the amount and composition of waste reaching the landfill site. The municipal solid waste (MSW) handled at the landfill consists of degradable waste (textile, textiles, paper, food waste, yard waste), partially degradable waste (wood, disposable napkins) and non-degradable materials (synthetic and non-synthetic polymers). There are worries over health concerns from such a landfill site, including skin cancer, birth defects, mortality, and low birth weight (WHO, 2007) in addition to other environmental problems, which are as a consequence of greenhouse gas (GHG) emissions. Methane gas which is the main GHG liberated from landfills is a big threat to our environment, because its global warming potential is 25 times of that of carbondioxide (CO_2) (Solomon et al., 2007) and is at least 56 times more heat-trapping than a molecule of carbon dioxide (Nakibuuka et al., 2012). Methane generation from landfills is projected to account for 3-19% of the anthropogenic sources in the world (Kumar et al., 2004). Although, on the contrary solid waste management is not put into consideration that much and maintenance of record is poor, in Uganda. The aim of this research was to quantitatively estimate the methane generation at Kiteezi landfill.

METHODS AND MATERIALS

Study area

The study was carried out at Kiteezi landfill located north of Kampala, approximately 12 km from the city centre, in Wakiso district, central Uganda. The landfill is accessed from Kampala city through Kampala-Gayaza road about nine (9) km, then branch off to the left at Mpererwe into Namere road. It was opened in 1996, and has a spatial extent of about 29 acres (Mugisa et al., 2015). All waste received is heaped and later compacted in layers within a confined area and covered according to the practical requirements and content aspects the cover material.

Sample collection and analysis

The solid waste samples were collected for three months in a period that covered both dry and wet seasons with five replicates for each season. Characterization of the samples followed a procedure described by Komakech et al. (2014).

Moisture content was determined by drying 10 g for each waste sample at 105°C for 4 h following the method explained by Sluiter et al. (2008). The average moisture content for the five replicates was taken as the sample moisture content. To determine generation of methane by field measurements, a one (1) kg waste sample was taken to the laboratory for anaerobic digestion (Plate 1). The procedure described by Glenn et al. (1989) was followed to estimate methane gas generation by the anaerobic decomposition of waste.

Methane estimation by mass balance models

IPCC models (2006), viz. mass balance (Equation 1) was used for estimating methane gas at Kiteezi landfill. By knowing the monthly waste flow records reported in literature and using default values as presented by the IPCC guidelines of 2006, the methane generation was estimated at Kiteezi landfill.

$$\text{Methane}(\text{GgCH}_4/\text{month}) = \text{M}(\text{x}) \times \text{L}_0(\text{x}) \quad (1)$$

Where, M(x) is the monthly waste acceptance to the landfill site x under study (Gg/month) and $L_0(x)$ = ultimate methane yield (Gg methane/Gg waste).

$$\text{L}_0(\text{x}) = \text{MCF}(\text{x}) \times \text{DOC}(\text{x}) \times \text{DOC}_\text{F} \times \text{F} \times \frac{16}{12} \quad (2)$$

Where, MCF(x) is the methane correction factor in a month x, DOC(x) is the degradable organic carbon in a month x (Equation 3), DOC_F fraction of DOC dissimilated a function of average ambient temperature (Equation 4), F is the fraction by volume of methane in landfill gas, and $\frac{16}{12}$ is the conversion of carbon to methane.

$$\%\text{DOC}(\text{by.weight}) = 0.4(\text{A}) + 0.17(\text{B}) + 0.15(\text{C}) + 0.3(\text{D}) \quad (3)$$

Where, solid waste composition consists of: A = % paper and textile, B = % garden and park waste, or other organic putrescible, C = % food waste; and D = % wood or straw.

$$\text{DOC}_\text{F} = 0.014(\text{T}) + 0.28 \quad (4)$$

Where, T is the average temperature at Kiteezi landfill.

RESULTS AND DISCUSSION

Municipal solid waste (MSW) characterization

Based on the physical composition of waste, different waste samples showed no significant differences (P>0.05) in the organic, hard plastics, metals, papers and soft plastics solid wastes. The mean percentage of waste composition are presented in Figure 1. The high variation in organic waste composition especially from residential and market zones is unique to Kampala, but makes it

Plate 1. Laboratory experimental setup for the generation and collection of methane gas.

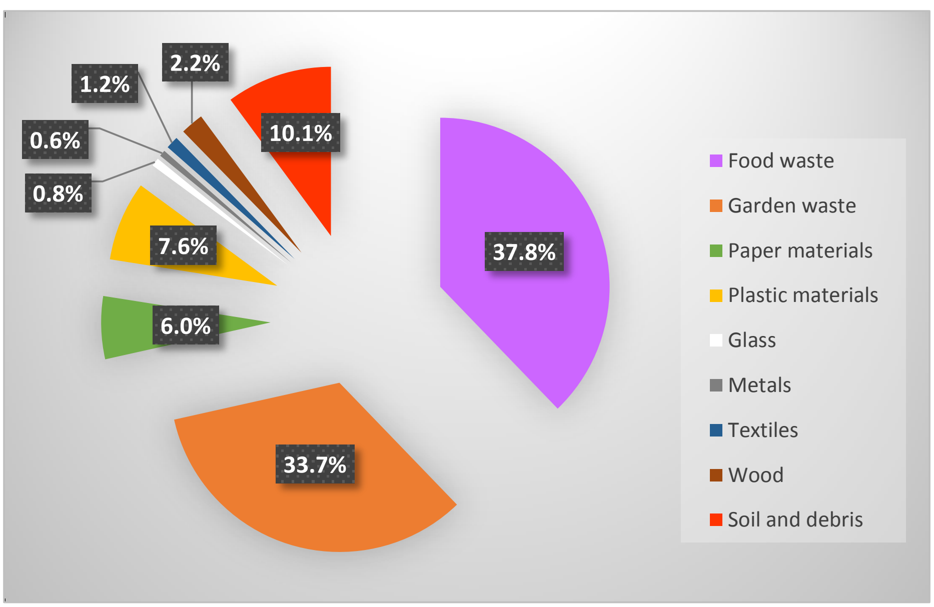

Figure 1. Mean percentage composition of municipal solid waste.

suitable for anaerobic digestion and hence production of landfill gas. Therefore studies assuming average values of organic waste for Sub-Saharan African (SSA) cities, may provide erroneous results in estimating methane generation. Indeed the results of this study are different from those reported from other SSA cities like Gaborone

Table 1. Measured Municipal solid waste moisture content.

Treatment	Rep 1 (MC), %	Rep 2 (MC), %	Rep 3 (MC), %	Average (MC), %
T1	90	96	87	91.0±4.6
T2	56	52	64	57.3±6.1

Mean±standard deviation, %dry basis.

(Bolaane and Ali, 2004), Abuja (Imam et al., 2008) and Accra (Fobil et al., 2008) in part explained by the intrinsic relationship of the solid waste content to the population lifestyle.

Total tonnage of waste entering the landfill

From a study conducted between July 2011 and June 2012, an average mass of approximately 28,000 tons of municipal solid waste from Kampala was dumped at Kiteezi landfill every month (Komakech et al., 2014). There was no significant difference (P > 0.05) in the waste quantities disposed at Kiteezi during the different months. However, the months of March to June had waste quantities higher than the average.

Moisture content of MSW

The municipal solid waste moisture content for each treatment is summarized in Table 1. The moisture content of waste influences the rate of decomposition and gas generation. Therefore more gas was generated from wetter waste sample than the dry waste sample. Abundant availability of oxygen molecules in water inhibits methane production. One way ANOVA showed no significant difference among replicates within treatment T1 and T2 (P > 0.05). However, a significant difference (P < 0.05) between Treatment T1 and T2 was observed.

Estimation of methane generation

The average estimated values of landfill gas from the laboratory scale anaerobic digestion generated in the wet and dry seasons are shown in Figure 2. The composition of methane in the landfill gas was determined following procedure described by Hedge et al. (1994), and the methane generation is depicted in Figure 3. Using one-way ANOVA, results showed significant differences (P < 0.05) in the gas generation due to seasonal variation. Specifically, 57 ml landfill gas/kg waste was produced at moisture content of 91.0% dry basis. Our methane gas estimates and measurements agree with those of Burton et al. (2005) findings when moisture content of the samples is taken into account.

The time taken for gas production to cease was 360 hwith only 0.04 Kg out of 1 Kg waste sample decomposed. This implied that a cumulative amount of waste of 2.2 Kg decomposed and generated 220.2 ml of methane gas in a 10 day period. Consequently 300.27 ml of methane gas was generated from 1 Kg of waste sample within a month. Using, approximately 28,000 tons of municipal solid waste from Kampala that is dumped at Kiteezi landfill every month, the corresponding volume of methane gas generated is 3.36×10^9 ml. Considering the density of methane is 0.4256 g/ml, the equivalent mass of methane produced on a monthly basis is 1.43 Gg.

Methane estimation based on mathematical modelling was done based on Equations (1) of the Mass balance model. Where, M(x) was the waste received to the landfill in a month x. MCF was taken as 0.8 for unmanaged deep landfill site (greater than 5 m), based on composition of waste for Kampala, DOC value was calculated (Equation 3) to be 0.142. The value for dissimilated organic fraction (DOC_F) using a temperature of 35°C was calculated (Equation 4) to be 0.766 and the average default value of the fraction of methane in LFG (F) was taken as 50%. Since no methane has ever been recovered from the landfill, the value for methane recovery factor and oxidation factor was taken to be zero and was not included in the models. The monthly methane production values calculated are shown in Table 2.

The average monthly methane production estimate from the mass balance model (1.63 Gg methane/month) was comparable (within 14%) to the amount estimated by laboratory-scale anaerobic digestion experiment (1.43 Gg methane/month). The difference may be explained by the selected fraction of methane in LFG (F) and unaccounted for emission paths in the anaerobic digestion experiment. From their study (Kyambadde et al., 2006), on Kiteezi landfill, in a report he submitted to National Environment Management Authority (NEMA), the estimated methane production was 1.44 Gg/ month and this is comparable to the methane estimates in this study.

Conclusions

Solid waste disposed at Kiteezi landfill mostly comprised of bio-degradable waste which has high methane gas production potential. In this study, the estimated methane values using mass balance model were comparable to those of the anaerobic digestion. It was observed that

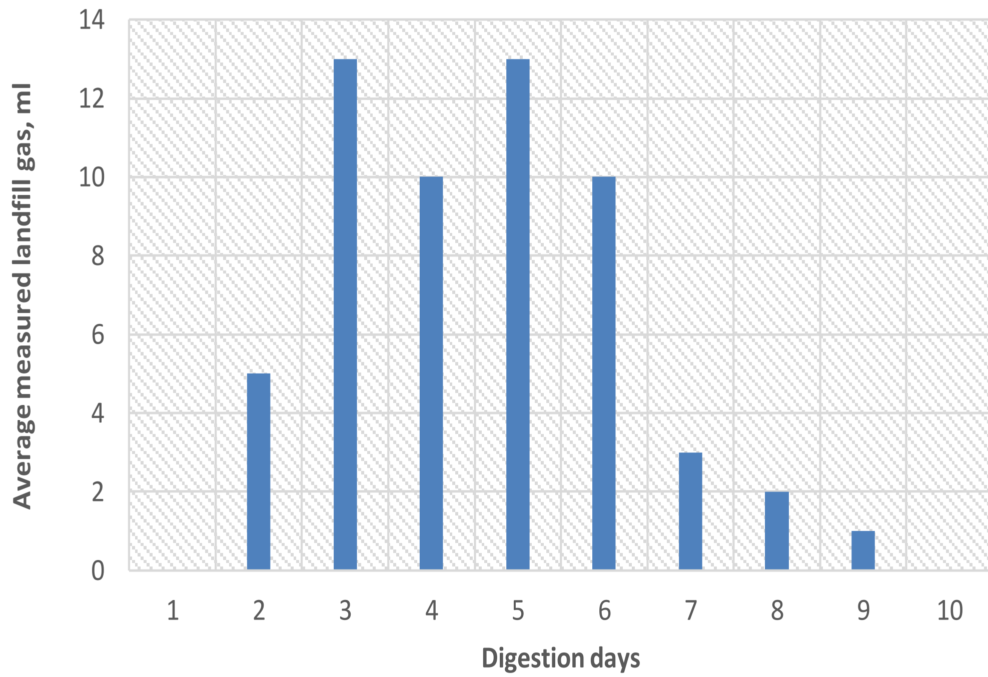

Figure 2. Landfill gas estimations using laboratory scale anaerobic digestion.

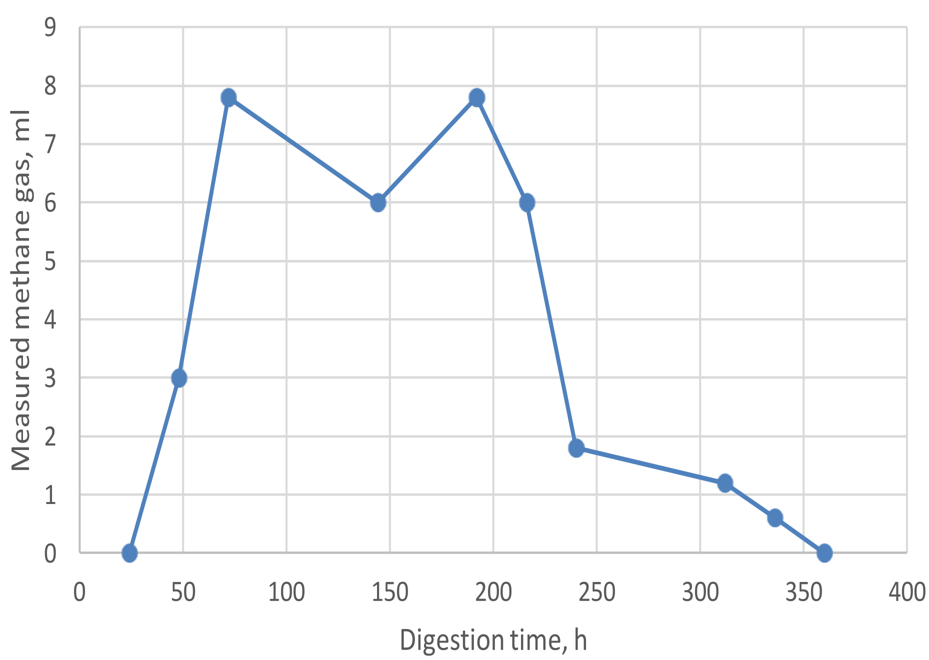

Figure 3. Methane gas estimations using laboratory scale anaerobic digestion.

moisture content has a substantial effect on reducing methane gas production during the anaerobic decomposition of refuse due to abundant availability of oxygen molecules. The rate of gas production, and total gas production increased at lower moisture contents. Given the volume of methane gas estimated, energy recovery process for electricity production using the methane generated from landfill as natural resource is recommended. However, assessing individual or composite categories of organic waste in Kiteezi landfill

Table 2. Methane estimations using the mass balance model.

Year	Month	M(x) (Gg waste/month)	Lo(x) (Gg methane/Gg waste)	Methane generated (Gg methane/month)
2011	July	27.9	0.058	1.618
2011	August	27.6	0.058	1.601
2011	September	26.8	0.058	1.555
2011	October	27.1	0.058	1.573
2011	November	27.9	0.058	1.619
2011	December	27.0	0.058	1.567
2012	January	28.0	0.058	1.628
2012	February	27.0	0.058	1.567
2012	March	29.3	0.058	1.699
2012	April	29.7	0.058	1.723
2012	May	29.5	0.058	1.711
2012	June	29.5	0.058	1.711
Average		28		1.630

to determine their methane potentials, developing Monte Carlo Simulations (Stochastic Analysis) for Kiteezi landfill, and performing gas chromatography experiments at Kiteezi landfill site should be done to achieve accurate estimations of methane gas.

Conflicts of interests

The authors have not declared any conflict of interests.

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