Reuse of Greywater for the Production of Spinach (Amaranthus spp) in **Semi-Arid Region of Nigeria**

S. B. Igboro, U. C. Ezenwe,*M. O. Nwude and **G. A. Fumen
Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria.
**National Water Resources Institute Mando Road Kaduna*
*** Samaru College of Agriculture A.B.U Zaria*
Corresponding author: igboro@yahoo.com

Abstract

As global water resources decline, reuse of greywater for the irrigation of home gardens is quickly becoming widespread in many parts of the world. However, the sanitary implications of reusing greywater to irrigate edible crops remain uncertain. This study examined the benefits and risks associated with domestic greywater reuse for the purposes of vegetable garden irrigation. Untreated (settled only) and treated (settled and filtered) greywater collected from Dan Fodio hall, Ahmadu Bello University, Zaria was analysed for basic water quality parameters, over a period of four weeks. During this time, both treated and untreated greywaters were used to irrigate individually potted blocks of Amaranthus spp (spinach) in a greenhouse, while tap water was used as control. Each experimental block contained 4 pots. Watering by sprinkling was done twice a day for every 2 days with 300ml of the water samples. Plant growth and fresh weight (freshly harvested and weighed plants) was measured. The soil was also analysed for physico-chemical parameters and pathogenic organisms. Upon maturity, plants were harvested and the edible portions tested for the presence of faecal coliforms, a common indicator for the presence of pathogenic microorganisms. Although faecal coliforms were present in high levels, averaging 40 x 10^5*/100 ml in raw greywater, 15 ×* 10^5*/100 ml in treated greywater and 1 ×* 10^3 *in the control, no contamination was observed on the edible portions of the plants, and thus do not represent a significant health risk to humans. Plant growth and productivity were observed to be high in crops irrigated with the untreated greywater followed by the crops irrigated with treated greywater due to high nitrogen N (9.8-20.0 mg/l) and phosphorus P (1.10-1.21 mg/l), while the crops irrigated with tap water produced less, owing to the low N (3.0-4.5 mg/l) and P (0.9-0.99 mg/l) levels of the water. All soil samples exhibited SAR (sodium absorption ratio) less than 1, and the soil irrigated with untreated greywater had the highest coliform count than soils irrigated with treated greywater and tap water, with tap water irrigated soil* *having the least. These results reinforce the potential of domestic greywater as an alternative irrigation source.*

Key words: Greywater, irrigation, Spinach, semi-arid region

Introduction

"Greywater", which refers to used water flowing from sources such as showers, washing machines, and bathroom sinks, often represents over two-third of household wastewater but is considered to be only weakly contaminated by pathogenic organisms and other potentially dangerous substances (WHO, 2006). It has been put forward by scientists and technological companies that this water could therefore be treated with simple technology and reused for non-potable water needs such as toilet flush and outdoor irrigation. Garden watering is an obvious potential end-use for recycled greywater since irrigation does not demand drinking-water quality and can represent a high percentage of domestic water use- up to 40% of dry season consumption in Nigerian households (Finley, 2008).

In many parts of the world, water scarcity is one of the most significant challenges to human health and environmental integrity. As the world's population grows and prosperity spreads, water demands increase to and multiply without the possibility for an increase in supply. The mounting demand on this finite and invaluable resource has inspired creative strategies for freshwater management, including innovative techniques for wastewater recycling. Greywater reuse is one such strategy, and its usefulness to fulfil non-potable water needs should be thoroughly investigated (Finley, 2008).

The aim of this research is to fully understand the benefits and risks of greywater reuse in irrigation. This was achieved by evaluating the chemical and biological characteristics of greywater, determining the effects of greywater irrigation on the quality of spinach, determining the effects of greywater- irrigation on soil properties.

Materials and Methods

The following materials: greywater originating from showers and laundry, slow sand filter, green house, potting soil (loamy), seeds of *Amaranthus spp* (spinach), tap water, pH meter, flame photometer, Kjeldahl set-up, conductivity bridge, weighing balance (machine), evaporating dish, desiccator, EMB: Eosin methylene blue agar, oven, water bath, turbidimeter, photometer, incubators, colorimeter, vibrating machine, measuring tape, beaker, volumetric flask, BOD bottles and conical flask were used during the study.

*Sampling:*Raw-grey water originating from bath room (shower), laundry and kitchen from Dan Fodio Hall of Ahmadu Bello University, Zaria, was collected by inserting sterile sampling container directly into the collecting system, in a 50l container. Some of the collected samples were treated (filtered not exposed) by passing it through a slow sand filter bed. Tap water for the control was from the Ahmadu Bello University water works. All samples used were subjected to physico-chemical (pH, BOD, nitrate, DO, suspended solids, phosphate, electrical conductivity, turbidity) and microbiological analysis in the W.R.E.E laboratory using standard methods (Al-Hamaiedeh, 2010; Salukazana, 2006; Finley, 2008; Travis *et al.*, 2010).

Irrigation operation: Three experimental treatments were employed. Tap water served as a control. While the raw and the treated greywater served as experimental treatments. Plants were watered by sprinkling twice a day (morning and evening) for every two days with 300ml beaker due to the high evapotranspiration rate in the green house as a result of high temperature during the day time. Watering was done manually by directly applying the water to the root zone of the plant (soil surface) and avoiding contact of the water with plant surface. Three (3) experimental blocks were used and a total of 12 pots, 4 on each block (i.e. for the tap water/ control, raw greywater, and treated greywater treatments). Each container was filled to the brim with potting soil (loamy) and seeded with 0.6g spinach (*Amaranthus spp*) seedlings. Mulching operation was also done to reduce loss of water due to evapotranspiration (Finley, 2008).

Plant growth monitoring: Plant growth was measured weekly. Growth parameters included plant height (using measuring tape), number of leaves, fresh weights. Harvested crops were assessed for fresh weights. Although other results were obtained in this report, only plant height and yield (fresh weight) were compared (Salukazana, 2006).

Soil analysis: Soils from all treatments (including before irrigation with any of the water samples) were analysed for physico-chemical parameters and nutrient content, which includes; pH, electrical conductivity, Sodium Absorption Ratio (SAR), Total Kjeldahl nitrogen, total phosphate, potassium and microbiological analysis of soil (Al-Hamaiedeh, 2010; Salukazana, 2006; Travis et al., 2010)

Microbial surface loading on the plants: This was done by washing the leaves (the edible portion) in distilled water and carrying out plate count using standard procedures.

Microbial Risk Analysis: Data for probability of infection and likeliness of illness per incidence of infection is based on Hurst (2002) who provided overall values for enteric pathogenic bacteria. The risk analyses presented in Table 4 assume that the vegetable crops will be consumed at an estimated rate of one 40 g serving/day, every day, over a three-month harvest period, based on the short growing.

Results and Discussions

Table 1 shows all the parameters analysed were higher in the untreated greywater followed by the treated greywater with the tap water having the least. Nutrients important for plants growth namely nitrogen (N) and phosphorus (P) were detected in ratio of 14.3:1, 13.3:1, 3.4:1 for untreated greywater, treated greywater and tap water respectively. Comparatively low P levels in this study can largely be attributed to the use of phosphate free soaps and detergents within the study area. Greywater nitrogen N detected mainly as NH_4^+-N was high due to the presence of urine in it. Also of concern are the high values of electrical conductivity of both untreated and treated greywaters, which may lead to salinization of the soil.

Table 1: Greywater quality test for the different samples on the first week (3th June, 2013)

Parameter	Raw greywater	Treated greywater	Tap water(Control)
BOD_5 (mg/l)	60	33	1
Total solids (mg/l)	570	300	140
Nitrate (mg/l)	17.1	6.0	3.4
Phosphate (mg/l)	1.20	0.45	0.99
pH	7.25	7.24	7.44
Turbidity (NTU)	51.3	6.81	1.63
Electrical conductivity (µhos/cm)	1000	370	16
Total coliform (cfu/100ml)	180×10^5	65×10^5	0×10^3

Growth Measurement

Figure 1 shows the plant growth for raw greywater, treated greywater and control (tap water). The results indicated that there was a consistent increase in plant height when crops were irrigated with raw greywater followed by treated greywater as compared with the control. Plants irrigated with tap water did not increase significantly in height throughout the study time i.e. 4 weeks (using a measuring tape), whereas height increased steadily over time with both raw and treated greywater irrigation. The limited growth in tap water irrigated vegetables was due to the fact that tap water contains less nutrients as compared to that of raw and treated greywater.

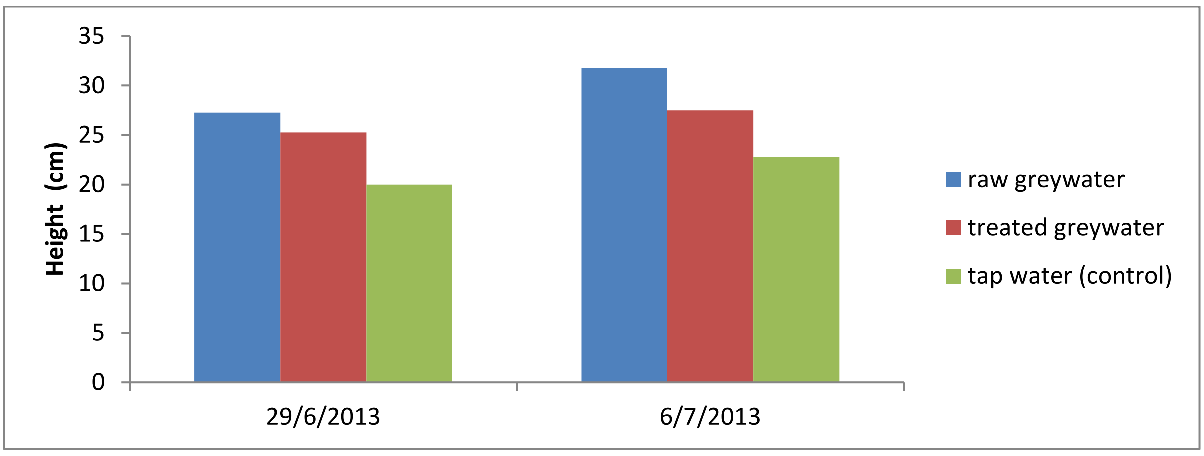

Fig. 1: Average height of Spinach in centimetres (*Amaranthus spp*) after 4 weeks.

Total yield

Figure 2 shows the yield of the trial measured by total fresh weight (g) as yields per treatment. The yield was significantly higher in the raw greywater treatment than both the treated greywater treatment and control, while the treated greywater treatment was higher than the control treatment.

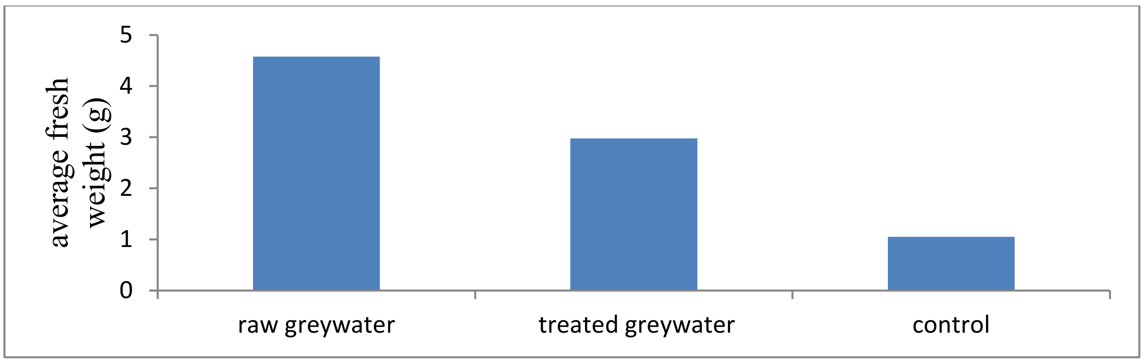

Fig. 2: Fresh weight of Spinach (*Amaranthus spp*) on the fourth week.

Soil characteristics

The chemical properties of the soils are summarized in Table 2. All soil samples exhibited SAR less than 1. The data indicate that the sodium concentrations in both greywaters used in this short-term study would not be detrimental to soil structure. Long- term use of certain greywater may lead to sodium build-up and damage.

Table 2: The chemical properties of the soils

Parameter	pH	Electrical conductivity (dsm^{-1})	Available phosphate (ppm)	Total nitrogen (%)	Calcium (cmol/kg) or (m_{eq}/100g)	Magnesium (cmol/kg)	Potassium (cmol/kg)	Sodium (cmol/kg)	SAR
Control	6.95	0.09	17.50	0.266	2.20	0.60	0.97	0.19	0.16
Raw grey	6.70	0.24	15.75	0.231	3.20	0.10	0.87	0.32	0.25
Treated	6.76	0.15	14.00	0.231	2.80	0.90	0.87	0.09	0.07
Before	6.83	0.11	17.93	0.256	2.37	0.61	0.94	0.13	0.11

Soil microbiology

Table 3 below shows the coliforms count in each soil sample. In all three soils, containers irrigated with raw greywater had significantly higher feacal coliform counts than soils irrigated with treated greywater or tap water. This would be reasonable, as the raw greywater had 2 orders of magnitude more feacal coliforms than the treated greywater. But the low levels of indicator bacteria detected in the soil samples despite high numbers in greywater samples may indicate some buffering effect of the soil biotic community.

Table 3: Coliform counts in soil samples

Soil samples	Soil irrigated with raw greywater	Soil irrigated with treated greywater	Soil irrigated with tap water	Soil sample before irrigation
Feacal coliforms (cfu/100mg)	50×10^4	20×10^4	6×10^4	1×10^4

Microbial surface loading on plants: Feacal coliforms were not detected at the surface of the Spinach due to the watering technique. The movement of pathogenic organisms on plant surfaces (including roots) and into plant tissues will naturally be species specific and may be difficult to predict with the same methodology employed for water quality testing.

Risk analysis: Results presented in Table 4 show no clear trend in the risk associated with consuming greywater-irrigated crops. This is a random result and suggests that further research is needed.

Table 4: Risk assessment based on faecal coliform counts

	Spinach–Raw greywater	Spinach – treated greywater	Spinach – tap water
Bacteria (CFU[a]/gram of crop)	0	0	0
Mass ingested (g/d)	40	40	40
Ingestion frequency (d/y)	45	45	45
Probability of infection[b]	0.00001	0.00001	0.00001
Probability of illness[b]	0.49	0.49	0.49
Estimated annual risk of Illness	0	0	0
Comparative risk	Nil	Nil	Nil

[a] CFU= Colony Forming Unit

[b] Source= Hurst et al. (2002)

Conclusion

In conclusion, the benefits of reusing greywater for the production of Spinach (Amaranthus spp) are high yield production which can help in the production of crops throughout a year. The risks associated with the reuse of greywater are; wrong handling of greywater with contains pathogens which can lead to outbreak of diseases (cholera etc.) and continuous use of certain greywater may lead to sodium build up and damage of soil. It suffices to note that more factors need to be investigated, including transmission of pathogens (viruses and parasites) into the tissues of plants, the presence of metals in the tissues of plants and the long term effect of using greywater to the soil structures, in order to fully investigate the use of faecal polluted greywater for irrigation purposes. The true safety of these practices must be addressed as part of the effort to reconcile food production water needs in an era where freshwater supplies are increasingly limited and difficult to access.

References

Al-Hamaiedeh, H., Bino, M. (2010). Effect of treated greywater reuse in irrigation on soil and plants. Desalination, 256:115-119.

Finley, S. (2008). Reuse of domestic greywater for the irrigation of food crops. M.Sc project Department of Bioresources Engineering, McGill University, Montreal, Canada.

Hurst, C. J. (2002). Estimating the risk of infectious disease associated with pathogens in water. In Hurst, C. J., Crawford, R. L., Knudson, G. R., McInerney, M. J. and Stetzenbach, L. D. (eds). Manual of Environmental Microbiology. 2nd edition, Washington DC, ASM Press, pp. 309 – 319.

Salukazana, L., Jackson, S., Rodda, N., Smith, M. (2006). Re-use of greywater for Agricultural Irrigation, eTheKwini municipality, 6 prior road, Durban 4001, South Africa.

Travis, M. J., Wiel-Shafran, A., Weisbrod, N., Eilon, A., Gross, A. (2010). Greywater reuse for irrigation. Effect on soil properties. Science of the Environment, 408: 2501- 2508.

World Health Organization. (2006). Guidelines for the safe use of wastewater, excreta and greywater. Resource document, WHO.

Gender Differences in the Perception and Practice of Rainwater Harvesting in Saki, Oyo State, Nigeria

Adeola A. Amori

Department of Water Resources Management and Agro-Meteorology, College of Environment Resources Management, University of Agriculture Abeokuta.

drdeolaamori@yahoo.co.uk, drdeolaamori@gmail.com

Abstract

Rainwater harvesting in the last two centuries has gained prominence as alternative source of water supply in most Nigerian rural communities in response to increasing incidents of water scarcity. This paper examined whether there are differences in the way practitioners assess rain water harvesting on the basis of gender. The study was conducted in Saki, a town located in the north of Oyo State, Nigeria. It involved a sample of 270 respondents (consisting of 125 males and 145 females) spread across the eleven wards in the town. The major instrument used was a questionnaire while data analysis employed frequency counts and t-test. Result showed that there was a significant difference in the perception and practice of rainwater harvesting on the basis of gender (t=2.377, p<0.05). This finding underscores the need to encourage people especially women to take more active role in the practice of rainwater harvesting

***Key Words**: Rainwater Harvesting, Gender, Water Resources, Evaluation, Rural Water Supply.*

Introduction

In recent years, there has been an increasing awareness as to the impact and relevance of gender perspective in water resources management. This has become imperative in view of the fact that water resource management have come to be regarded as an issue that must not be restricted mainly to the male gender alone if it is realized that women have over the years assumed a traditional role (especially in most developing countries) of 'drawers and managers' of scarce water resources. Indeed, women and children are now seen as the primary recipients and beneficiaries of improved water supplies granted the fact that in most settings they are often involved in the search for fresh water supplies. Cleaver (1998); Mather

(1984); Dikito-Wachtmeister (2000), O' Reilly (2006), O' Reilly (2010), Cole and Wallace (2005); Van Wijk-Sijbesma (1998); Wakeman, *et al.* (1996), Sultana (2007) and Sultana (2009). Women in several studies have been confirmed to be prime users of domestic water and the most vulnerable group open to water-related diseases as observed by Frazier and Myers (1983), Wall and McCown (1989), Rico (1998), Lahiri-Dutt (2006), Lowes (1983), Nissen-Petersen (1982), UNEP (1982), Pacey and Cullis (1989), Haga (1988), Kumar and Takao (2004), Liow and Tsau (2004), and Li and Gong (2002). This is in addition to the fact that women often bear the burden of poor management of water resources as they are largely saddled with the task of not only searching for viable sources of water but also manage the available one such that diseases are limited and human living becomes less cumbersome, tasking and monotonous. It is in realization of this fact that most countries of the world have developed policies that sought to articulate a gendered approach involving men and women in the task of evolving a balanced framework that will enhance efficient water resources management given the fact that both consume water and also need it in attaining their respective goals and aspirations.

In most developing countries, women and children constitute the greatest proportion of people that are involved in the search, use and consumption of water. In Nigeria, this traditional role is evident as women constitute the greatest force saddled with the task of searching for water and managing it effectively for the use of the family. In most rural communities, public water supply is often lacking and where it is available it is usually inadequate to meet both individual and family demand. Hence, there is the search for viable source of water supply. One of the sources so far exploited is through rainwater harvesting. Rainwater harvesting is an activity that is common in communities that are blessed with copious rainfall spread over a large part of the year. In Nigeria, it is practiced mostly in the southern part where rainfall is well distributed over the year and in large amount. Rainwater harvesting can be regarded as the collection and storage of rainwater where it falls or capturing it along the run off part. It could be captured from rooftops or local catchment.

The harvesting of rainwater is made up of three components namely: a collection area, the conveyance systems and the storage area of the system. Gould (1992 and 2000), Martinson (2001), Gould and McPherson (1987), Schiner and Latham (1987), Oni et al. (2008), Efe (2006) and Ehinamen (1998) For this study, rainwater harvesting is defined as the collection of rainwater from rooftops through drains or gutters into storage facilities such as drums and surface tanks made of metal, plastic or concrete materials and underground tanks/reservoirs made of concrete with storage capacity of 0.4m^3 for household use. Over the years, rainwater harvesting has increased in terms of use, popularity and acceptance particularly in rural communities. Recent studies such as Schiller and Latham (1987), Martinson (2001), Adelia et al. (2005) and Boeri and Ben-Asher (1982). Gould (2000) has also confirmed the involvement of women in the practice of rainwater harvesting. In spite of this however, there appears to be no- consensus as to whether men and women differ in their perception of rainwater harvesting. This is considered necessary in view of the fact that their involvement and indeed acceptance of rainwater harvesting will to a large extent be determined by the way they perceive it particularly its usefulness, adequacy and ability to meet their water requirement granted the fact that potable water is not readily available in most rural communities where rain water harvesting is practiced. Hence, the study examined whether there are significant differences in the way men and women perceive rainwater harvesting using Saki, a semi –urban community in Oyo State as a case study.

Methodology

The study involved 270 respondents consisting of 125 males and 145 females spread over the eleven wards in Saki West Local Government. The respondents were selected using stratified random sampling on the basis of the long periods for which they had practiced rainwater harvesting. The following research questions were posed:-

1. How many of the sampled respondents practice rainwater harvesting?
2. What benefits do respondents derive from the practice of rainwater harvesting?
3. What problems do respondents encounter in the practice of rainwater harvesting?
4. To what extent do respondents differ in their perception of rainwater harvesting on the basis of gender?

The major instrument used in the study for the purpose of obtaining information from respondents practicing rainwater harvesting was a questionnaire titled "Questionnaire on Health and Socio-Economic Problems of Rainwater Harvesting in Saki West Local Government". The questionnaire was designed to measure the perception of the respondents on the health and socio-economic problems affecting the practice of rainwater harvesting. It consisted of three sections. Section A sought information on the demographic attributes of respondents while Sections B and C required respondents to answer some items on rainwater harvesting and also indicate the extent of their agreement or otherwise with the items. The final version of the instruments was pre-tested on fifty (50) respondents who are not part of the final sample for the study. The instrument was tested for reliability and was done through the computation of Cronbach alpha which yielded a value of 0.774 and was considered suitable for use in data collection.

The data collection exercise was undertaken by the researcher with the aid of two trained assistants. The purpose of the study was highlighted after verbal consent was got from the respondents and confidentiality guaranteed by the researcher. Questionnaires were administered on the respondents and were retrieved immediately after they had been filled. The data collection exercise took place in July, 2009. Analysis of the collected data involved the comparison of the means of the responses from the male and female respondents using the t-test for independent samples. The significance level was set at 0.05. Analyses were computed with SPSS software version 15.0 for windows.

Results

The results of the study are presented in Tables 1, 2, 3 and 4. The research questions were answered using frequency counts and t-test analysis. Specifically research questions 1, 2 and 3 were answered using frequency counts while research question 4 was answered using t- test statistics.

Research question 1 was answered using frequency counts and the result is presented in Table 1. From this table, it is evident that out of 270 respondents, 258 respondents or 95.6% of the respondents practice rainwater harvesting while 12 respondents or 4.4% of the respondents do not practice rainwater harvesting. This implies that a lot of people are familiar with the practice of rainwater harvesting in Saki. This is not surprising given the fact that public water supply is not regular. Rainwater harvesting therefore comes in as an alternative source of water supply.

Table 1: Respondents Practising Rainwater Harvest

Respondents	Frequency	%
Respondents Practising Rainwater Harvesting	258	95.6
Respondents who does not Practise Rainwater Harvesting	12	44
Total	**270**	**100.0**

Field survey (2009)

Research question 2 centred on the benefit respondents derive from the practice of rainwater harvesting. The result is presented in table 2. It is evident that respondents derived quite a lot of benefits from the practice of rainwater harvesting, chief of which are that, it is a cheap method of water conservation which was identified by eighty (80) respondents or (31.01%), followed by another benefit having to do with the fact that rainwater harvesting guarantees regular supply of water. This was identified by sixty-seven (67) respondents or (25.96%) while fifty (50) respondents or (19.77%) identified a benefit of rainwater harvesting which relates to the fact that it reduces the stress associated with the search for water during scarcity periods. Twenty-one (21) respondents or (8.13%) identified the benefit of rainwater harvesting enables them to make more judicious use of water rather than waste it since it allows them to store water adequately whenever it rains. Twenty-three (23) respondents or 8.93% believed that rainwater harvesting has been an easy activity to maintain since the time they have been practicing it. In all, this result implies that respondents have reaped numerous benefits from the practice of rainwater harvesting.

Table 2: Benefits Respondents Derived from Rainwater Harvesting

Benefits Derived from Rainwater Harvesting	**Frequency**	**%**
Ensures regular supply of water	67	25.96
A cheap method of conserving water	80	31.01
Enhances privacy in the use of water	16	6.20
Reduced the stress associated with water scarcity	51	19.77
Enhanced judicious use of water	21	8.13
Easy to maintain and run	23	8.93
TOTAL	**258**	**100.00**

Research question 3 was equally answered using frequency counts and percentages. The result is presented in Table 3. From the table, problems such as high cost of acquiring necessary implement needed for rainwater harvesting, frequent collapse of tanks, the risk of water pollution, increasing incidents of water theft and vandalisation, the possibility of contacting water-borne disease, irregular rainfall and the use of primitive technology in the building of tanks and reservoirs constitute the major obstacles that respondents face in the practice of rainwater harvesting.

Table 3: Problems Encountered in the Practice of Rainwater harvesting

Problems	Frequency	%
High cost of acquiring implements such as tank	58	22.48
Collapse of tanks	40	15.50
Risk of water pollution and contamination	75	29.07
Open to theft and vandalisation if not well protected	18	6.58
Prone to contacting water-borne diseases		
Irregular rainfall often affects the output of water	21	8.14
obtained	27	10.47
Use of primitive technology		
	20	7.76
TOTAL	**258**	**0**

Field Survey (2009)

Table 4: T-test Comparison of the Means, Perceptions of Male and Female Practitioners of Rainwater Harvesting

Gender	Sample (N)	Mean Difference	Degrees of Freedom	t calculated	t observed	P Value
Male	125					
		2.690	258	2.377	1.96	0.018
Female	145					

*significant at p<0.05

Research question 4 was answered using t-test analysis which is presented in Table 4. The table shows that respondents differ in their perception of rainwater harvesting on the basis of their gender. This is because the t value obtained (2.377) is greater than the t value observed from the statistical table that is, 1.96. Furthermore, the test is significant at 5% confidence level (0.05 level) since the p value calculated, that is 0.018 is less than 0.05. In other words, it is evident that respondents differ in their perception of rainwater harvesting based on gender. Indeed, respondents vary in their perspectives on rainwater harvesting whether they are male or female, as they do not see the practice in the same way.

Discussion and Implication of Findings

The summary of the above result shows that respondents derived benefits from rainwater harvesting, but they encountered some problems in the practice of rainwater harvesting. In terms of gender, respondents varied significantly in their perception of rainwater harvesting. As mentioned earlier on, both males and females are crucial in the areas of devising means by which available water resources can be adequately managed as they both consume water and equally need it in satisfying their goals and aspirations. No doubt, females tend to be more involved in the search and use of water. For this reason, it is essential that any considerations and planning for water resources must not only involve them but must also seek for ways by which their contributions can be incorporated into the use and management of water resources.

From this study, it could be inferred that the reason for the significant difference in the way male and female respondents perceived the practice of rainwater collection stems from the fact that they both differ in the way they view water, its collection, use and management. Males are more prone to see water as a resource that is needed more for domestic purposes, hence the need for female involvement. This study has not only confirmed the fact that more females are involved in rainwater harvesting but also show that they are more committed to its practice. Their involvement goes to show that female participation in water resource use and management is no longer an issue but a reality which managers and policy makers on water related issues ought to take cognizance of. Perhaps, one vital fact that has been established is that rainwater harvesting is a viable alternative to the conventional rural water supply and women are actively involved in it. For rainwater harvesting to be encouraged and improved upon, the role of women must be duly acknowledged. In promoting the practice particularly in rural areas, the views of the female practitioners must be sought. Not only that, projects aimed at enhancing the potentials of rainwater harvesting in rural areas must involve females right from the conception, planning, down to the final implementation. Their active participation in such projects will not only ensure the effective and better practice of rainwater harvesting but also go a long way in projecting its numerous advantages and usefulness as a means of obtaining and conserving available water resources in Nigerian rural communities.

Conclusions

The study was able to establish that there is a significant difference in the perception of male and female practitioners of rainwater harvesting in the study area. It is evident that females should be encouraged to participate in the practice of rainwater harvesting in view of their critical role as managers and users of water. While the findings of this study do not underplay the role of males in the articulation, planning and management of water resources, they point to the fact that both males and females can be better mobilized to participate actively in rainwater harvesting and by so doing enhance better management of water resources in rural and urban settlements.

Recommendations

(i) Government should assist by subsidizing the cost of acquiring materials needed in the practice of rainwater harvesting.

(ii) Government should mobilize women as a group to take to the practice of rainwater harvesting particularly in the southern part of the country where rainwater is well spread and much available in large quantities as an alternative source of rural water supply.

References

Adelia, B., S. Joao and V. Semiral (2005) Improving Access to Water Resources Through Rainwater Harvesting as a Mitigation Measure: The Case of the Brazilian Semi-Arid Region. Mitigation and Adaptation Strategies for Global Change, 10 (3): 393-409.

Bennett, V., Davila-Poblete, S. and Rico, M. N. (2008) Water and Gender: The Unexpected Connection That Really Matters. J. International Affairs, 61(2): 107 -126.

Boers, T. M. and Ben-Asher, J. (1982). Review of Rainwater Harvesting. Agricultural Water Management, 5: 145-158.

Cleaver, F (1998) Incentives and Informal Institutions: Gender and the Management of Water. Agriculture and Human Values, 15(4): 347 -360.

Cole, A and T Wallace (2005) (eds) Gender, Water and Development Oxford: Berg.

Dikito-Wachtmeister, M. S. (2000). Women's Participation in Decision-Making Process in Rural Water Projects. Unpublished PhD Thesis, University of Bradford.

Efe, S. I. (2006). Quality of Rainwater Harvesting for Rural Communities of Delta State, Nigeria. The Environmentalist, 26 (3): 175-181.

Ehinomen, C. (1998). The Use of Community Participation in Potable Water Supply in Nigeria. The Case of Edo State, Nigeria. J. Economics and Social Studies, 40 (1): 67 - 86.

Frazier, G. and Myers, L. (1983). Handbook of Water Harvesting. Washington DC: Department of Agriculture, Agricultural Research Service.

Gould, J. (2000). Rainwater Catchments Systems for Domestics Supply, Design, Construction and Implementation. London: Intermediates Technology Publication.

Gould, J. E. (1982). Rainwater Catchment Systems for Household System for Household Water Supply. Environmental Sanitation Reviews No. 32. Bangkok: ENSIC, Asian Institute of Technology.

Gould, J. E. and McPherson, M. J. (1987). Bacteriological Quality of Rainwater in Roof and Groundwater Catchment Systems in Botswana. Water International, 12: 135-138.

Hagg, R. (1988). Water Harvesting and Agricultural Production in Semi-Arid Kenya. Development and Change, 19: 69-87.

Khosia, P., van Wjk, C. and Verhagen, T. and Viju, J. (2004). Gender and Water. Defft, The Netherlands: IRC, 80 pp.

Kumar, J. V. and Takao, H. (2004). Significance of Rainwater Harvesting in Mega-Diversity Water Resources Country, India J. Rainwater Catchment System, 10 (1): 21-28.

Lahiri-Dutt (2006). (ed.) Fluid Bonds: Views on Gender and Water. Kolkhata, Stree Publishers.

Li, X.Y and Gong, J. D. (2002). Compacted Micro-Catchments with Local East Material for Rainwater Harvesting in the Semi-Arid Region China. J. Hydrology, 257 (1-4): 134-144.

Liaw, C. H., and Tsai, Y. L. (2004). Optimum Storage Volume of Rooftop Rainwater Harvesting Systems for Domestic use. J. American Water Resources Association, 40 (4): 901-912.

Lowes, P. (1987). The Water Decade: Half Time. In Pickfor, J. (ed.) Developing World Water. London: Grosvenor Press International, 16-17.

Martinson. B. (2001). Domestic Roof Water Harvesting in the Humid Tropics. Warwick: University of Warwick Press.

Mather, J. R. (1984). Water Resources: Distribution, Use and Management. New York, McGraw Hill.

Nissen-Petersen, E. (1982). Rain Catchment and Water Supply in Rural Africa: A Manual. London: Hodder and Stoughton Ltd.

O'Reilly, K. (2006). Traditional Women, Modern Water: Linking Gender and Commodification in Rajasthan, India. Geoforum, 37: 958 -972

O'Reilly, R. (2010). Combining Sanitation and Women's Participation in Water Supply: An Example from Rajasthan. Development in Practice, 20(1): 45-56

Oni, S. I., Ige, E. , Ascnime, C. and Oke, S. A. (2008). Rainwater Harvesting Potential for Domestic Water Supply. Industrial J. Management and Social Sciences, 2(2): 87-98.

Pacey, A. and Cullis, A. (1989). Rainwater Harvesting: The Collection of Rainfall and Run-off in Rural Areas. London: WBC Print Ltd

Schiller, E. J. and Latham, B. G. (1987). A Comparison of Common Used Hydrologic Design Methods for Rainwater Collectors. Water Resource Development, 3: 36-40

Sultana, F. (2007). Water, Water Everywhere But Not A Drop To Drink: Pani Politics (Water Politics) in Rural Bangladesh. International Feminist J.Politics, 9:1-9.

Sultana, F. (2009). Community and Participation in Water Resources Management: Gendering and Naturing Development Debates from Bangladesh. Trans. Institute of British Geographers (New Series), 34: 346 – 363.

UNEP (United Nations Environment programme) (1982). Rain and Storm Water Harvesting in Rural Areas. Dublin: Tycooly International Publishing Ltd.

Wakeman, W. S., Davis, C. and Van Wikj (1996). Sourcebook for Gender Issues at the Policy Level in the Water and Sanitation Sector. Washington, DC: World Bank.

Wall, B. H. and McCown, R. L. (1989). Designing Roof Catchment Water Supply Systems Using Water Budgeting Methods. Water Resources Development, 5: 11-18.

Hydraulic Geometry of River Alaro, Ibadan, Nigeria.

[1]A. Adediji, [2]O. A. Fashae and [2]O.T. Joseph
[1]Obafemi Awolowo University, Nigeria, [2]University of Ibadan, Ibadan, Nigeria
[1]E-mail: remiadediji@yahoo.co.uk

Abstract
This study focuses on hydraulic geometry of small stream (River Alaro) in Ibadan, South East of Oyo State, Nigeria. In the studied stream, measurements were taken to assess the morphometric and morphologic attributes. The morphologic attributes selected were channel bankfull width (m), depth (m) and velocity (m/s). Bankfull width and depth were measured with tape. The width was measured across the river perpendicular to stream flow, while depth was taken at regular intervals along the channel cross-section. The river discharge (m^3/s) was determined using Velocity-Area technique. The relationship among the variables selected was determined using regression analysis and expressed in power function in order to derive the exponent values of width (b), depth (f) and velocity (n). The exponents values obtained for b, f, and n were 0.59, 0.31 and -0.01, respectively. The exponents derived for the studied stream (River Alaro) showed that $b > f > n$. The b value (0.59), with $R^2 = 0.89$ indicate that width is the most important predictor compared to channel depth and velocity. The sum of values of the three hydraulic exponents (b+f+n) derived were greater than 0.5. This indicated that Alaro stream had a 'well developed' hydraulic geometry. The product moment correlation coefficient obtained showed significant relationship between cross-sectional area and discharge (with value $r^2 = 0.86$).

Key words: Hydraulic geometry; Bankfull discharge; channel morphology; channel cross-section; stream discharge.

Introduction
The Measurement of drainage parameters in quantitative terms began with the ideas of James Horton (Gregory and Walling, 1973), whose law of Accordant Tributary Junctions was expressed by Play Fair in 1802. Many published studies exist on river hydraulic geometry (Horton, 1945, Langbein, 1947; Anderson, 1957; Gregory and Walling, 1973). Hydraulic geometry attributes that relate stream channel dimensions and discharge to watershed drainage basin are useful tools in understanding the process involved in widening and narrowing of stream channel. Studies on hydraulic geometry (Gregory and Walling, 1973)

showed that relationships exist between stream channel forms and discharge downstream along a stream network in a drainage basin. The channel form includes the cross-sectional geometry attributes (i.e. width, mean depth). The hydraulic variables include the slope, friction and velocity. This is for a given influx of water and sediment to the channel and the specified channel boundary conditions. These relationships were studied as hydraulic geometry of stream channels (Thorne *et al.,* 1997; Wohl and Wilcox, 2004; Jens *et al*; 2007 and Ronald *et al.,* 2007).

Similarly, compilation by Thorne et al. (1997), addressed the importance of hydraulic geometry relationships. They opined that "understanding the physical process that regulate the dimensions of natural, self-maintaining river channels is of critical importance in developing hydraulic designs for streams. Brunner (1989) and Dutnell (2000) observed that the knowledge of hydraulic geometry relationships is often used to:-

i) predict the behaviour of a river from its appearance;
ii) develop specific hydraulic relationships for a given morphological region; and
iii) provide quantitative data used to develop at-a-station curves that describe the manner by which width, depth, and velocity change with stream flow.

The hydraulic-geometry relations often are calibrated to a reference flow known as bank full discharge. Bank full discharge is the maximum volume of channelized flow expressed as volume per unit of time that completely, fills the channel up to elevation of the flow plain, without overtopping the stream banks (Dudley, 2004). The elevation of the channelized water surface is called the bank full stage. The bank full flow is useful reference flows because it can be estimated at ungagged sites based on observable physical channel features. This does not require knowledge of flow frequency in the river.

Furthermore, the bankfull flow is thought to be the flow that determines the dominant stream channel geometry in a drainage area. Gregory and Walling, 1973) defined a drainage basin (or catchment) as an entire area providing run-off to, and sustaining part or all of the stream flow of the mainstream and its tributaries. Numerous methods of describing drainage basin have been proposed; some of these apply to the whole basin, while others apply to a particular drainage basin characteristics (Gregory and Walling, 1973). Hence, this study attempts to evaluate the relationships among the hydraulic variables in River Alaro Catchment in Ibadan, Oyo State, Nigeria.

Study Area

Ibadan the capital of Oyo State is located in Western Nigerian on geographic grid reference Longitude 3.08^0 E, and Latitude 7.33^0 N. Ibadan is the largest city in West Africa and second largest in Africa, with land size covering an area of 240 km^2 and with the population of 3,139,500 by 2003 (Fig. 1). Ibadan is situated at an average elevation of 200 m above the mean sea level, drained by four main rivers and surrounded by secondary rainforest, as well as a savannah. Spatially, it sprawls over a radius of 12-15 km and experiences a mainly tropical climate with an estimated annual rainfall of about 1250 mm (Oyedele *et al.*, 2011).

River Alaro basin constitutes the study area and drains through industrial layouts in Ibadan Metropolis (Fig.1) It lies between Latitudes 7.32^0 N and 7.39^0 N and Longitudes 3.84^0 E and 3.92^0 E. It is about 1.5 km away from Mobil Filling Station along Ring Road-Challenge expressway in Ibadan Southwest Local Government Area. River Alaro is pear-shaped. Its drainage density (Dd) ranges from 0.3 to 1.2 with an average of 0.5 km^{-1}, having an area of 41.5 km^2. It has stream frequency (S_f) of 0.41. The Constant of Channel Maintenance (CCM) is approximately 2.0 (Joseph, 2012). The river is one of the major rivers in the area. It is a third – order stream flowing through the Oluyole Industrial Estate. During the rainy season, the stream is known to overflow some of its banks along its flow route. The water is more turbid in the wet session than dry season, possibly due to runoff and other discharges. The bed of the stream consists of sand silts, gravels and rocks characterized by vegetation growing around it and pondweeds growing in some portions of the pond (Akinyeye, 2011). The bed of the pond consists of sand, silt and generally muddy dark-coloured sediment with decaying vegetable matter.

The catchment is underlain by basement complex rocks, with dark-coloured soils (Akinyeye, 2011). The climate is characterized by high temperature all year round, being in a tropical region. Industrial and urban development and changing social practices of people in the lower part of the catchment especially with the presence of industries such as Seven Up Company, and INTERPACK Factory which are situated about 80m away from River Alaro. Apart from the industries in the study area, there are also several residential estate and local communities. The catchment area encompasses semi-urban communities such as Owodu, Oluode, Alapan, Apata and minor communities, (e.g. Akuku, Elebu and Elewure).

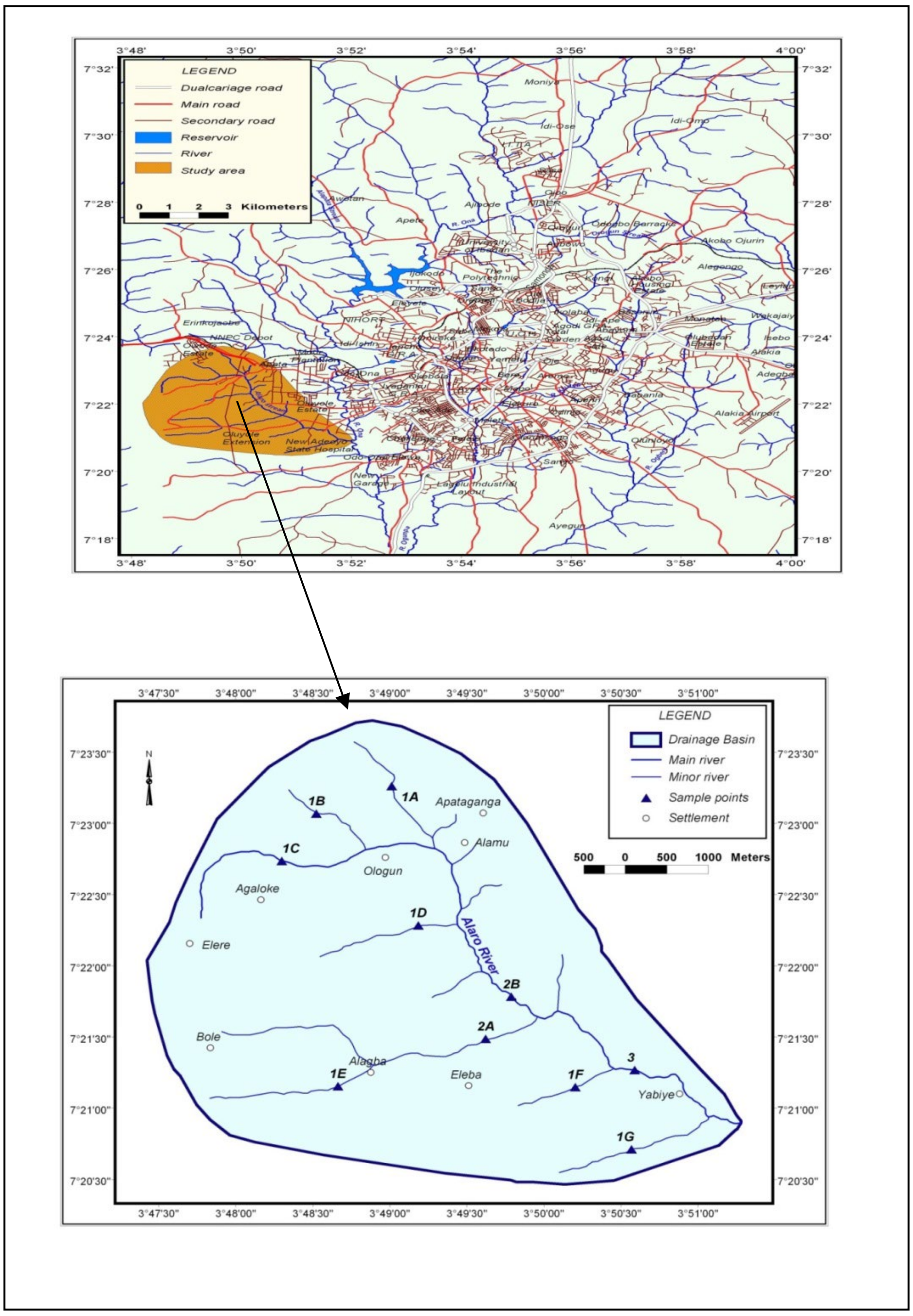

Fig. 1: River Alaro Catchment (Source: Topo Sheet of Ibadan N.W)

Materials and Methods

Topographic map (1:50000, Ibadan N.W) of the study area was obtained from the Oyo State Ministry of Land and Survey, Ibadan. The map was corrected following the methods suggested by Morisawa (1959) and Morgan (1971). Subsequently, the delimited basin was used to determine channel morphological attributes, following the methods outlined by Gregory and walling (1973). The procedure adopted is consistent with the method used by Adediji and Jeje (2004) as well as Adediji *et al. (*2011).

In order to evaluate the morphologic characteristics of the river channels, some parameters which define hydraulic geometry of a stream channel were selected and determined. These parameters are: width (w), average depth (d), and velocity (v), while cross-sectional area (CA), and discharge (Q) were determined from these parameters. Channel width was measured using the surveyor tape, and in order to evaluate the characteristics of the river during flood event, bankfull width was taken. The bankfull level as described by Dudley (2004) was identified and measured. The start and finishing points considered for the measurement were the points where the vegetation and gradient of the bank showed that the river has reached its maximum capacity. The distance between the two edges of bankfull width were determined by observation, that is, directly above the tape at 90º to the streambed. Depth was measured using a straight surveyor pole in meters. To find the average depth, measurements of depths across the width (perpendicular to channel flow) at regular intervals not less than 20% of the total width were determined. Average depth was calculated as the total depths divided by the number of points/ verticals taken along the line of bankfull width. Velocity was measured using the VALEPORT Current Meter. The current meter was used to measure instantaneous velocity at a point along the width of the stream channels in the study catchment. The velocity (V) obtained was multiplied by cross sectional area (CA) in order to obtain stream flow discharge (Q). In order to determine the values of the exponents: b, f and n, the stream flow discharge (Q) was taken as independent variable in the bivariate regression analysis used in this study. This is because Q was found to be positively related to channel width, depth and velocity as reported in Leopold and Maddock (1953).

Both descriptive and inferential statistics were used in the analysis of data for this study. Inferential statistics was employed in the determination of the relationship between width, depth, velocity and discharge. The non-linear regression analysis was used to determine the most important predictor of stream discharge of the study catchment. The relationship among the variables was expressed in power function. The power function was also used to show the implications for widening and narrowing of stream channels as indicated by their respective parameters such as b, f, and n which explain the behaviours of width, depth and velocity, respectively, as developed by Leopold and Maddock (1953). The correlation between discharge and the cross-sectional area was determined using the product moment correlation co-efficient and implemented using the SPSS software 16.0.

Results and Discussion

Table 1 shows the values of cross sectional area (A), width (w), average depth (d) and velocity (v) at the selected points. The cross sectional area and width appear to increase with increase in stream flow discharge of the study stream.

Table 1: Morphologic characteristics of the study catchment

Stream Order	Channel width at Bankfull(m)	Average Depth (m)	Cross-sectional Area (m^2)	Stream velocity (m/s)	Stream flow discharge (m^3/s)
1a	2.0	0.7	1.40	0.26	0.36
1b	3.5	0.7	2.45	0.19	0.47
1c	3.2	0.6	1.92	0.22	0.42
1d	3.2	0.6	1.92	0.24	0.46
1e	2.7	0.7	1.75	0.15	0.26
1f	3.6	0.6	2.16	0.22	0.48
1g	2.5	0.5	1.25	0.21	0.30
2a	7.0	1.3	9.10	0.09	0.82
2b	10.0	1.3	13.0	0.21	2.73
3	11.0	1.2	13.2	0.32	4.22

Source: Fieldwork (2012).

Hydraulic geometry relations derived for the morphologic parameters are displayed in Table 2. The hydraulic geometry relations were expressed in power functions of the form:

$$W = aQ^b = 0.72Q^{0.59} \quad (1)$$

$$d = cQ^f = 0.05Q^{0.31} \quad (2)$$

$$v = kQ^n = 0.60Q^{-0.01} \quad (3)$$

where the respective values for a, c, k, b, f and n are numerical coefficients. The values a, c, and k are intercepts of the regression links and the exponents b, f, and n indicate the slopes of the regression lines when the hydraulic parameters are plotted logarithmically; for instance, equation (1) gives:

$$\text{Log}(W) = \text{Log}(a) + b\,\text{Log}(Q) \quad (4)$$

The regression coefficient for b, f and n are 0.59, 0.31 and -0.01 respectively. The coefficient of determination ($R^2 = 0.01\%$) which indicates that velocity is an insignificant predictor of stream flow discharge.

The width, depth, and velocity exponents b, f, and n in equations (1) – (3) are 0.59, 0.31 and -0.01, respectively. This indicates that width increases more rapidly with discharge. In other words, with changes in discharge, velocity increases at the lowest rate and width increases at the highest rate. The b value (0.59), with $R^2 = 0.89$ (89%) shows that width is the most important variable compared to channel depth and velocity. This is in agreement with Ebisemiju (1989) that b values should be highest for small headwater catchment because small headwater catchments are more homogenous in terms of lithology, soil, areal differentiation of rainfall and runoff. This was also confirmed by Wohl and Wilcox (2004).

However, the velocity appears to be inversely related to stream flow discharge in the study catchment ($r = -0.01$). This finding is in agreement with observation made by Mackin (1963) that in many smaller streams the velocity may increase or decrease downstream consequent on discharge.

The results show that the average relations in hydraulic geometry downstream of the studied stream basin is 0.59. This, according to Singh (2003), is considered to be a good average, and in most cases, the b value is close to the calculated value (0.56) or less for small basins (during lower flows) and for very big basin (in very high flows). Thus, b = 0.59, being a good average tends to smooth out deviations from average, and the value of b ranges between 0.2 and 0.89 (Singh, 2003). However, as reported in Klein (1981), the simple power function for hydraulic geometry is valid for small basins and therefore attests to the robustness of the results obtained in the study. Despite this, according to Klein (1981), these values may not hold over a range of discharge regimes for larger basins.

The exponent values in Equation 1-3 show the adjustment of discharge to increase in width in the ten (10) stations along studied stream channels where measurements were carried out. The values of b, f and n obtained showed that b > f > n, i.e. 0.59 > 0.31 > -0.01, respectively. This further confirms one of the findings reported by Aziegbe (2006) in the study of channel morphological response of two watersheds to urbanization in Benin City, Edo State, Nigeria. This also confirms findings reported in studies carried out by Leopold *et al*. (1964) in which width increases more rapidly with discharge.

The results show that depth as a hydraulic variable influences discharge but does not however account for the little or no variation in the studied stream flow discharge. This is because as observed during the field survey most of the channel beds of the study catchment are rocky, hence the slow adjustment. The depth ($r^2 = 0.68$) is significantly correlated with discharge (Q). Equation 3 shows a non-significant relationship between velocity and discharge with $r^2 = 0.01\%$.

Mackin (1963) has noted that in individual channels, there are just as many of such segments with a downstream decrease in velocity as there are with a downstream increase in velocity. However, Carlson (1969), in his studies of River Susquehanna in the United States, argues that the number of streams with a downstream velocity increase was balanced by an equal number of streams with either a constant velocity or a downstream decrease in velocity. This explains the variation in velocity within basin and between basins. But Singh (2003) opined that in many smaller streams, the velocity may increase or decrease downstream because of geological influences at the mean annual discharge. This seems to be the case in the studied stream. The condition of velocity decrease that characterizes Alaro stream may not be unconnected to the geological influence. This is attributable to the fact that the river downstream has a rocky bed. Hence, depth decreases downstream. This condition therefore contributes to incidences of flooding in the area.

Table 2: Relation between Cross-sectional area and Discharge

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics R Square Change
1	0.93[a]	0.87	0.79	0.33665	0.18

a. Predictors: (Constant), Cross-sectional Area (m^2)

Analysis of morphologic characteristics also reveals the nature of hydraulic geometry of Alaro stream. Although existing literature provides no definition of what constitutes well-developed downstream hydraulic geometry, exponent values for downstream hydraulic geometry relations are usually simply compared to the average values originally cited by Leopold and Maddock (1953). Park (1977) however notes that exponent values cover a wide range. Wohl and Wilcox (2004) attempted to designate downstream hydraulic geometry as being well-developed where variation in discharge explains at least half of the variation in the response variable. They therefore stated that if two of the three downstream hydraulic geometry variables (wbf, dbf, vbf) had r^2 values of 0.50 with Qbf for a given basin or group of basins, the areas are classified as having well-developed downstream hydraulic geometry.

The results also show that width (wbf) and depth (dbf) have r^2 values of 0.89 and 0.68 respectively. These values are greater than the marked value designate of $r^2 = 0.50$ as having well-developed downstream hydraulic geometry (Wohl and Wilcox, 2004). Therefore, the basin under investigation is considered as having well-developed hydraulic geometry.

Cross-sectional Area and Discharge

River Alaro is a third-order basin. As evident from Table 2, there is a relationship between the stream cross-sectional area and its discharge. The coefficient of determination: $r^2 = 0.87$, explains 87% of the total variation in the discharge. The relationship between a stream and its cross-sectional area logically suggests a relationship between stream order and cross-sectional area i.e. discharge increases with increase in stream order as well as cross-sectional area downstream. This implies a concordant relationship (Joseph, 2012) i.e. discharge increases with increase in the order of stream. This relationship is directly opposite to that proposed by Horton (1945), in which he related stream order to stream number, showing a discordant relationship which is analogous to the relationship between stream order and stream length. Order 1 shows average discharge of 0.39 m^3/s for first-order streams. Also, the value 1.78 m^3/s as average discharge rate for order 2 gives a significant increase of 1.39 m^3/s discharge for second order streams. Order 3 shows discharge rate of 4.22 m^3/s, giving an appreciable value increase of 2.44 m^3/s for 3 order streams.

As noted, cross-sectional area and discharge increase with increasing order of streams. Also, discharge increases with the order of streams in the downstream direction. Channel size and shape according to David (2007), are usually quantified by measuring bankfull channel dimensions in cross-section. The significance of bankfull water level in discharge is that flow resistance (via friction of the bed and bank) reaches a minimum at bankfull stage. So the conveyance of water at this level is most efficient; however, the demarcation of the position of bankfull stage in the stream channels is arbitrary and problematic in many cases. (see Gregory and Walling, 1973). Langbein and Leopold (1968) suggested how the problem could be solved. According to them, a simple uniform channel cross-section with two straight banks (reach) which intersect or perpendicular to the river flow should be identified and measured.

Bankfull discharges are useful indicators for the prediction of flood occurrence according to Wohl and Wilcox (2004). According to Ronald *et al*. (2007), bankfull channel geometry and discharge provide important inputs to catchment scale models for predicting flood frequency and extent. This view supports the observation made by Wohl and Wilcox (2004), in their studies on channel geometry of mountain streams in New Zealand.

Conclusions

The hydraulic geometry of a third order, River Alaro Basin in Ibadan Southwest Nigeria was investigated in this study. The hydraulic geometry of the basin has two values $r^2 = 0.89$ and $r^2 = 0.68$ for width and depth, respectively. This suggests that the basin can be identified according to Wohl and Wilcox, (2004) as well-developed. This implies that the condition of a stream being 'well-developed' or 'poorly developed' is not necessarily dependent on the size of a given basin.

In Alaro stream, with changing discharge, width increase at the highest rate while velocity increases at the lowest rate. The exponent value (r^2=0.89), shows clearly that width is the most important predictor of discharge in Alaro Stream. As a result of variation in channel cross-section, discharge increases downstream. This assumption may not hold for all basins due to factors such as geology and operational variance. Therefore the understanding of hydraulic geometry variation relation provides an insight for further understanding of the mechanisms involved in drainage basin form and process as far as fluvial geomorphology is concerned.

References

Adediji, A. and Jeje, L. K. (2004). Channel Erosion in the Opa Basin, Southwest Nigeria. J. Environmental Hydrology, 12: 1 - 10.

Adediji, A., Adewunmi, J. A. and Ologunorisa, T. E. (2011). Effects of Irrigation on the physio-chemical quality of water in irrigated areas of upper Osin Catchment, Kwara State, Nigeria. Progress in Physical Geography, 35 (6): 707-719.

Akinyeye, I. (2011). "Textural characteristics of River Alaro Bed material," Ibadan J. Science, 10: 25-29.

Anderson, H. W. (1957). Relating Sediment yield to watershed variables. Trans. American Geophysical Union, 38(6): 921-924.

Aziegbe, F. I. (2006). Channel and Morphological Response to Two Watersheds to Urbanization in Benin city, Edo State, Nigeria. J. Human Ecol., 20(3): 177-18

Bruner, D. S. (1989). Methods for Estimating Bankfull Discharge in Gauged and ungauged urban streams. Unpublished B.Sc Thesis, University of Waterloo, Waterloo. pp. 29.

Carlson, M. (1969). Channel Morphology and Topology in the River Handbook, 1: 126-143.

David, R. E. (2007). Development of Bankfull Discharge and Channel Geometry Relationship for Natural Channel in design in Oklahoma using a fluvial geomorphic Approach. Unpublished M.Sc. Thesis, University of Oklahoma, Oklahoma, USA.

Dudley, R. W. (2004). Hydraulic Geometry Relations for Rivers in Coastal and Central Maine U.S. Geologic Survey 5042, 18pp.

Dutnell, R. E. (2000). Development of Bankfull Discharge and channel Geometry Relationship. For Natural channel in design in Oklahoma using a fluvial geomorphic Approach. Unpublished M.Sc Thesis, University of Oklahoma, Oklahoma.

Ebisemiju, F. S. (1989). Morphology and Downstream hydraulic geometry relations of alluvial stream channels in a humid Tropical environment, Southwestern Nigeria. IAHS Publ. no 187: 221-236.

Horton, E. (1954). Drainage basin characteristics. American Geophysical Union, 13: 350-361.

Gregory, K. J. and Walling, D. E. (1973). Drainage Basin form and process, A Geomorphological Approach. Edward Arnold Publishers Ltd.

Jens, M. T., Niels, H., Andrew, W. and Ming-Jame, H. (2007). Hydraulic geometry, river sediment and the definition of bedrock channels. Geomorphology, 99: 26- 38.

Joseph, O. T. (2012). Hydraulic Geometry and Grain size Distribution Pattern in Alaro River, Ibadan, Oyo-State, Nigeria. Unpublished M.Sc. Dissertation of Department of Geography, University of Ibadan, Ibadan, Nigeria, 22-50.

Langbein, W. B. and Leopold, L. B. (1968). River Channel bars and dunes. Theory of kinematic waves. US Geological Survey Professional Paper 122.

Leopold, L. B., Wolman, M. G. and Miller, J. P. (1964). Flunal processes and Geomorphology. San Francisco, California, Freeman and Co.

Leopold, L. B. and Maddock, T. J. (1953). Hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey Professional paper 252.

Longbein, B. (1947). Ephemeral stream-hydraulic factors and their relation to drainage net. US Geological Survey Professional Paper 282-A.

Mackin, L. (1963). The importance of physical habitat assessment for evaluating river health. Fresh Water Biology, 21 (2): 241-250.

Maddock, I. (1999). The importance of physical habitat assessment for evaluating river health, fresh water biology, 41 (2): 373-391.

Morgan, R.P.C. (1971). Climatic geomorphology, its scope and future. Geographica 6: 26-35.

Morisawa, M. E. (1959). Relation of Morphometric Properties to runoff in Little Mill Creeks, Ohio, Drainage Basin project NR 389-042. Report 17. Columbia University, Department of Geology: New York.

Oyedele, S. O., Chifunmaya, I. and Oyegoke, S. (2011). Relationship between drainage basin arch and stream length for River Gongola Nigeria. Pacific J. Science and Technology, 8: 184-189.

Park, C. C. (1977). Worldwide variation in hydraulic geometry exponents of stream channels. An analysis and some observations. J. of Hydrology, 33 (Issue 1-2): 133–146

Ronald, C. D., Michael J. S. and Garan, H. (2007). Downstream hydraulic geometry of rivers in Victoria, Australia Civil and Environmental Engineering. The University of Melboume, 3010 VIC, Australia, pp. 302-316.

Singh, V. P. (2003). Downstream Hydraulic Geometry relations using the principles of minimum energy dissipation rate and maximum Entropy, Part I and II, Water Resources Research, 5, 21-27.

Wohl, E. E. and Wilcox, A. (2004). Channel geometry of Mountain streams in New Zealand. J. Hydrology, 300 (Issues 1-4): 252-266.

Assessment of Stream Hydrological Response Using Artificial Neural Network: A Case Study of River Kaduna, Nigeria.

Yusuf Martins Otache[1], Jiya John Musa[1], Abayomi I. Kuti[2] and Murtala I. Animashaun[1]

1. *Department of Agricultural & Bioresources Engineering, Federal University of Technology, Minna, Email: drotachemartyns@gmail.com*

2. *Centre for Disaster Risk Management & Development Studies, Federal University of Technology, Minna*

Abstract

Hydrological alterations may result either from changes in average condition or from changes in the distribution and timing of extreme events. In view of this, the study attempted an evaluation of the hydrological response of River Kaduna at Shiroro Dam site, Nigeria to hypothetical climate change scenarios using the Artificial Neural Network (ANN) paradigm. For the deployment of the ANN, monthly historic hydrometeorological data (i.e., evaporation, rainfall, streamflow and temperature) spanning 33 years were obtained. To this end, four climate change scenarios: +10% rainfall, 2×coefficient of variation in rainfall, -10% rainfall and +3^{0}C average temperature were considered. The historical data were used as input to the ANN and selected monthly synthetic streamflow hydrographs in the seasons (i.e., dry and wet) were generated with an average high value of the goodness-of-fit (R^2=0.96). The response pattern indicated a variability index for the River to be in the range of 0.85-1.25 while for the recession pattern, it is 0.75-0.81. It is imperative to note that the ANN enhanced the generalization of the flow dynamics of the extreme events (peak and low flow regime) with relative predictability capacity values of 103% (R_{max}) and 96.35% (R_{min}), respectively. However, considering the fact that the upgraded temperature and coefficient of variation in rainfall might impact negatively on the average runoff, flow variability, flood frequency and predictability, there is the need for the use of an extensive hydrometeorological data base coupled with the application of associated risk value for effective flood forecasting in real-time.

Keywords: Stream hydrological response, climate change scenario, artificial neural network, Shiroro River, dynamics

Introduction

In line with Alexi *et al*. (2007), any critical evaluation of hydrological impact of climate change find relevance against the backdrop of the need to plan for effective water resources management. Because of the importance of this subject, different methods have been employed to assess the severity of the impact of climate change. Thus, regardless of uncertainty in future climate, there are manifestations/features that there would be significant result on the water cycle and its environs (Merritt, *et al.*, 2006). Water cycle rises when there is increasing evaporation which in turn causes excessive rainfall (Zhang *et al.*, 2007a and Ahn, *et al.*, 2011). Rainfall intensity and amount vary with time and space and these changes have either positive or negative significance on the water resource management (Ahn *et al.*, 2011) thereby causing hydrological response. In this context therefore, hydrological response of a stream is simply by the production of runoff against a given rainfall, which in turn is characterized by basin morphometric properties, soil characteristics and land use pattern (Ajibade *et al.*, 2010).

There are basic methods for the assessment of hydrological response which are downward and upward approaches. Downward approach gives best fitness between observations and simulations while the upward approach represents all the hydrological processes in the river system (Hulme and Brown, 1998; Merritt *et al.*, 2006). Climate impacts on runoff and stream response are assessed and accomplished by coupling General Circulation Model (GCM) outputs and hydrological models. Andersson *et al.*, (2006) employed four GCMs and Pitman employed stochastic and physical based model to measure the impact of varied development and climate change scenarios about river system within Okavango river basin. Merritt *et al.* (2006) appraised the response of the river to scenarios of climate change in Okanagan basin accompanied with three GCMs. Zhang *et al.*, (2007b) forecasted the consequence of possible climate change on streamflow quantity in Luohe river basin using two GCMs and Soil and Water Assessment Tool (SWAT) model (Ahn *et al.*, 2011). Regardless of this, prediction of climate change is still challenging (ASCE Task Committee, 2000; Merritt *et al.*, 2006) since available information lacks adequate real-time planning especially during the incidences of flood situation and its mitigation. Therefore the study aimed to assess stream hydrological response using ANN.

Materials and Methods

Hydrology of the study area

The Shiroro is located on latitude 9° 58’ 00” N and latitude 6° 51’ 00” E (Fig. 1). Kaduna River has fifteen drainage tributaries among its watershed and these tributaries are rivers Dinya, Sarkin Pawa, Guni, Erena, and Muyi. The tributaries flow in the North-South direction and then meander in the Northwest to Southeast direction. This river has a low base flow problem and the volume of the rivers swell in volume with ranging torrent while in the dry season they dry up.

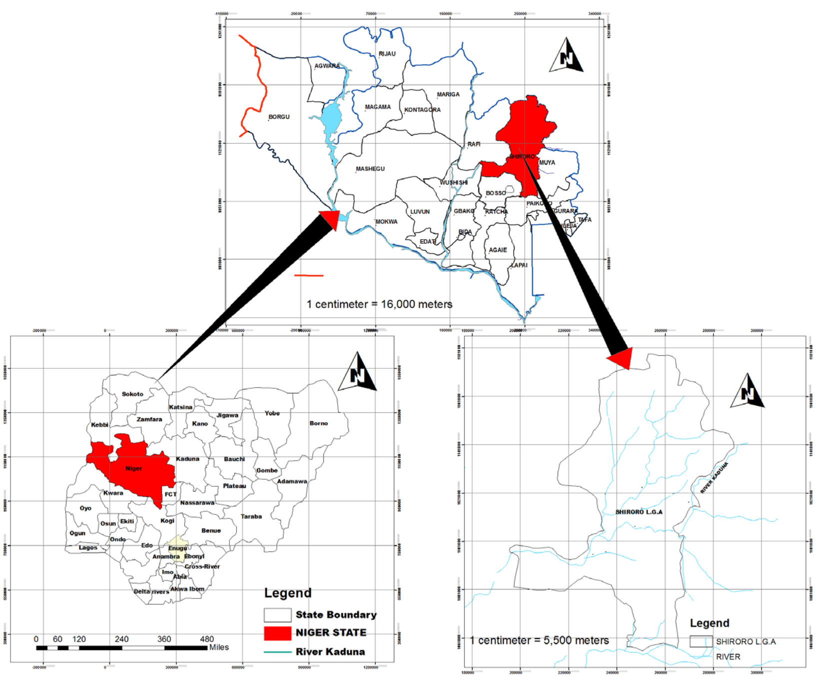

Fig. 1: Location of Niger State with Shiroro dam inset and the River Kaduna drainage basin
Source: Shiroro Local Government Secretariat (2005)

Data collation

Monthly discharge (streamflow), rainfall, temperature and evaporation records were obtained for a period of thirty three (33) years (1980 -2012) from the Shiroro Hydroelectric Plc.(2013). These variables were used to examine the hydrological response of the area.

Establishment of Climate Change Scenarios

This study utilized incremental scenarios to determine the climate change scenario of the river. The establishment of the climate change scenarios was hypothetical, premised on the recommendations of Shaka (2008). The thirty-three (33) years streamflow, rainfall and temperature data were subjected to climate change scenario and these are as follows:

Scenario I: rainfall data increases by 10%; this was predicated on the seasonal variation of the rainfall; 1.13 seasonal variation index. This implies that on the average, the river experiences about 10% increase at the commencement of the raining seasons.

Scenario II: rainfall data decreases by 10%

Scenario III: rainfall's Coefficient of Variation was doubled

Scenario IV: temperature data was increased by 3^0C.

The study used hydrological statistics such as mean flow, high flow and low flow of the river; in this case, the mean flow estimates the average flow in the river channel. The percentage coefficient of variation of the monthly hydro-climatic data was estimated as the division of the standard deviation by the mean times 100. In the same context, flood frequency and baseflow were also considered. Based on the submissions of Poff *et al.* (1996), flood predictability was estimated as the degree or magnitude to which all bank full events occur over the entire period of the record. It was computed as the ratio of the number of flood occurrence to the entire event distribution or size while baseflow on the other hand, as the ratio of the minimum average flow to the mean flow.

Development of the ANN

Artificial Network structure consists of input and output dimensions; the Network architecture is as shown in Fig. 2. The input include monthly discharge (Q), rainfall (±10%, R), coefficient of variation (2CV), temperature (+3^0C (T) and evaporation (E) for time steps of t-1. while the output dimension is streamflow at time t. The ANN has a total of 15 nodes in the hidden layer for both training and validation based on sequential network optimization.

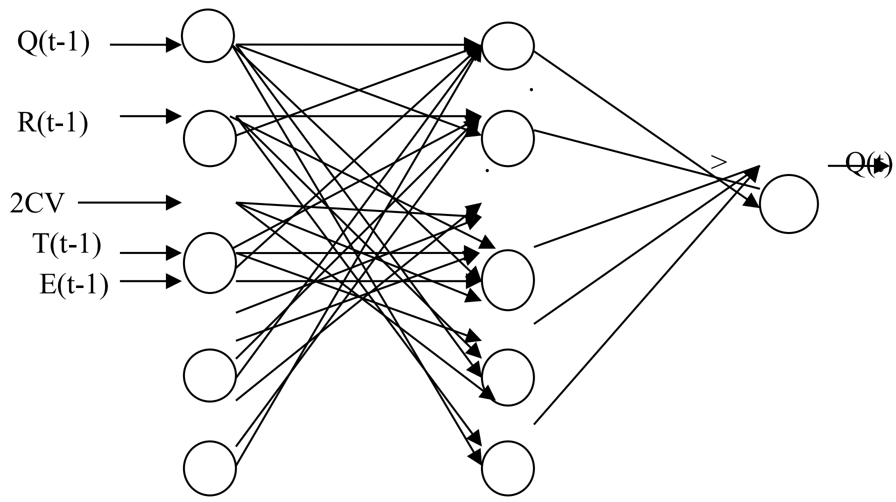

Fig. 2: Structure of the feed-forward Artificial Neural Network Architecture

(a) Modelling Strategy

The ANN model is written as shown below:

$$y = f\,(uj) \tag{1}$$

where

$$uj = \Sigma w_i x_i - \theta_j$$

and

x_i= inputs to flow, w_i= weight of $x_i$and θ_j= critical value. The output of node j, y_j, was calculated to determine the response of a node to the total input signal it received.

The forecast function used for this study is as stated in equation 2.

$$\bar{Q}_{i,j} = \gamma_1 + \alpha_{1,1}б\,(-\beta + \omega_i{}^{(i)} Q_{i,j-1} + \omega_1{}^{(2)}\eta_{i,j-1} + \omega_1{}^{3}\eta_{i,j-2} \tag{2}$$

where:

i= year,

γ, α, **β,** and $\boldsymbol{\omega}$ are parameter sets,

$\bar{Q}_{i,j}$ = predicted streamflow

$\eta_{i,j}$ = applicable hydro-climatic variables as a function of season and elements of climate change scenario.

$Q_{i,j-1}$ = previous monthly streamflow

(b) Database Management

The entire time series of length of 198 monthly values was partitioned into two sets of 138 and 60 data point corresponding to training and validation, respectively. The outcome of the training procedure relies on the power of the optimization method utilized to search the response surface for the best parameter estimates; training was executed using the Bayesian regularization training algorithm so as overcome generalization problems that do results from over fitting (Otache *et al.*, 2012). The entire input and output data were pre-processed and standardized using the long term mean and standard deviation for the training and validation data sets. The network training was implemented using Matlab routine.

Performance Criteria

The performance of the ANN model was evaluated by using both global and distribution statistics; these statistics were correlation coefficient (R^2), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) as in equations 3-5:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(y_i - x_i)^2}{N}} \quad (3)$$

$$R^2 = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \bar{x})^2 \sum_{i=1}^{N}(y_i - \bar{y})^{\ 2}}} \quad (4)$$

$$MAPE = \frac{1}{N}\sum_{t=1}^{n}\frac{(x_i - y_i)}{x_i} \quad (5)$$

where:

x_i are the observed values at the *i*th time step

y_i are the simulated values

N is the number of data points

$\bar{x}$ and $\bar{y}$ are the mean value of observations and simulations

The measures of forecast accuracy were computed with respect to high and low extreme values (Otache *et al.,* 2012):

$$R_{max}(\%) = \frac{\hat{y}_t}{\hat{\jmath}_t} \quad (6a)$$

$$R_{min}(\%) = \frac{\bar{y}_t}{\bar{\imath}_t} \quad (6b)$$

where:

$\hat{y}_t$ = forecasted maximum

$\hat{\jmath}_t$ = observed maximum

$\bar{y}_t$ = forecasted minimum

$\bar{\imath}_t$ = observed minimum

Results and Discussion

Flow Simulation

The results of the convergence patterns as a function of RMSE and R^2 are as shown in Table 1. The table shows the RMSE and Correlation Coefficient computed for training and validation data sets. Generally, RMSE values ranged between 1.04E-03 and 6.55E-04 for training set while that of validation set ranges from 3.25E-04 to 6.58E-04, respectively. The ANN model shows varying predictive capability for both seasons in terms of R^2.

Table 1: Convergence patterns as a function of RMSE and R^2

	Training		Validation	
Month	**RMSE**	$\mathbf{R^2}$	**RMSE**	$\mathbf{R^2}$
Jan	6.55E-04	0.97	6.58E-04	0.96
Feb	1.04E-03	0.79	6.40E-04	0.97
Mar	5.96E-04	0.92	5.92E-04	0.93
Sept	6.20E-04	0.87	3.25E-04	0.83
Oct	6.42E-04	0.86	4.81E-04	0.87
Nov	4.69E-04	0.92	6.28E-04	0.88

As shown in Table. 1, the ANN model, on the average performed much better in the dry season period for the training and validation periods. The situation in the wet season though good relatively perhaps considering the test statistics in the overall could be explained as a direct consequence of the seeming variable runoff accretion dynamics. On the other hand, Figure 3(a-f) shows that the comparative simulation hydrograph for the different months considered and the variations in the simulation regime. It is obvious from the figure that the ANN was able to capture the flow dynamics well; this lends credence to the adequacy of the model architecture and effectiveness of the optimization algorithm employed. But while it is obvious from Fig. 3 (a-c) that the results of the estimation between observed and predicted have relative good agreement, Fig. 3 (d-f) is to the contrary; there is a seeming under-prediction between 2004 and 2008 year periods. The only conjecture for this is sheer debilitating climate change effects.

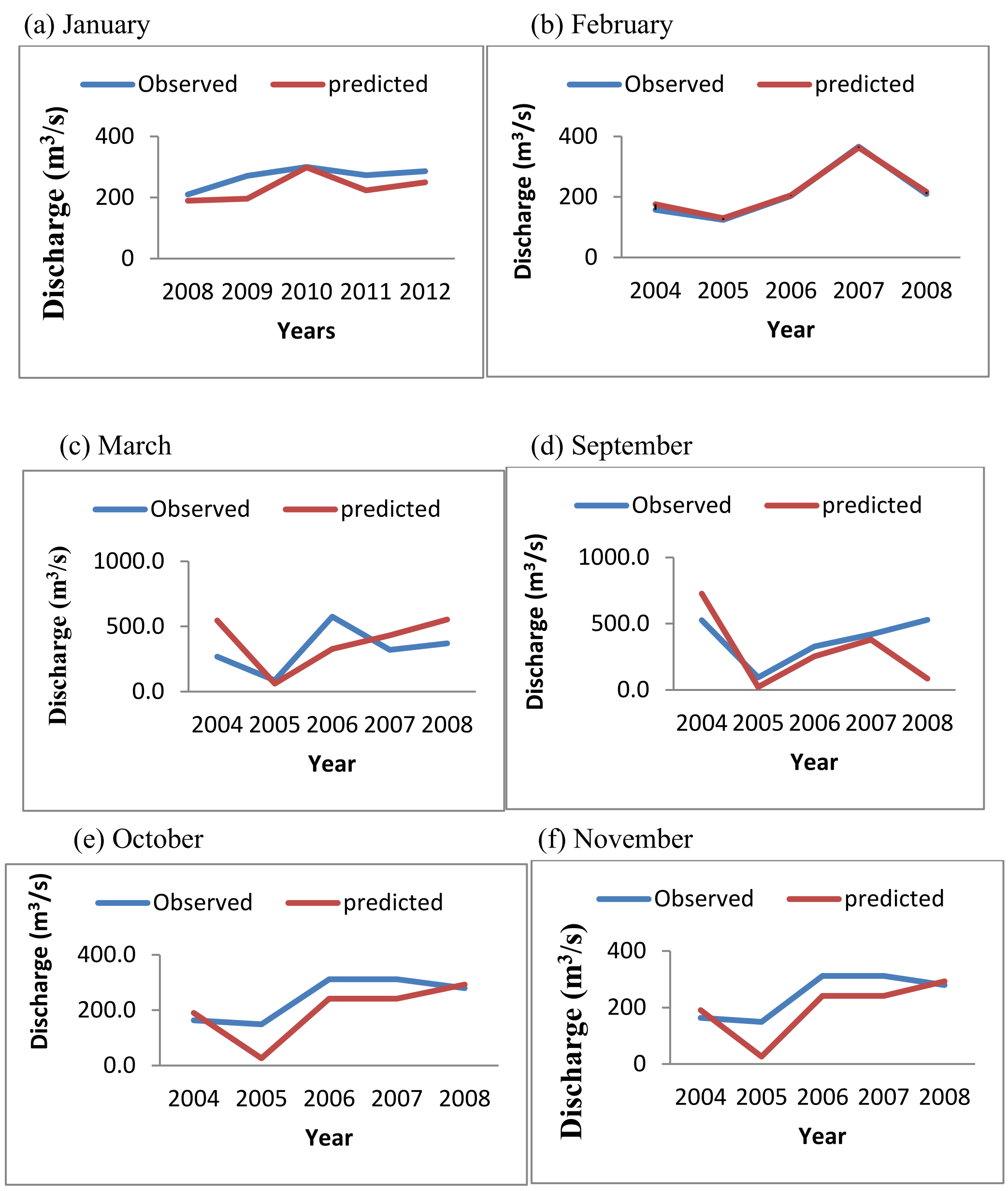

Fig. 3: Simulation hydrographs of the seasons in Shiroro hydrological Station

Table 2: Summary of measured and simulated hydrological Characteristics

Variables	Observed	Predicted
Average flow	6.6	6.2
Monthly CV (%)	20.1	16.7
Predictability of monthly flow (%)	30	70
Flood Frequency(1/yr)	0.9	1.1
Flood free period(Fraction of year)	0.3	0.7
Baseflow (Min/Mean)	0.8	0.3

The monthly predictability, flood frequency, flood free period show greater deviation than observed values as shown in Table 2 above. Also, the average flow, CV, and base flow exhibited greater deviation than simulated values. It is interesting to note that the findings here are relatively in accord with similar works, e.g., Poff *et al.* (1996), though values of climate change scenarios on incremental basis differ slightly and too, there is a seeming variation in hydro-climatic regime. Precisely, the simulated values had greater deviation than the actual values whereas monthly predictability, flood frequency and flood free period exhibited greater deviation than the observed streamflow in this study. This can be attributable to the erratic inflow regime or accretion in the upstream and probably the definition of climate change scenarios adopted.

Table 3: ANN Model Performance in terms of extreme events

Months	R_{max} (%)	R_{min} (%)
Jan	99.6	90
Feb	91.2	104
Mar	101	99
Sept	137	129
Oct	96.2	71.4
Nov	94	84.7
Average	103	96.35

Table 3 shows the performance of the Artificial Neural Network model in terms of flow variability. The extreme flow indices: R_{max} and R_{min} indicate that the ANN model, on the average, reproduced the variability of the flow pattern adequately. The Artificial Neural Network model over predicted maximum and minimum flow situation; the inability of the Artificial Neural Network model to adequately produce flood situation and low flow situation could be attributed to variability in rainfall-runoff formation regime.

Hydrological Response to Climate Change Scenarios

Figure 4 shows the hydrological response of the flow system to climate change scenarios adopted for the study. The results of the 10% increase in rainfall yielded excess runoff in the area. When compared with the normal mean rainfall pattern, the river experienced about 9.5 % increase in rainfall which in turn produced increased hydrological variability whereas 10% decrease in rainfall resulted in less runoff in the area culminating in 18.5% reduction in flow volume of the river. By and large, this scenario led to reduction of flood frequency, mean flow, flow coefficient of variation and baseflow.

The results of double CV increased flood frequency, mean flow and reduced coefficient of variation flow and base flow. Lastly, the results of increase temperature by 3^0Cled to low mean flow, flood frequency; the river experienced additional 11.1 % increase in temperature and thus reduced coefficient of variation and baseflow which in turn increased the surface water evaporation of the drainage basin. In summary, against the backdrop of the findings here, it suffices to note that the application of climate change scenarios particularly by ±10% in rainfall and doubled coefficient of variation produced staggering high flood during the wet season and low flow availability in the drying season period. On the other hand, increase in temperature led inadvertently to high evaporation. Considering the overall scenario, the definition of the hypothetical climate change situation should as a matter of principle derive directly from a holistic analysis of the long term trend pattern of the historic data. It is important because anything to the contrary might fail to capture appropriately the variations in hydro-climatic dynamics of the basin. This is so because of the nonlinear nature of the rainfall-runoff relationship against the unusual assumption of linearity.

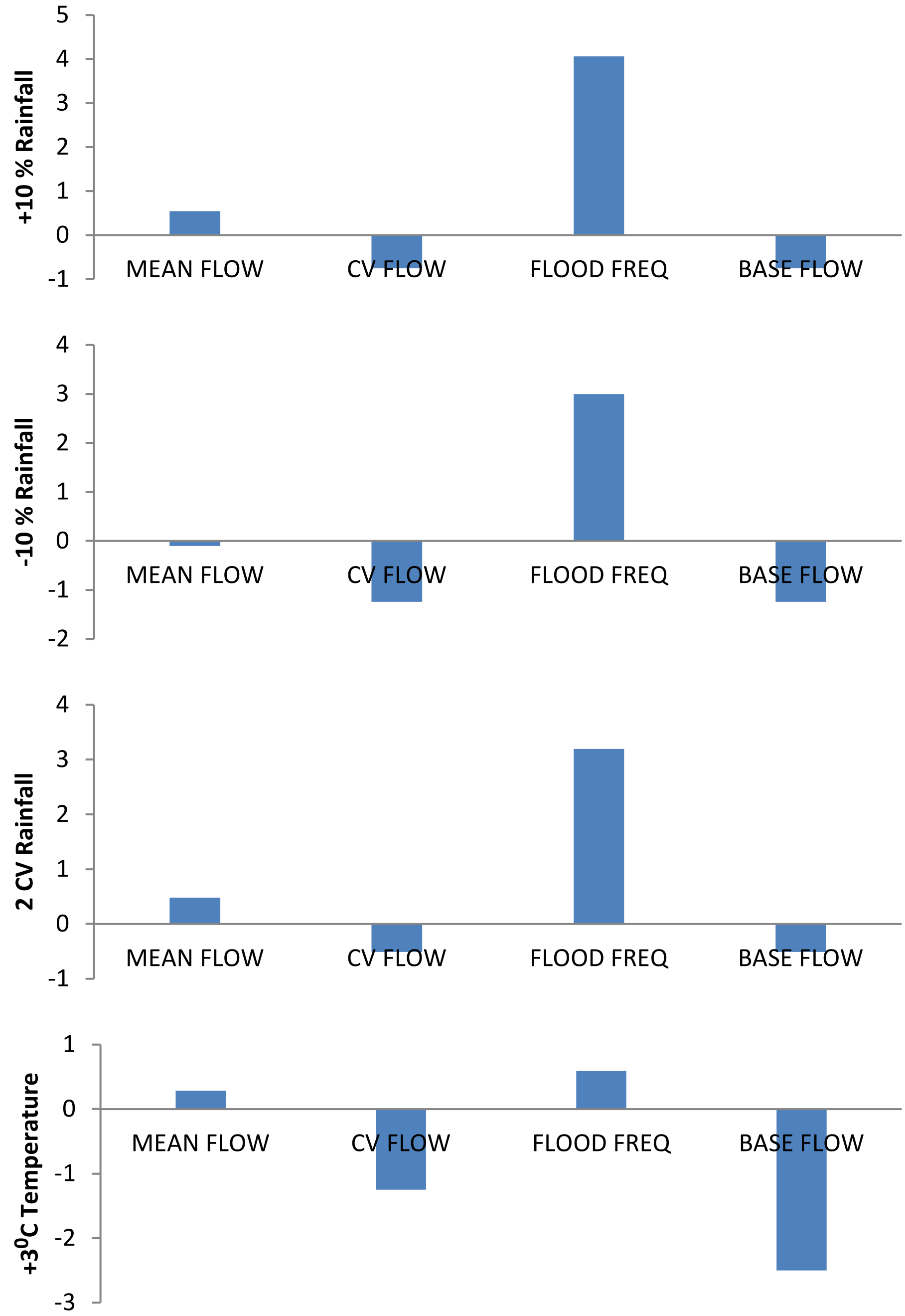

Fig. 4: Responses of hydrological variables in the flow system

Conclusions

Globally, climate variability has resulted in fluctuations and increasing rainfall which in turn cause river/stream to rise and fall. In view of this, the study assessed the stream hydrological response of the basin. From the results, monthly predictability, flood frequency, and flood free period deviated strongly from normality; this could be as a result of seeming volatility in hydro-climatic processes. It is evidently clear however that the ANN forecasting approach is robust and effective in view of its high generalization ability. The ANN could simulate stream hydrological response hydrograph with staggering vagaries. The ANN model predicted high flow much better than low flow regime; basically because of erratic inflow regime in the upstream of the river culminating in unstable dry season regime. The maximum prediction coefficient of correlation (R^2) between the observed and predicted value for the long term monthly streamflow was found to be 0.97 (February) while the least was found to be 0.83 (November) which is in concord with the variability in wet and dry seasons' inflow dynamics with respect to the basin drainage density. However, based on the findings it is imperative to stress the need for mobilization of sufficient hydrological and climatic data for effective and efficient flood forecasting based on flood frequency analysis. Similarly, the use of risk value, resilience and reliability relationship with respect to flood adaptation and mitigation in the general context of varying hydro-climatic change scenarios is not just expedient but a viable complement to the overall general assessment protocol.

References

Ahn, S. R., Park, G. A., Jung, I. K., Lim, K. J., and Kim, S. J. (2011). Assessing Hydrologic Response to Climate Change of a Stream Watershed Using SLURP Hydrological Model. KSCE J. Civil Engineering, 15(1): 43-55.

Ajibade, L. T., Ifabiyi, I. P., Iroye, K. A. and Oguntеru, S. (2010). Morphometric Analysis of Ogunpa and Ogbere Drainage Basins, Ibadan, Nigeria. Ethiopian J. Environmental Studies and Management, 3(1): 13-19.

Andersson, L., Wilk, J., Todd, M. C., Hughes, D. A., Earle, A., Kniveton, D., Layberry, R., and Savenije, H. G. (2006). Impact of climate change and development scenarios on flow patterns in the Okavango River. J. Hydrology, 331 (1-2): 43-57.

Alexi, S. C., Juan, B. V., Javier G. P., Kate, B., Luis, J. M. and Thomas, M. (2007). Modelling climate change impact and uncertainty on the hydrology of a riparian system. J. hydrology, 347 (Issue 1-2): 48-66

ASCE Task Committee (2000). Artificial Neural Networks in Hydrology: Hydrologic Applications. J. Hydrologic Engineering, 5(2): 124- 137. .

Hulme, M. and Brown, O. (1998). Portraying climate scenario uncertainties in relation to tolerable regional climate change. Climate Research, 10: 1–14

Merritt, W. S., Alila, Y., Barton, M., Taylor, B., Cohen, S., and Neilsen, D. (2006). Hydrologic response to scenario of climate change in sub watersheds of the Okanagan basin. British Columbia J. Hydrology, 326 (Issue1-4): 79-108.

Otache, Y. M., Mohammed, A. S., Ahaneku, I. E. and Egharevba N. A. (2012). Modelling daily flows of River Benue using Artificial Neural Network approach. Nigerian J. Hydrological Sciences, 1: 41-56.

Poff, N. L., Tokar, S. and Johnson, P. (1996). Stream hydrological and ecological responses to climate change assessed with an artificial neural network. J. Limnology and Oceanography, 41(5): 857- 863.

Rajib, K., Matin, M. A. and Sharmina, N. (2013). Response of River Flow Regime to Various Climate Change Scenarios in Ganges-Brahmaputra- Meghna Basin. J. Water Resources and Ocean Science, 2(2): 15-24.

Shiroro Hydroelectric Plc. (2013). Reservoir operational and meteorology records. Shiroro, Niger State, Nigeria

Solaimani, K. (2009). A Study of Rainfall Forecasting Models Based on Artificial Neural Network. Asian J. Applied Sciences, 2: 486-498.

Zhang, X., Srinivasan, R. and Hao, F. (2007a). Predicting hydrologic response to climate change in the Luohe River Basin using the SWAT model. American society of Agricultural and Biological Engineer, 50(3): 901-910.

Zhang, G. H., Fu, S. H., Fang, W. H., Imura, H., and Zhang, X. C. (2007b). "Predicting effects of climate change on runoff in the Yellow River Basin of China." American Society of Agricultural and Biological Engineers, 5(3): 911-918.

Application of index method for evaluation of groundwater quality around dump sites in basement complex

S. A. Ganiyu*[1], B. S. Badmus[1], V. C. Ozebo[2], O. A. Idowu[3] and O. T. Olurin[1]

[1] *Department of Physics Federal University of Agriculture Abeokuta Ogun State, Nigeria,*
Email: adekunsa@yahoo.com

[2] *Department of Physics, University of Lagos, Lagos State Nigeria*

[3] *Department of Water Resources and Agrometeorology, Federal University of Agriculture Abeokuta, Ogun State Nigeria*

Abstract

Twenty water samples were collected from hand-dug wells around Aba-Eku and Ajakanga dumpsites during dry and wet seasons to assess the water quality using water quality indexing method. These samples were analysed for physicochemical parameters: pH, TDS, TH, HCO_3^-, CO_3^-, Cl^-, NO_3^-, SO_4^{2-}, Na^+, K^+, Ca^{2+} *and* Mg^{2+}. *The values of GWQI of the samples were found in the range of 7.39 – 37.8 in dry season and 10.7 – 40.9 during wet season. For Aba-Eku water samples, Ninety per cent of sampling locations belong to "excellent" water status while 10% (well 3) revealed "Good" water quality status during dry season. However, 80% of Aba-Eku water samples revealed "excellent'' water quality status while 20% (wells 2 and 5) belonged to "Good" water quality during wet season. For Ajakanga water samples, 50% of water samples revealed "Excellent" water status while 50% indicated "Good" class during dry season. During wet season, 70% of water samples revealed "Excellent" water status while 30% revealed "Good" water status. None of the water samples revealed fair, poor or unfit classes for drinking purposes. The GWQI values for all water samples during both seasons reveal their fitness for drinking and human consumption purposes. Pearson correlation coefficients among selected water parameters show strong associations between EC and TDS,* Cl^-, *TH and* Na^+ *during both seasons. This confirmed that EC depends largely on the quality of dissolved salts present in the sample. The concentration of EC on the nearby hand-dug wells will increase as the dumpsite ages.*

Keywords: landfill, physico-chemical, leachate, quality index, groundwater

Introduction

Groundwater is used for various purposes ranging from drinking, domestic, industrial and agricultural purposes all over the world. Groundwater quality depends on the quality of recharged water, quantity and quality of generated waste, sewage treatment and subsurface geochemical process (Rizwan and Gurdeep, 2010). The groundwater contamination has become a great problem due to rapid growth of population, industrialization and urbanization rate in the metropolitan city all over the world. Solid wastes are being produced everyday by residential, commercial and agricultural sources as direct consequences of human activities. In an attempt to dispose of these large volume of daily wastes, man has carelessly polluted the environment especially surface, groundwater, soil and air through leachate plume and landfill gases. Pollution of groundwater is a major threat posed by leachate plume which is formed by anaerobic decomposition of waste and may infiltrate and join the aquifer (Tesfaye, 2007). According to Freeze and Cherry (1979), water table mounding and gravity causes leachate to move through the subsurface soil to the bottom and sideway until it reaches the groundwater zone thereby polluting the groundwater. With the inconsistent variation of groundwater table, soil condition and contamination by leachate plume through percolation, infiltration and seepage, groundwater quality determination assumes greater significance in the field of water quality management (Venkata et al., 1998).

In Ibadan, the capital of Oyo State in south western part of Nigeria, there is scarcity of pipe borne water due to non-availability and inadequate presence of laid down pipe in most parts of the city. Consequent upon this, groundwater from hand-dug wells serves as an alternative and major source of water supply for domestic purposes. Siting of dumpsite within the vicinity of residential areas can contaminate groundwater quality of wells bordering the landfill. The use of polluted groundwater for drinking and consumption purpose can cause major health problem. According to WHO, about 80% of all diseases in human beings are caused by water (Ramakrisnaiah et al., 2009). Therefore, a periodic assessment of groundwater quality is necessary in order to ascertain the quality of water to be used for human consumption purpose as well as to provide an overall scenario about the source of groundwater contamination; this could open an avenue for better planning to achieve sustainable management of groundwater.

The groundwater quality is normally characterized by different levels of physiochemical parameters. These parameters change widely due to various types of pollution, seasonal variation and groundwater extraction.. Groundwater quality Index (GWQI) indicates the overall quality of water in terms of a single value which represents the water quality level (Saeedi et al., 2010). It is defined as a reflection of the composite influence of different quality parameters on the overall quality of water (Horton, 1965, Shankar and Sanjeer, 2008). It is also one of the most effective ways of communicating the information on water quality trends to the general public and policy makers in water quality management. It is associated with the need to provide a general means of comparing and ranking various bodies of water throughout the geographic region (Armah et al., 2012). Moreover, GWQI assessment is important because of the spread of water-borne diseases, several epidemiological studies show that, about 8% of human diseases in the world are due to poor quality of drinking water.

Several researchers have examined groundwater quality using indexing method. Sayed and Gupta (2009) investigated the GWQI of groundwater samples from hand pump and bore wells in Beed city of Maharashtra, India. Srinivas et al., (2013) estimated the water quality index of borehole waters in industrial areas of Kakinada Andhra Pradesh, India. The quality of groundwater in Tarkwa Gold mining area in Ghana was assessed using GWQI (Armah et al; 2012) while quality of groundwater in Tumkur Taluk, Karnataka State was assessed by Ramakrishnaiah et al. (2009) using WQI. Rao and Nageswararao (2013) used the method of GWQI to assess the quality of groundwater at Greater Visakhapatnam city using water quality index. The main objective of this study is to estimate the GWQI values of groundwater samples from hand-dug wells bordering the two landfills so as to know their suitability for the purpose of human consumption.

The Study Area and its Local Geology

Ibadan is located approximately within the square of Latitude 7.33^0 to 7.67^0 North of the equator and Longitude 3.58^0 to 4.17^0 East of the Greenwich meridian. There are three major rivers draining the city, these are Ogunpa, Ogbere and Ona rivers with many tributaries (Fig. 1). The population was estimated to be 2,550,993 according the National Population Commission (NPC) breakdown of 2006 census. The rainy season runs from April to October and the dry season is from November to March with highest rainfall of 170mm in the month of September. Temperature in Ibadan ranges from 21^0C to 35^0C.

There are four (4) major open dumpsites that serve as repositories of municipal solid wastes within Ibadan metropolis. These are Aba-Eku, Ajakanga, Awotan and Lapite dumpsites. For the purpose of this research work, the study areas are Aba-Eku and Ajankanga dumpsites.

Aba Eku dumpsite is located along Akanran road in Ona Ara Local Government area on Longitude 3.99^0 E and Latitude 7.32^0 N. Ajakanga landfill is located along Odo Ona Elewe road in Oluyole Local Government Area on Longitude 3.89^0 E and Latitude 7.31^0 N. The two study areas fall within the humid and sub humid tropical climate of Southwestern Nigeria with a mean annual rainfall of about 1230 mm and mean maximum temperature of 32^0C (Akintola, 1986). Aba-Eku and Ajakanga landfills are active open dumpsite managed and maintained by Oyo State Waste Management Authority. The two landfills were opened in 1998 and still active till date.

The geology of the area is basement complex formation with dominant rock types being quartzites of the meta sedimentary series, banded gneiss, augen gneisses and migmatites. Other minor rock types present include: pegmatite, quartz, aplites, amphibolites and xenoliths (Okunlola et al., 2009). In a basement complex formation, the occurrence, movement and storage of groundwater are found in the weathered and fractured parts of the bedrock formation (Fig. 2).

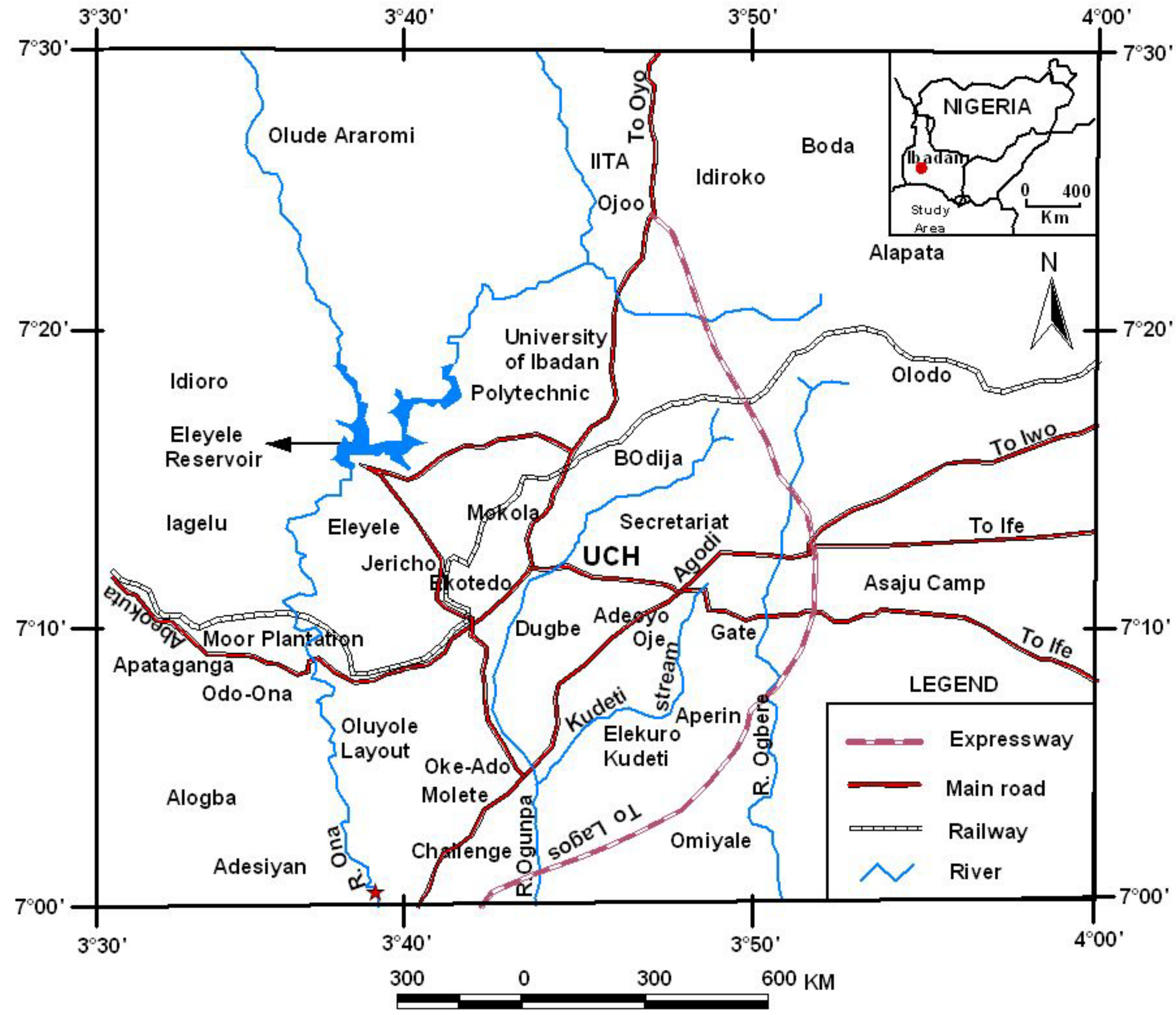

Fig. 1: The major rivers in parts of Ibadan

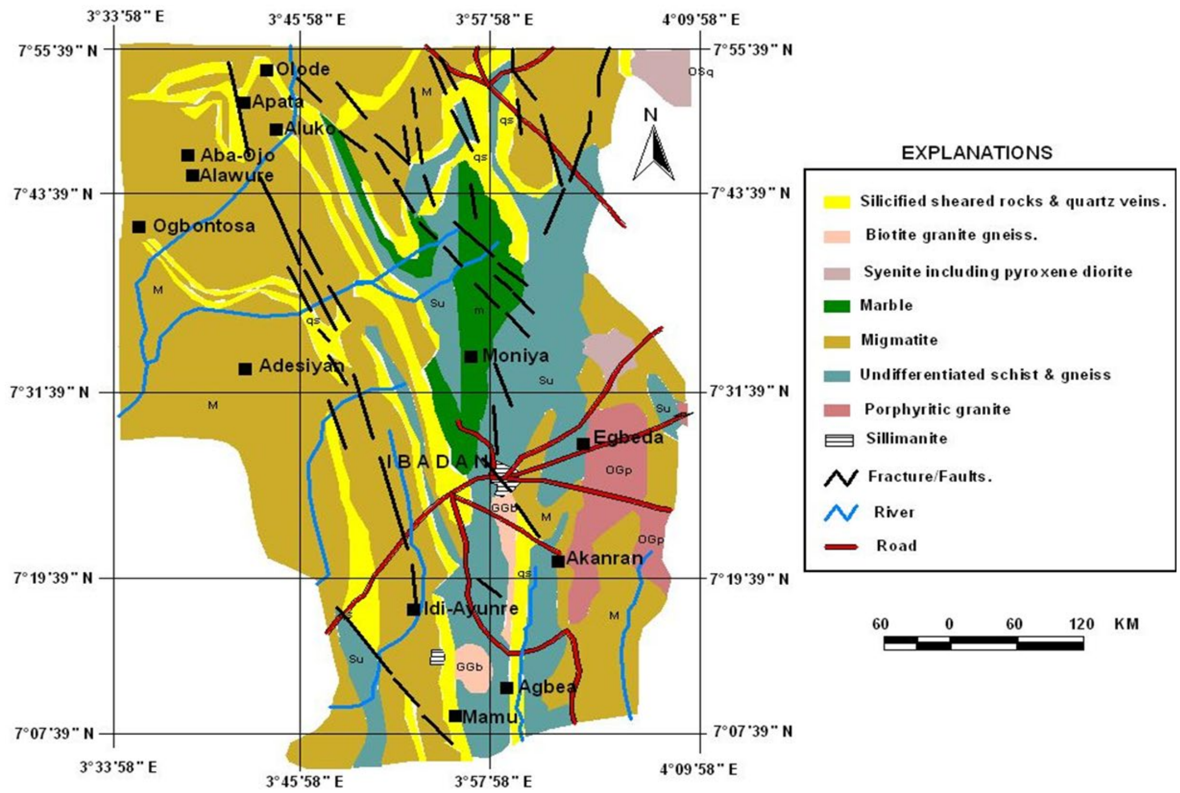

Fig. 2**:** Generalized geological map of Ibadan

Materials and Methods

Groundwater samples were collected using 2 litres polyvinyl chloride bottle from ten residential locations within the vicinity of Aba-Eku landfill. Geo-satellite positioning of all the sampling locations were determined with the aid of Garmin Etrex GPS. The depth to static water level and total depth of hand-dug wells were recorded during the sampling periods as shown in Tables 1 and 2. The collection of groundwater samples were done in March (dry season) and August (wet season) of year 2013. In each study area, 10 groundwater samples were collected from hand-dug wells around each landfill site making twenty samples for the two sites in March 2013. Samples 1- 10 were collected from hand-dug wells around Aba-Eku dumpsite while samples 11- 20 were collected within Ajakanga dumpsite (Tables 1 and 2).

Table 1: Well parameter for Aba-Eku water samples (Dry and Wet Season)

Well	Distance to Landfill (m)	Depth to water table (m) (Dry)	Depth to water table (m) (Wet)	Depth to Bottom (m)
1.	110.00	5.90	4.00	7.30
2.	30.00	6.60	4.30	13.40
3.	50.00	5.50	3.30	10.90
4.	50.00	6.40	2.50	10.90
5.	20.00	3.00	3.50	5.40
6.	350.00	2.50	2.40	5.40
7.	360.00	5.50	3.60	6.00
8.	360.00	4.30	2.90	7.30
9.	170.00	4.30	2.60	7.00
10.	200.00	0.90	1.50	4.20

Table 2: Well parameters for Ajakanga water samples (Dry and Wet Season)

Well	**Depth to water table (m) (Dry)**	**Depth to water table (m) (Wet)**	**Depth to Bottom (m)**	**Distance to Landfill (m)**
11.	3.70	2.70	9.10	90.00
12.	2.00	2.10	2.70	110.00
13.	3.50	3.20	4.50	100.00
14.	5.80	2.70	6.40	200.00
15.	5.20	2.70	5.50	220.00
16.	4.60	4.30	5.50	200.00
17.	5.50	3.20	5.80	270.00
18.	7.20	6.50	8.20	520.00
19.	-	-	-	120.00
20.	1.80	1.80	3.70	120.00

The locations of sampling points in Aba Eku dumpsite are shown in Fig. 3, while location of sampling points in Ajakanga are shown in Fig. 4. Each of the groundwater samples was analysed for thirteen physico chemical parameters such as: pH, EC, TDS, TH, HCO_3^-, CO_3^-,

Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+ and K^+ using standard procedures recommended by APHA (1998). pH, TDS and EC were measured in- situ with the aid of multi-purpose conductivity meter. Na^+ and K^+ were determined with flame photometric method, HCO_3^-, CO_3^- and Cl^- determined using titrimetric method, NO_3^- by UV spectrophotometric method, SO_4^{2-} amount was determined using turbidimetric method while Ca^{2+} and Mg^{2+} concentrations were analysed using absorption mode of Atomic Absorption spectrometric method. The chemical parameters obtained were used for correlation coefficient analyses during both seasons. The Groundwater Quality Indices were calculated from the point of view of suitability for drinking and human consumption purposes.

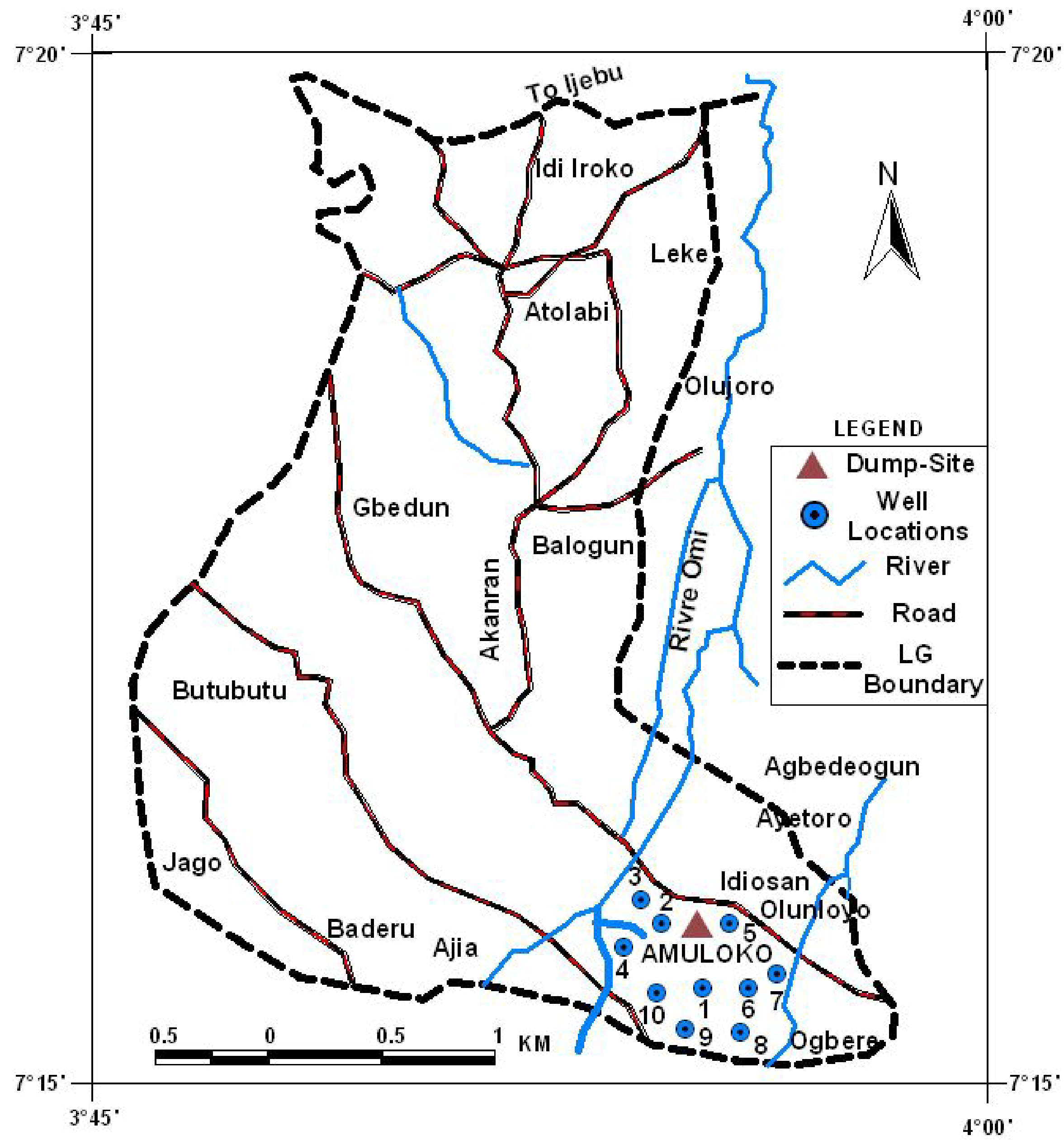

Fig. 3: Location of Aba Eku Dumpsite and water sampling points

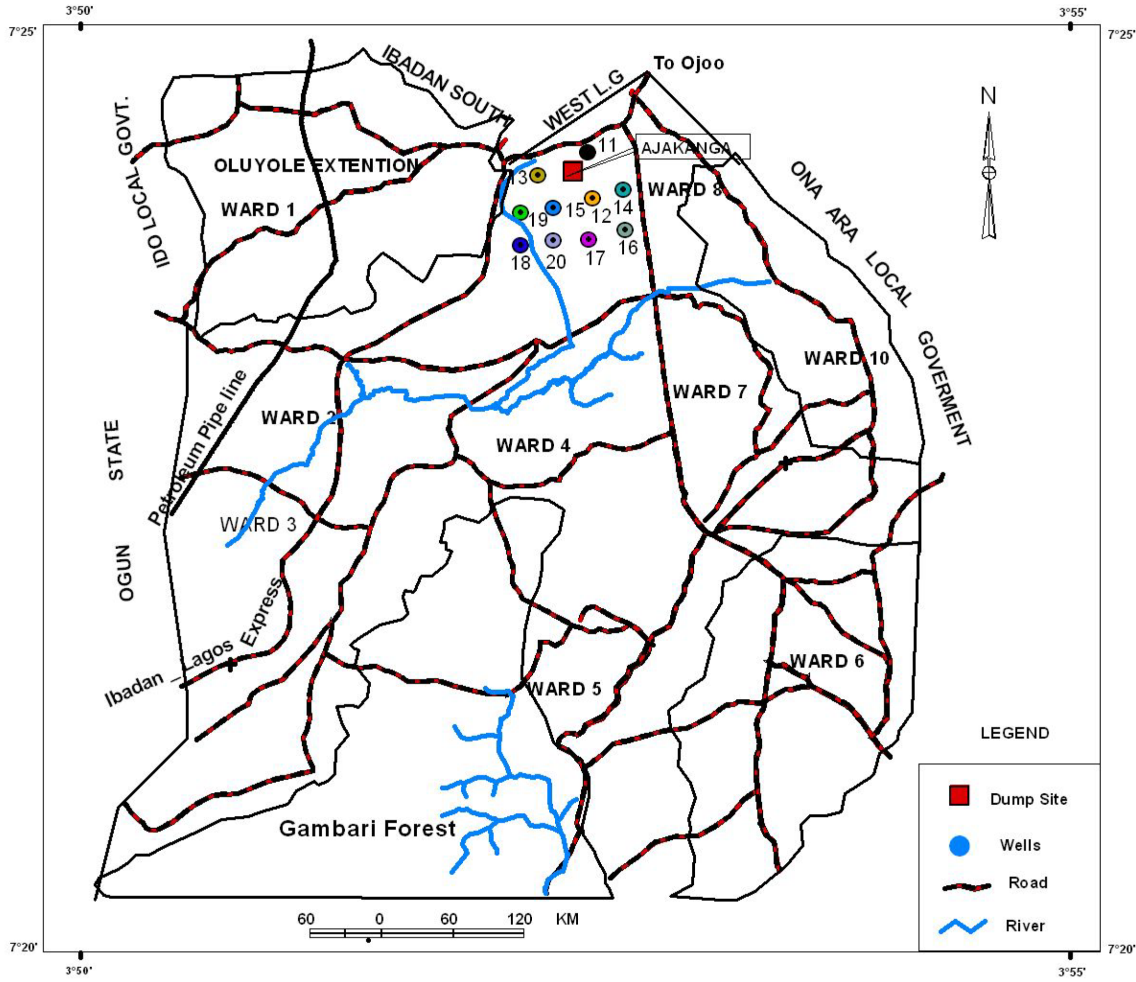

Fig. 4: Location of Ajakanga Dumpsite and Water sampling points

Groundwater Quality Index

The numerical value of GWQI reflects its suitability for drinking and domestic purpose. The higher the GWQI, the more polluted the groundwater. Three steps were followed to calculate GWQI. In the first step, 11 parameters in each sample were given a weight (wi) according to their respective importance in the overall water quality for drinking purpose (Srinivasamoorthy et al., 2008). Nitrate was assigned a maximum weight of 5 due to its major importance in water quality determination. The weight of other parameters varied from 2 to 5 depending on their significant importance in water quality determination. The relative weight of chemical parameters is shown in Table 3.

Table 3: Relative weight of Chemical Parameters

Chemical parameter	S_i	Weight (w*i*)	Relative weight (Wi)
pH	6.5 – 8.5	4	0.121
TH	150	2	0.061
Ca^{2+}	75	2	0.061
Mg^{2+}	50	2	0.061
Na^{+}	200	2	0.061
K^{+}	55	2	0.061
HCO_3^{-}	1000	3	0.091
Cl^{-}	250	3	0.091
TDS	500	4	0.121
NO_3^{-}	50	5	0.152
SO_4^{2-}	250	4	0.121
		$\sum wi = 33$	$\sum wi = 1.002$

In the second step, the relative weight Wi was calculated using the equation

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \quad (1)$$

where, "W*i*" is the relative weight, "w*i*" is the weight of each parameter and ''n'' is the number of parameters. Calculated "W*i*" of each parameter is presented in Table 3. The third step involved the calculation of quality rating scale (*qi*) for each parameter which is given by:

$$qi = \left(\frac{Ci}{Si}\right) \times 100 \quad (2)$$

where *Ci* is the concentration of each parameter in each water sample in mg/L and *Si* is the WHO/NSDWQ drinking water standard for each chemical parameter in mg/L. For pH, its quality rating is:

$$qi = \left(\frac{Ci-7.0}{Si-7.0}\right) \times 100 \quad (3)$$

In the case of remaining parameters, the ideal concentration value is zero.
For computing the GWQI, the sub index SI_i for *i*th parameters was first determined for each parameter, which was then used to determine the GWQI using the following equation:

$$SI_i = W_i q_i \quad (4)$$

and

$$GWQI = \sum_{i=1}^{n} SI_i \quad (5)$$

The GWQI value has been categorized into five types from "Excellent" to "Unsuitable for drinking" purpose according to Mishra and Patel (2001) as presented in Table 4

Table 4: Status and Index level of water Quality (Mishra & Patel, 2001)

Water quality status	GWQI level
Excellent	0 - 25
Good	26 – 50
Poor	51 – 75
Very poor	76 – 100
Unsuitable for drinking	> 100

Results and Discussion

The physicochemical parameters of groundwater samples for both dry and wet seasons collected around Aba-Eku and Ajakanga dumpsites are shown in Table 5, while the result of chemical analysis of the groundwater samples and their percentage compliance with the WHO and NSDWQ (2007) for both season are summarized in Tables 6 and 7, respectively.

Table 5: Physiochemical parameters during dry and wet season for Aba-Eku and Ajakanga water samples

Sample	pH		EC		TDS		Cl^-		HCO_3^-		CO_3^-		TH		Na^+		K^+		SO_4^{2-}		NO_3^-		Mg^{2+}		Ca^{2+}	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
S_1	7.2	7.0	207	244	103	122	25	19	170.8	414.8	84	204	74	170	17	13	2	1	19.56	27.10	1.9	0	7.71	5.95	2.97	1.62
S_2	7.1	6.9	381	511	190	254	68	41.5	170.8	195.2	84	96	78	320	30	26	1	1	15.65	12.10	1.6	0	5.59	15.63	0.79	2.80
S_3	6.7	6.5	227	253	113	130	20	13	219.6	195.2	108	96	84	222	15	12	1	2	14.19	10.65	1.6	0	9.32	11.93	2.02	6.27
S_4	6.8	6.7	240	315	120	156	25	19.5	219.6	244	108	120	90	266	15	15	1	1	13.39	12.42	1.4	0.4	7.05	10.67	1.73	9.40
S_5	6.7	6.9	784	539	392	268	106	120	366	390.4	180	192	288	446	40	24	5	4	144.03	75.32	2.8	0.2	14.78	26.24	5.87	15.09
S_6	6.9	7.1	231	233	115	116	25	16	170.8	219.6	84	108	08	154	18	16	1	1	15.00	15.32	1.5	0.2	2.69	5.08	0.94	5.58
S_7	7.3	6.8	176	237	88	118	25	17	146.4	195.2	72	96	26	132	13	17	0	1	14.19	24.52	2.8	3.3	0.43	4.18	0.12	2.22
S_8	7.6	6.9	245	255	122	126	17	10	195.2	268.4	96	132	98	208	12	13	1	1	26.94	10.32	4.0	0.3	4.15	5.88	3.93	11.33
S_9	6.9	6.8	263	229	131	113	26	15.5	219.6	195.2	108	96	116	216	12	12	1	1	42.42	22.26	1.9	0	12.31	11.28	4.17	7.53
S_{10}	7.1	6.5	148	202	74	100	19	16	122	146.4	60	72	60	174	8	11	1	1	26.13	21.77	4.8	1.2	4.36	8.87	0.59	3.47
S_{11}	7.1	7.0	598	465	299	237	96	52	414.8	317.2	204	156	180	432	30	22	2	1	26.45	25.49	1.8	0.1	13.88	18.02	24.01	20.76
S_{12}	7.1	7.3	420	425	210	214	24	33.5	195.2	366	96	180	276	404	17	18	5	3	14.36	16.45	2.2	0	13.61	23.32	18.26	22.63
S_{13}	7.4	6.9	367	377	184	185	24	13	292.8	414.8	144	204	178	350	13	17	1	1	19.68	7.58	1.5	0	12.69	20.07	8.12	14.27
S_{14}	7.8	7.3	275	259	138	128	54	10.5	585.6	268.4	288	132	100	234	16	17	4	6	38.71	15.32	2.7	0	10.35	5.89	5.38	23.05
S_{15}	7.4	7.1	176	205	88	101	16	10	219.6	219.6	108	108	46	180	18	11	2	1	57.74	18.23	10.2	2.9	1.12	3.29	0.41	9.66
S_{16}	7.2	6.7	530	411	264	205	113	52.5	170.8	219.6	84	108	200	260	18	24	6	1	127.74	27.74	11.9	3.2	12.97	14.69	7.28	4.51
S_{17}	7.2	6.9	299	191	150	95	32	16.5	366	122	180	60	96	116	16	14	4	1	88.07	24.68	16.0	3.0	5.03	5.32	1.32	2.01
S_{18}	7.6	7.0	225	242	112	121	28	15	122	170.8	60	84	70	206	15	16	2	1	45.81	14.20	5.1	0.9	5.68	5.42	2.19	8.43
S_{19}	7.3	7.2	273	251	137	125	26	13.5	268.4	219.6	132	108	118	210	12	15	3	2	21.77	14.20	5.8	3.9	11.63	9.64	9.02	10.88
S_{20}	6.9	7.2	568	705	284	351	39	40.5	536.8	610	264	300	406	190	19	24	2	2	29.19	52.26	3.4	2.6	14.23	49.34	49.18	173.42

Note All Parameters are in mg/L except pH and EC in $\mu S / cm$

Table 6: Comparison of groundwater quality parameters with drinking water standards for Aba-Eku (Dry and Wet Season)

Parameters	Range (Dry) Min	Range (Dry) Max	Per cent compliance	Range (Wet) Min	Range (Wet) Max	Per cent compliance	WHO & NSDWQ (2007)
pH	6.69	7.59	100	6.51	7.06	100	6.5 – 8.5
EC	148	784	100	202	539	100	1000
TDS	74	392	100	1000	268	100	500
Cl^-	17	106	100	10	120	100	250
HCO_3^-	122	366	100	146.4	414.8	100	1000
CO_3^-	60	180	90	72	204	70	120
TH	08	288	90	132	446	10	150
Na^+	08	40	100	11	26	100	200
K^+	0	5	100	1	4	100	55
NO_3^-	1.36	4.81	100	0	3.27	100	50
Ca^{2+}	0.12	5.87	100	1.62	15.09	100	75
Mg^{2+}	0.43	14.78	100	4.18	26.2	100	50
SO_4^{2-}	13.39	144.03	100	10.32	75.32	100	250

Table 7: Comparison of water quality parameters with drinking water standard for Ajakanga (Dry and Wet season)

Parameters	**Range (Dry) Min**	**Range (Dry) Max**	**Per cent compliance (Dry)**	**Range (Wet) Min**	**Range (Wet) Max**	**Per cent compliance (Wet)**	**WHO & NSDWQ (2007)**
pH	6.97	7.81	100	6.71	7.33	100	6.5 – 8.5
EC	176	598	100	191	705	100	1000
TDS	88	299	100	95	351	100	500
Cl^-	16	113	100	10	53	100	250
HCO_3^-	122	586	100	122	610	100	1000
CO_3^-	60	288	40	60	300	50	120
TH	46	406	50	116	432	10	150
Na^+	12	30	100	11	24	100	200
K^+	1	6	100	1	6	100	55
NO_3^-	1.54	15.9	100	3.90	0.00	100	50
Ca^{2+}	1.32	49.2	100	2.01	173.4	100	75
Mg^{2+}	1.12	14.23	100	3.29	49.34	100	50
SO_4^{2-}	14.36	127.74	100	7.58	52.26	100	250

The percentage compliance of CO_3^- increased from 40% in dry season to 50% in wet season. This may be due to dissolution of carbonate minerals into the aquifer system during raining season (S_{13} and S_{14}) or nearness to dumpsite ($S_{11}$and S_{12}). Also, sample 20 (S_{20}) was collected from hand-dug well situated in Farmland where animal management and farming activities are taking place. The percentage compliance of total hardness decreased from 50% in dry season to 10% in wet season. This may be due to more dissolution of carbonate and bicarbonate minerals into the aquifer system during raining season or may be due to action of carbon dioxide upon the basic materials of soil and granitic rock. The percentage compliance of CO_3^- reduced from 90% in dry season to 70% in wet season. This may be due to more dissolution of carbonate minerals into the aquifer system during raining season (S_1 and S_8) or nearness to dumpsite (S_5). The percentage compliance of total hardness decreased from 90% in dry season to 10% in wet season. This may be due to more dissolution of carbonate and bicarbonate minerals into the aquifer system during raining season or may be due to action of carbon dioxide upon the basic materials of soil and granitic rock.

Water Quality Around Aba-Eku Landfill

The average pH of analysed water samples during dry season sampling period ranged from 6.69 to 7.59 while it ranged 6.51 to 7.06 during wet season. The permissible limit for drinking water is between 6.5 and 8.5. The permissible total dissolved solids for drinking water is 500 mg/l. The analysis revealed that all TDS values lie within the limit of 500 mg/l in both dry and wet seasons. The average concentration of Total Hardness (TH) varies from 08 to 288 mg/l and from 132 to 446 mg/l during dry and wet seasons respectively. The hardness value for the water samples are found to be high for 90% of sampling locations during wet season compared to 10% during dry season. Based on Crittenden et al. (2005) classification for total hardness of Aba-Eku water samples, 20% of samples revealed “Soft” class, 60% revealed “Moderate” class while 10% revealed “Hard” while 10% belong to very ‘’hard’’ class during dry season. During wet season of samples collection in Aba-Eku area, none revealed “Soft” class of hardness, 10% showed “Hard” class while the remaining 90% revealed “Very hard” class.

The average concentration of chloride in the samples ranged from 17 to 106 mg/l and 10 to 120 mg/l during dry and wet seasons, respectively which lie within the permissible level. In Aba-Eku area, the Nitrate value ranged from 1.4 to 4.8 mg/l and 0 to 3.3 mg/l during dry and wet seasons, respectively. The nitrate value for the study area during both sampling periods was found to be within the limit of 50 mg/l specified by WHO (2007). It was observed that well 5 has higher concentration of most parameters than other wells. This may be attributed to proximity of well 5 to Aba-Eku dumpsite which is about 20 m to the landfill.

Water Quality Around Ajakanga Landfill

The pH values of water samples during dry and wet season sampling periods ranged from 6.97-7.81 and 6.71 – 7.33 respectively. The result did not vary significantly in both seasons. All pH values for the two seasons lie within the permissible limit. The TDS concentrations for both dry and wet seasons varied from 88 – 299 mg/l and 95-351 mg/l respectively. Seasonal changes were highest (299 mg/l) at S_{11} (90 m to the gate of Ajakanga landfill) during dry season and highest (351 mg/l) at S_{20} (well located within Garden Farm) in wet season. Dumping activities might have caused high value of TDS in well 11 while agricultural runoff and animal management practice might have caused high value in well 20. Well 20 is close to both poultry and piggery farms with attendant risk of animal waste flowing into the well. The observed values are within the permissible limit. Electrical Conductivity measures the amount of dissolved ions in a solution. EC value showed highest value of 598 mS/cm at well 11 in dry and 705 mS/cm at well 20 during wet season. All EC values in both season lie within the standard limit of WHO (2007) and NSDWQ (2007).

The average concentration of Total Hardness (TH) varies form 46 – 406 mg/l and 116 – 432 mg/l during dry and wet seasons, respectively. Highest value of TH (406 mg/l) was observed in well 20 during dry and 432 mg/l during wet season in well 11 which is about 90m to the landfill. Based on Crittenden et al. (2005) classification for total Hardness, 10% of water samples revealed "soft" class, 20% showed "hard" class, about 20% revealed "moderate" class while 50% revealed "very hard" (as shown in well 20) during dry season. During wet season sampling period, none of the samples revealed either "soft" or ''moderate'' class of hardness, 10% showed "Hard" class while remaining 90% revealed "very hard" class. In all the sampling locations in Ajakanga, TH was higher in wet season and lower in dry season due to dissolution of minerals by infiltration of groundwater into the aquifer system.

The chloride concentration of water samples during dry and wet seasons ranged from 16 – 113 mg/l and 10 – 53 mg/l, respectively. The observed values for chloride in both seasons were within the permissible limit. Nitrate concentration in groundwater and surface water is normally low. It ranged from 1.54 to 15.9 mg/l and 0 - 3.9 mg/l during dry and wet seasons respectively. The low concentration of nitrate value for the study area during both sampling periods were found to be within the limit of 50 mg/l specified by WHO (2007). Seasonal variations of bicarbonate in groundwater showed higher value of 586 mg/l at well 14 during dry season and 610 mg/l at well 20. The bicarbonate values for both seasons at all sampling locations lie within the specified standard limits. This may be due to dissolution of minerals from lithological composition, or the action of chemical fertilizers upon the basic materials of soil. Sodium concentrations in groundwater ranged from 12-30 mg/l and 11-24 mg/l during dry and wet seasons respectively. High value of 30mg/L was observed in well 11 during dry season while well 16 and 20 have highest value of 24 mg/l during wet season. There is no significant seasonal variation of potassium. The lowest and highest concentration values in both seasons were the same. The lowest (1 mg/l) concentration was found at well 13 in dry and highest (6 mg/l) for well 14 during wet season. The low concentration of K^+ in groundwater may be due to the fact that most potassium bearing minerals are resistant to decomposition by weathering process and fixation in the formation of clay minerals (Scheytt, 1997).

Calcium concentrations during both sampling periods ranged from 1.32 to 49.2 mg/l and 2.01 to 173.4 mg/l respectively. At most of the locations, calcium values were higher in wet than dry season. Highest values of 49.2 and 173.4 mg/l in both dry and wet seasons were observed in well 20. The magnesium concentration value ranged from 1.12 – 14.23 mg/l and 3.29 – 49.32 mg/l during dry and wet seasons respectively with well 20 having highest value in both seasons. The average concentration of calcium in all analysed water samples lie within the specified limit of WHO (2007) and NSDWQ (2007).

GWQI for Aba-Eku and Ajakanga Water Samples

The computed GWQI values of groundwater samples in Aba-Eku area varies from 7.39 to 37.77 and from 10.69 to 40.90 during dry and wet season, respectively. In Ajakanga area, GWQI values ranged from 16.79 to 38.43 and from 11.36 to 48.94 during dry and wet periods. The groundwater samples was categorized into five types. Tables 8 and 9 show the sub-indices, GWQI and class of different water quality for dry and wet seasons. In Aba-Eku sampling locations, it was observed that S_5 retains 'Good' water status during both seasons while for locations S_{11}, S_{12} and S_{20}, the water quality was "Good" in both dry and wet seasons. However in well 14, it was "Good" in dry season but "Excellent" in wet season. Similarly at S_{16}, the water quality was "Good" in dry season but "Excellent" in wet season. This may be due to improved hygiene practice, casing of concerned wells and use of water guards in wells 14 and 16 during the raining season.

Table 8: Calculation of sub-indices, GWQI and class for Aba-Eku (Dry and Wet seasons)

Samples code	$\sum qiwi$ **(Dry)**	**GWQI (Dry)**	**Class (Dry)**	$\sum qiwi$ **(Wet)**	**GWQI (Wet)**	**Class (Wet)**
S_1	12.8557	12.83	Excellent	17.1943	17.16	Excellent
S_2	15.4208	15.39	Excellent	25.3005	25.25	Good
S_3	9.8296	9.81	Excellent	13.6572	13.63	Excellent
S_4	10.7515	10.73	Excellent	18.3066	18.27	Excellent
S_5	37.8455	37.77	Good	40.9818	40.90	Good
S_6	7.4045	7.39	Excellent	15.6512	15.62	Excellent
S_7	10.1002	10.08	Excellent	16.7534	16.72	Excellent
S_8	17.9458	17.91	Excellent	16.1728	16.14	Excellent
S_9	15.3106	15.28	Excellent	15.9017	15.87	Excellent
S_{10}	10.1102	10.09	Excellent	10.7014	10.68	Excellent

Table 9: Calculation of sub-indices, GWQI and class for Ajakanga (Dry and Wet seasons)

Samples code	$\sum qiwi$ **(Dry)**	**GWQI (Dry)**	**Class (Dry)**	$\sum qiwi$ **(Wet)**	**GWQI (Wet)**	**Class (Wet)**
S_{11}	28.8976	28.84	Good	34.2383	34.17	Good
S_{12}	25.3907	25.34	Good	35.2504	35.18	Good
S_{13}	26.9658	22.92	Excellent	14.5390	14.51	Excellent
S_{14}	26.6231	26.57	Good	22.4949	22.45	Excellent
S_{15}	16.8236	16.79	Excellent	16.0420	16.01	Excellent
S_{16}	34.9598	34.89	Good	22.4548	22.41	Excellent
S_{17}	21.2424	21.20	Excellent	11.3827	11.36	Excellent
S_{18}	17.8556	17.82	Excellent	16.0921	16.06	Excellent
S_{19}	19.8696	19.83	Excellent	20.1602	20.12	Excellent
S_{20}	38.5068	38.43	Good	49.0378	48.94	Good

The retention of 'Good water' status of S_5, S_{11}, S_{12} and S_{20} may be due to percolation of leachate through various layers of soil, more dissolution of minerals from lithological composition and agricultural runoff leading to more leaching of ionic dissolved salts. Moreover, well 5 is nearer to the landfill than other hand-dug wells bordering Aba-Eku dumpsite while S_{20} was located inside a farm at about 120m to Ajakanga landfill. The degree of a linear association between any two of the analysed parameters measured by Pearson correlation coefficient for both dry and wet seasons sampling periods for both locations are presented in Tables 10 and 11. There is a very strong association between EC and TDS, HCO_3^- and CO_3^- during both seasons in the two study areas. The very strong association between EC and TDS buttressed the fact that EC depends largely on the quality of the dissolved salts present in the sample.

Table 10: Correlation coefficient of Aba-Eku and Ajakanga water samples parameters during dry season

	pH	EC	TDS	Cl	Bicarbonate	Hardness	Carbonate	SO4	NO3	Na	K	Mg	Ca
pH	1												
EC	-0.369	1											
TDS	-0.368	1.000(**)	1										
Cl	-0.213	0.813(**)	0.812(**)	1									
Bicarbonate	0.091	0.489(*)	0.492(*)	0.313	1								
Hardness	-0.277	0.817(**)	0.818(**)	0.424	0.538(*)	1							
Carbonate	0.091	0.489(*)	0.492(*)	0.313	1.000(**)	0.538(*)	1						
SO4	-0.118	0.564(**)	0.563(**)	0.662(**)	0.171	0.321	0.171	1					
NO3	0.225	-0.030	-0.030	0.114	0.011	-0.055	0.011	0.588(**)	1				
Na	-0.394	0.784(**)	0.783(**)	0.757(**)	0.305	0.392	0.305	0.459(*)	-0.130	1			
K	0.032	0.564(**)	0.564(**)	0.577(**)	0.320	0.502(*)	0.320	0.714(**)	0.477(*)	0.340	1		
Mg	-0.271	0.743(**)	0.743(**)	0.511(*)	0.509(*)	0.803(**)	0.509(*)	0.271	-0.200	0.343	0.523(*)	1	
Ca	-0.154	0.573(**)	0.574(**)	0.204	0.593(**)	0.831(**)	0.593(**)	-0.071	-0.138	0.193	0.174	0.603(**)	1

Table 11: Correlation coefficient of Aba-Eku and Ajakanga water samples parameters during wet season

	pH	EC	TDS	Cl	CO3	HCO3	Hardness	SO4	NO3	Na	K	Mg	Ca
pH	1												
EC	.222	1											
TDS	.221	1.000(**)	1										
Cl	-.027	.688(**)	.690(**)	1									
CO3	.439	.723(**)	.720(**)	.365	1								
HCO3	.439	.723(**)	.720(**)	.365	1.000(**)	1							
Hardness	.174	.607(**)	.613(**)	.670(**)	.372	.372	1						
SO4	.016	.576(**)	.574(**)	.826(**)	.499(*)	.499(*)	.262	1					
NO3	.001	-.084	-.087	-.099	-.162	-.162	-.477(*)	.137	1				
Na	.117	.635(**)	.637(**)	.717(**)	.144	.144	.666(**)	.320	-.102	1			
K	.445(*)	.206	.205	.300	.261	.261	.314	.308	-.205	.197	1		
Mg	.207	.914(**)	.913(**)	.536(*)	.797(**)	.797(**)	.458(*)	.586(**)	-.021	.323	.209	1	
Ca	.335	.681(**)	.678(**)	.159	.738(**)	.738(**)	-.009	.446(*)	.186	-.033	.179	.830(**)	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Conclusions

An assessment of the groundwater quality index (GWQI) was carried out in two study areas bordering two landfill sites using twenty hand-dug wells around Aba-Eku and Ajakanga dumpsites. All the samples GWQI values lie below 100. Ninety per cent of samples in Aba-Eku area lie within "Excellent" status during dry season while it reduced to 80% during wet season. However, 50% of water samples revealed "Excellent" status during dry season and increased to 70% during wet season. The highest values of GWQI during both seasons were observed at wells 5 and 20 situated at about 20m and 120m to the dumping sites. The high values of GWQI for wells 5 and 20 have been found to be mainly due to higher values of TH, HCO_3^-, Mg^{2+}, Cl^-, TDS and SO_4^{2-}. Electrical conductivity (EC) showed very strong associations with TDS, an indication that EC depends largely on quality of total dissolved salts. The results so far revealed that groundwater within the study areas can be categorized as "Excellent" and "Good" and thus safe for human consumption. Periodic assessment of GWOI of water samples around these two dumpsites should be encourage as this will provide an overall scenario about the actual sources of groundwater contamination. This will provide an avenue for proper planning to preserve fragile ecosystem.

References

APHA (1998). American Public Health Association, standard methods for examination of waters and waste matters, 20th Edition, Washington, DC, USA.

Akintola, J.O. (1986). Rainfall distribution in Nigeria, 1892-1983. Ibadan, Impact publishers, 380pp.

Armah, F.A., Luginaah, I. and Ason, B. (2012). Water Quality Index in the Tarkwa Gold Mining Area in Ghana. Journal of Transdisciplinary Env. Studies 11(2):1-15.

Crittenden, J.C., R. Trussell, D.W. Hand, K.J. Howe and G. Tchobanoglous, (2005): Water Treatment: Principles and Design. 2nd Edition, Hoboken, NJ, John Wiley.

Horton, R.K. (1965. An Index number system for rating water quality. J. Water Pollution Control Federation, 3: 300-305.

Mishra, P.C. and Patel, K. (2001. Study of the pollution load in the drinking water of Rairangpur, a small tribal dominated town of North Orissa. India Jour. Environment and Ecoplanning, 5(2): 283-298.

NSDWQ (2007. Nigerian Standard for drinking water quality. NIS 554. Standard Organization of Nigeria, Lagos.

Okunlola, O. A. Adeigbe, O. C. and Oluwatoke, O. O. (2009. Compositional and Petrogenetic features of schitose rocks of Ibadan area, Southwestern Nigeria. Earth Science Res. Journal, 13(2): 29 -43.

Ramakrishnaiah, C.R. Sadashivaiah, C. And Ranganna, G. (2009. Assessment of water quality Index for groundwater in Tunikur Taluk, Karnataka State. India. E-J. Chem. 6(2): 523-530.

Rao, G.S. and Nageswararao, G. (2013. Assessment of Groundwater Quality using water Quality Index. Arch. Environ. Sci, 7, pg 1-15.

Rao, S.N. (2006. Season variation of groundwater Quality in a part of Guntur District Andhra Pradesh, India. Env. Geology, 49: 413-429.

Rizwan, R. and Gurdeep, S. (2010. Assessment of Groundwater Quality status by using water Quality Index method in Orissa India. World Applied Sciences Journal. 9(12): 1392 – 1397.

Sabahi, E. A. I., Rahim, S. A., Zuhairi, N. Y. W., Nozaily, F. A. I. and Alshaebi, F. (2009. The characteristics of leachate and groundwater pollution at municipal solid waste landfill at Ibb City, Yewen. American Journal of Env. Sciences 5(3), 256-266.

Saeedi, M., Abessi, O. Sharifi, F. (2010. Development of groundwater quality Index. Environmental monitoring and Assessment 142, 263-268.

Sawyer, G.N and McCarthy, D.L. (1967. Chemistry of Sanitary Engineers, 2nd Ed., McGraw Hill, New York, p518.

Sayed, R.A. and Gupta, G.S. (2013. Groundwater quality evaluation in Beed City, Maharashtra, India. Africa Journal of Biotechnology, 12(51): 7081-7085.

Shankar, S. B, Sanjeeu, L. (2008. Assessment of Water Quality Index for the groundwater of an industrial area in Bangalore. India Envi. Engineering Science, 25(6): 911-915.

Srinivasamoorthy, K.., Chidambaram, M., Prasanna, M., Vasanthavigar, V. John Peter, M. and Anandhan, P. (2008. Identification of major sources controlling groundwater chemistry from a hard rock terrain- A case study from Mettur Taluk, Salem district, Tamilnadu, India. Journal of Earth system sciences, 117(1): 49-58.

Srinivas, J, Purushothan, A.V. and Murali Krishna, K.V.S.G. (2013. Determination of water Quality Index in Industrial area of Kakinada, Andhra Pradesh, India. Int. Research. Journal of Environmental Sciences, 2(5): 37-45.

WHO (2007. Water for pharmaceutical Use in Quality Assurance of Pharmaceuticals. A compendium of Guidelines and Related materials 2nd updated edition, World Health Organization. Geneva 2. 170-187.