Application of Discriminant Analysis to the Assessment of Seasonal Variability of Groundwater Quality around Municipal Waste Dumpsites within Lagos Metropolis

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ABSTRACT
This study assessed the seasonal variability of groundwater quality in the vicinities of Abule-Egba Dumpsite, and the Solous Dumpsites in the Igando area of Lagos, using Discriminant Analysis. This was with the aim of determining the relative contribution of each hydrochemical parameter to the seasonal variation in groundwater quality around the dumpsites. A total of 60 water samples were collected in the vicinities of the dumpsites for the wet and dry seasons and analysed for relevant physico-chemical and heavy metals parameters, using standard analytical methods. The results of the Discriminant Analysis showed that the seasonal variation in groundwater quality around the dumpsites is statistically significant. In the vicinity of the Abule-Egba dumpsite Zn^{2+}, Fe^{2+}, and pH accounted for most of the variation in the wet and dry season groundwater quality while Zn^{2+}, pH and TDS contributed most to the seasonal variation in groundwater quality around the Solous Dumpsites.

Keywords: Dumpsites, Groundwater Quality, Discriminant Analysis, Seasonal variation, Discriminant Function Equation

INTRODUCTION

One of the most prominent waste disposal approaches in major cities of Nigeria is the open dump approach. As an improvement over the open dump approach, the Lagos State Government through the Lagos Waste Management Authority owns and manages major municipal waste dumpsites within the Lagos metropolis. These dumpsites popularly referred to as landfills, qualify more as 'operated or semi-controlled dumps. According to Johannessen and Boyer (1999), this is the first stage in a country's efforts to upgrade landfills. They observed that controlled dumps operate with some form of inspection and recording of incoming wastes, practice extensive compaction of waste, and control the tipping front, and the application of soil cover. In addition, operated dumps still release unmanaged contaminants and do not take into account environmental cautionary measures such as leachate and landfill gas management. Due to the unmanaged contaminant release at the various municipal dumpsites in Lagos, the underlying aquifers and the groundwater resources are still vulnerable to contamination from the leachate generated at these dumpsites. Matias et al, as cited by Bahaa-eldin (2009) noted that waste disposal sites can seriously affect local wells and boreholes used for public water supply. Their locations, therefore, must be planned and they must be monitored carefully.

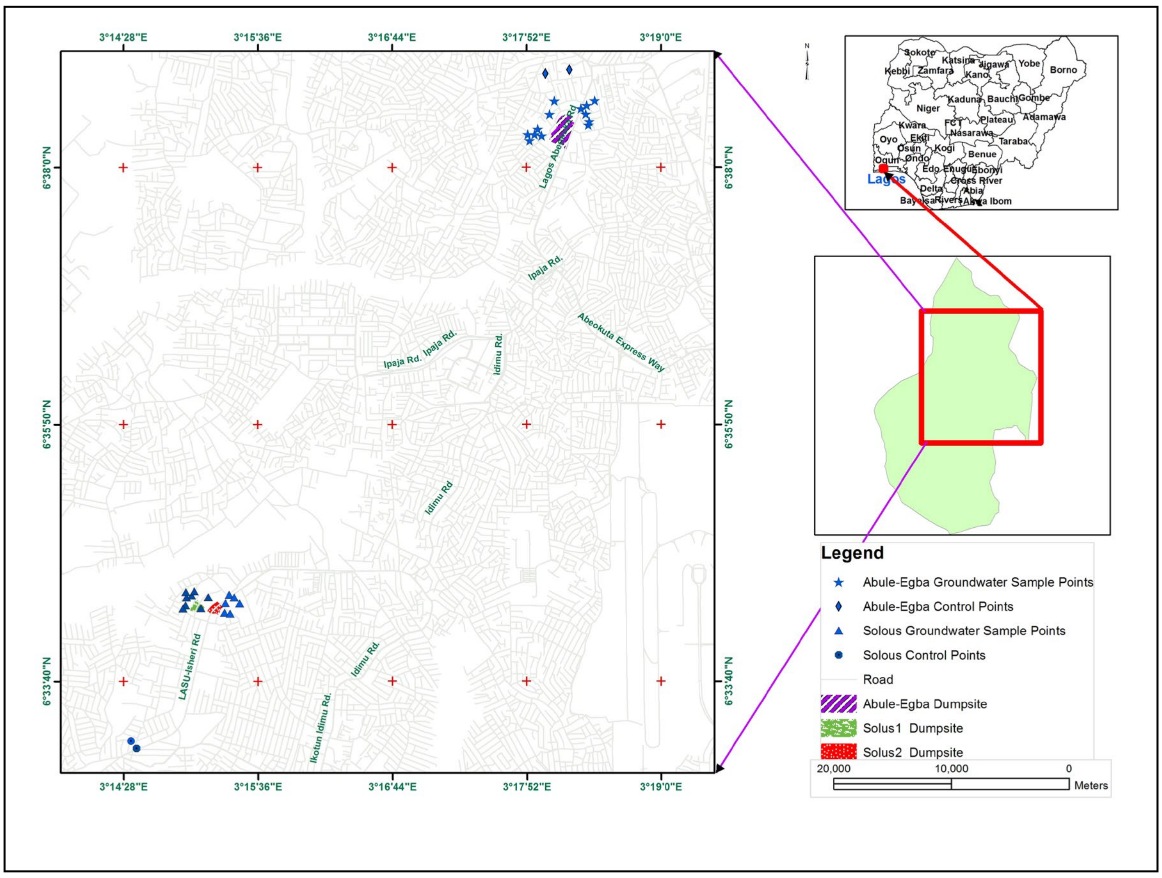
At Abule-Egba and the Solous areas of Igando where some of these municipal waste dumpsites are located, hand-dug wells and boreholes constitute the main source of water supply to the residents. These wells and boreholes are however vulnerable to leachate contamination due to the absence of environmental safeguard measures such as leachate collection pond and synthetic or compacted clay liners at the dumpsites. Furthermore, most of the wells and boreholes are sited without considering their locations relative to dumpsites and the groundwater flow pattern. The risk of consuming unwholesome and contaminated groundwater is further increased due to the fact that most of the residents of the dumpsites environs do not apply any form of treatment to the water before consumption.

The health risk that the consumption of contaminated groundwater portends for the people residing around the dumpsites undermines the need for an adequate knowledge of the groundwater quality in these areas. In the same vein, adequate knowledge of the variability that changes in season could impose on the quality of groundwater around the dumpsites is necessary, especially in the light of increased leaching (from waste deposited) and formation of leachate at the dumpsites, and the increased mobility of contaminants in groundwater during the wet season. Similarly, proper monitoring and management of groundwater quality around the dumpsites can only be instituted with a detailed knowledge of the quality of groundwater over space and time.

MATERIALS AND METHODS

Study Area

The study area (Fig 1) is the Oke-Odo area of Abule-Egba, and the Solous area of Igando, both of which are located in Alimosho Local Government Area, in the north-western part of Lagos State. Alimosho is located approximately between longitudes 3^0 13´ E and 3^0 17´E and, latitudes 6^0 28´N and 6^0 42´N. The mean elevation around Oke-Odo, Abule-Egba is approximately 40m, while the mean elevation around the Solous in Igando is approximately 28m. Soils within the study areas are predominantly clay with the subsurface geology made up of lateritic cover of variable thickness. The climate is characteristically tropical, with an annual rainfall of about 1,800mm, a relative humidity of approximately 80% with minimum and maximum temperature ranges of 24-26^{0}C and 28-33^{0}C, respectively.



Field Sampling

A total of 60 groundwater samples from 30 wells and boreholes were collected in the vicinities of the dumpsites during the wet and dry seasons. The 60 groundwater samples were collected in order to ensure good spatial representation. A total of 4 control points (2 for Abule-Egba Dumpsite and 2 for the Solous Dumpsites) were selected. The control points for the Abule-Egba Dumpsite are located 620.84m and 636.02m away from the dumpsite, while the control points for the Solous Dumpsites are located 2.33km and 2.54km away from the dumpsites. Field sampling for the wet season was done in November, 2010, while the dry season sampling was done in March 2011. The choice of sample locations including the control points were guided by the groundwater flow direction.

Water samples were collected in 1 litre polyethylene bottles which had been washed in detergent and rinsed with de-ionised water prior to sample collection. Sample bottles were also rinsed thrice with water from the sample wells and boreholes before the collection of water samples at each location. Each bottle was appropriately labelled, and the preserved samples were transported in ice to the Laboratory of the Department of Chemistry, University of Lagos, where the samples were analysed in less than a week.

Analytical Methods

The pH and TDS of the groundwater samples were determined in-situ using Hanna Combo pH and EC meter, and HM Digital EC/TDS/Temp meter respectively. NO_3^-, Cl^-, Zn^{2+}, and Fe^{2+} were analysed in accordance with American Public Health Association Standardised Method for the Examination of Water and Wastewater (APHA 1992) using Spectronic 20d+ for the determination of NO_3^-, Silver Nitrate titration with Potassium Chromate as an indicator for Cl^-, and 200 Perkin Elmer for the determination of Zn^{2+}, and Fe^{2+}.

A number of reasons are responsible for the choice of hydrochemical parameters analysed. For instance the pH of the groundwater was measured because pH gives an insight into the total chemical composition of water. According to Sundaram et al (2009), the amount and chemical form of many organic and inorganic substances dissolved in groundwater, the suitability of groundwater for various purposes, as well as its ability to transport potentially harmful chemicals are controlled by pH. TDS was analysed because a high level of TDS in groundwater around a dumpsite may be indication of the leaching of various contaminants from the dumpsite into the groundwater (Mor et al, 2006), while Cl^- was analysed because it is a good indicator and tracer of the extent of leachate dispersion in groundwater.

The concentration of NO_3^- in the groundwater was measured because leachate contamination could increase the NO_3^- level in groundwater. According to Enekwechi and Longe (2007), the background concentration of NO_3^- in groundwater may be increased due to contamination from municipal wastewaters such as leachate generated from dumpsites and sanitary landfills. Zn^{2+} and Fe^{2+} were analysed in the groundwater because they constitute some of the trace metals that are commonly found in landfill leachate. The combined effect of these parameters significantly impairs groundwater quality and makes it particularly injurious to health.

Discriminant Analysis

Discriminant analysis was used to investigate the seasonal variation in groundwater quality around the Abule-Egba Dumpsite in Oke-Odo, Abule-Egba, and the Solous 1 and 2 Dumpsites at Igando. Discriminant analysis is a multivariate statistical technique used to ‘investigate differences between groups on the basis of the attributes of the cases, indicating which attributes contribute most to group separation’ (Burns & Burns 2008). In water quality assessment, Discriminant analysis can be used to extract pertinent information about the similarities and differences in water quality parameters responsible for the observable variation in water quality over space and time (Zhou, Liu and Guo 2006). The Discriminant analysis of the data was undertaken by adopting Fisher’s Linear Discriminant Function technique with the aid of the Statistical Package for the Social Sciences, version 17 (SPSS Inc, 2008).

RESULTS AND DISCUSSION

Table 1 shows the statistical summary of the analysed hydrochemical parameters for the wet and dry seasons at Abule-Egba Dumpsite vicinity while Table 2 is the statistical summary of the hydrochemical parameters at Solous Dumpsites vicinity for both seasons. The results of the Discriminant Analysis for groundwater quality in the vicinity of Abule-Egba Dumpsite are shown in Tables 3 to 5, while the result of the Discriminant Analysis for groundwater quality around the Solous Dumpsites are shown in Tables 6 to 8.

Table 1: Statistical Summary of Groundwater Quality Parameters in the Abule-Egba Dumpsite Environs

Parameter	Season													
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
	Range		Minimum		Maximum		Mean		Standard Error		Standard Deviation		Variance	
pH	0.6	1.11	4.93	4.55	5.53	5.66	5.12	4.95	0.39	0.71	0.15	0.28	0.02	0.08
TDS	430.1	237	19.9	18	450	255	98.37	75.64	27.8	17.32	107.68	67.09	11595.51	4500.7
NO_3^-	2.38	25.13	0.12	0.07	2.5	25.20	0.88	2.80	0.16	1.67	0.65	6.45	0.42	41.63
Cl^-	50	132	20	16	70	148	38.27	35.47	2.98	8.68	11.56	33.6	133.64	1128.84
Zn^{2+}	4.05	2.09	0.07	0.11	4.12	2.20	1.75	0.59	0.27	0.20	1.05	0.79	1.11	0.62
Fe^{2+}	1.12	0.71	0.09	0.11	1.21	0.82	0.58	0.39	0.89	0.05	0.34	0.19	0.12	0.04

Table 2: Statistical Summary of Groundwater Quality Parameters in the Solous Dumpsites Environs

Parameter	Season													
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
	Range		Minimum		Maximum		Mean		Standard Error		Standard Deviation		Variance	
pH	1.22	2.58	6.33	5.33	7.55	7.91	6.8	6.48	0.97	0.23	0.37	0.89	0.14	0.81
TDS	475	369.2	13	12.8	488	382	117.46	122.27	34.05	28.81	131.88	111.59	1739	12453.14
NO_3^-	9.04	86.36	0.05	0.04	9.09	86.4	2.67	15.12	0.77	5.97	2.99	23.11	8.96	533.94
Cl^-	440	532	30	16	470	548	121.27	161.33	36.18	44.28	140.12	171.49	19632.92	29411.81
Zn^{2+}	9.20	0.22	1.10	0.17	10.3	0.39	3.43	0.28	0.72	0.19	2.73	0.75	7.48	0.006
Fe^{2+}	2.15	0.60	0.05	0.12	2.2	0.72	0.71	0.35	0.14	0.49	0.55	0.19	0.29	0.04

Seasonal Variability of Groundwater

Abule-Egba Dumpsite Vicinity

The pH of groundwater around Abule-Egba Dumpsite is acidic, varying between 4.93 and 5.53 in the wet season, and between 4.55 and 5.66 in the dry season. TDS levels of groundwater ranged between 19.90 and 450mg/L in the wet season and between 18 and 255mg/L in the dry season. On the basis of Fetter (2001) classification of water type based on TDS level, the groundwater can be classified as belonging to the freshwater class.

The concentration of NO_3^- for the wet and the dry season varied between 0.12 and 2.50mg/L, and between 0.07 and 25.20mg/L, respectively, while the concentration of Cl^- ranged between 20 and 70mg/L in the wet season and between 16 and 148mg/L in the dry season. Fe^{2+} in the groundwater varied between 0.90 and 1.21mg/L in the wet, and between 0.11 and 0.82mg/L in the dry season. For the wet season, 87 percent of the groundwater samples had concentration greater than the World Health Organisation (WHO) stipulated standard of 0.3mg/L, while 60 percent of the samples had concentrations greater than 0.3mg/L in the dry season. High concentration of Fe^{2+} in groundwater is a common phenomenon. According to the Lagos State Ministry of Environment and Physical Planning (2002), past studies on groundwater quality within the state have revealed that the three aquifers from which groundwater is mainly abstracted within the state have high levels of Fe^{2+} concentration. Zn^{2+} concentration in the vicinity of the dumpsite varied between 0.07 and 4.12mg/L in the wet season and between 0.11 and 2.20mg/L in the dry season. The minimum, maximum and mean values of the hydrochemical parameters for the wet and dry seasons are as presented in Figure 1.

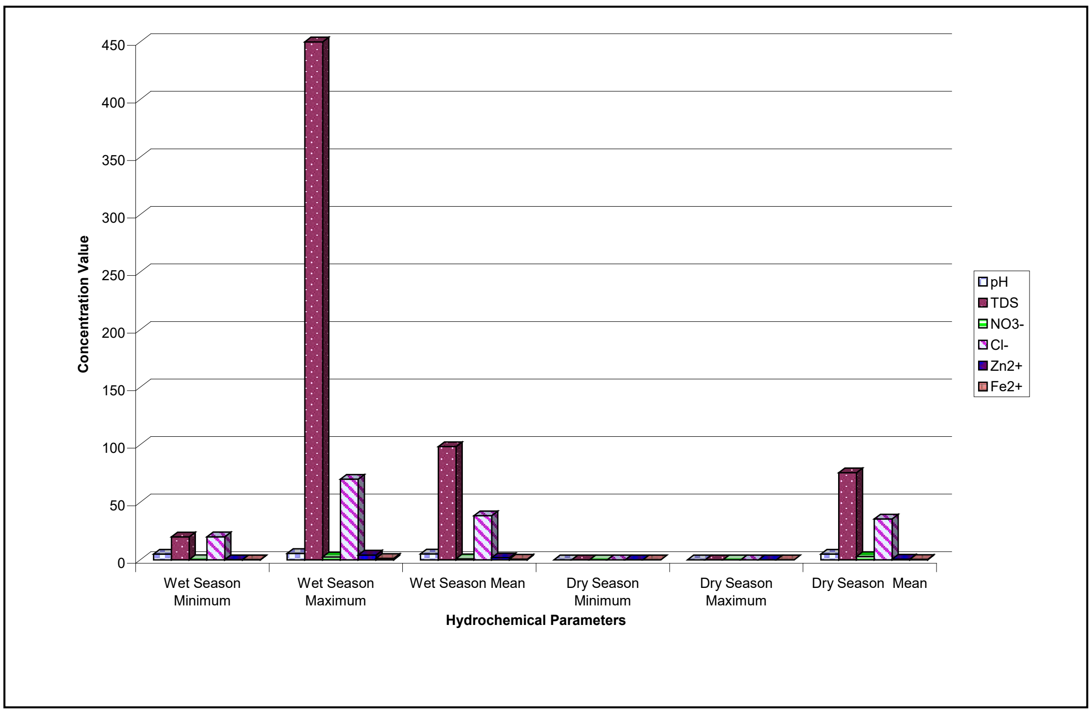


Fig 1: Minimum and Maximum Concentration of Groundwater Quality Parameters at Abule-Egba Dumpsite Vicinity for the Wet and Dry Season

Solous Dumpsites Vicinity

Groundwater pH in the Solous Dumpsites environs varied between 6.33 and 7.55 in the wet season and between 5.33 and 7.91 in the dry season. The measured TDS levels in the groundwater varied between 13 and 488 mg/L in the wet season and between 12.80 and 382mg/L in the dry season. NO_3^- concentration varied between 0.05 and 9.09 mg/L in the wet season and between 0.04 and 86.40 mg/L in the dry season. The concentration of Cl^- ranged between 30 and 470 mg/L in the wet season and between 16 and 548mg/L in the dry season. For the trace metals, the concentration of L Fe^{2+}varied between 0.05 and 2.20mg/L, and between 0.12 and 0.72 mg/L for the wet and the dry season respectively, while for Zn^{2+} the measured concentration was between 1.10 and 10.30 mg/L during the wet season and between 0.17 and 0.39 mg/L for the dry season. The minimum, maximum and mean concentration of the measured groundwater quality parameters around the Dumpsite is as presented in Figure 2.

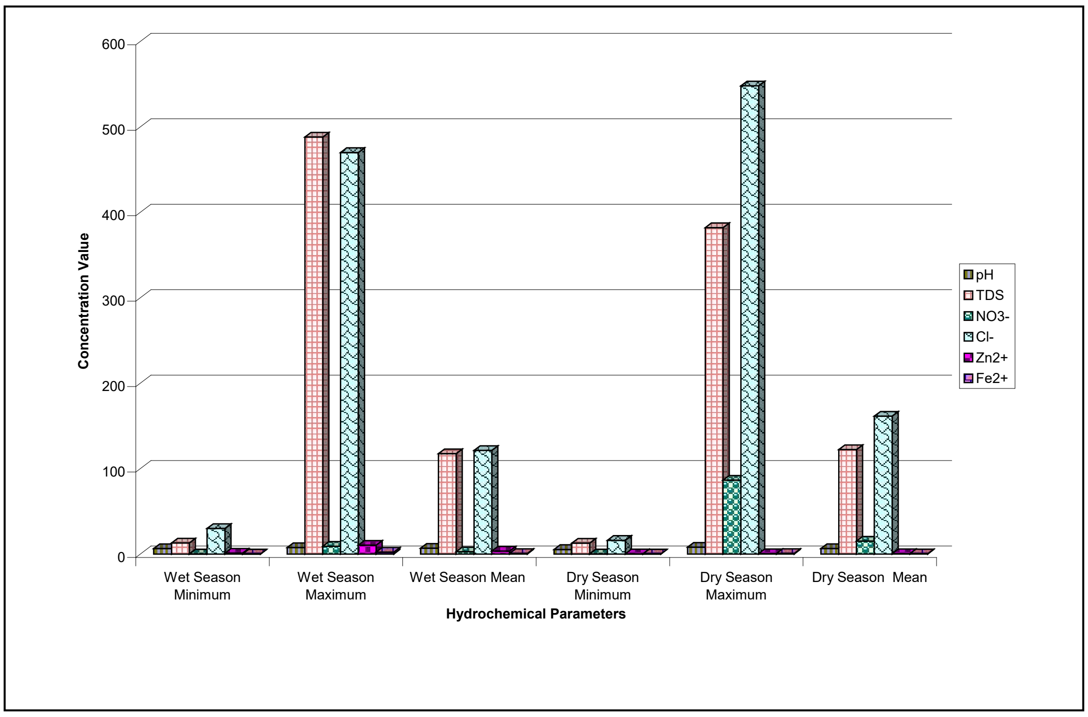


Fig 2: Minimum and Maximum Concentration of Groundwater Quality Parameters at Solous Dumpsites Vicinity for the Wet and Dry Season

Discriminant Analysis of Groundwater Quality for the Wet and Dry Season Abule-Egba

The result of the Discriminant Analysis as shown in Table 3 reveals that only one Discriminant Function (the number of groups minus 1) was found to discriminate between the groundwater quality during the wet and dry seasons. Furthermore, 100% of the total variance between the two seasons was explained by the single Discriminant function. The canonical correlation statistic of 0.650 (Table 3) indicates that the model explains 42.25% (of squared canonical correlation) of the variation between the wet and dry seasons groundwater quality. This value indicates a low degree of inter-seasonal variation for the constituents of groundwater in the vicinity of the dumpsite. As suggested by the Wilks' Lambda statistic of 0.577 (Table 4), the group means of the groundwater quality parameters for both seasons around the dumpsites are statistically significant ($p = 0.333$), and therefore differ. In terms of the relative contribution of each parameter to the seasonal variation in the groundwater quality around the dumpsite, Zn^{2+}, Fe^{2+} and pH are the greatest contributors as shown in Table 5. The relative contribution of all the groundwater quality parameters to seasonal variation around the dumpsite is given by the discriminant function equation as:

$$Z = 0.883pH + 0.004TDS - 0.057NO_3^- - 0.004Cl^- + 0.814Zn^{2+} + 1.890Fe^{2+} \quad (1)$$

This suggests that the relative contribution of each parameter in determining the groundwater quality in the vicinity of the dumpsite as a function of season is of the order:

Fe^{2+}> pH> Zn^{2+}> TDS> Cl^->NO_3^-, respectively.

Based on the relative contribution of the hydrochemical parameters to the inter-seasonal variation in groundwater quality as well as its implication for groundwater resources management around the dumpsite, there is a need for iron (Fe^{2+}) to be given priority attention especially in the wet season. This is due to increased leaching and transportation of the Fe^{2+} constituent of some of the waste deposited at the dumpsite into the groundwater, and secondly due to the dissolution of the Fe minerals present in the mostly lateritic and clay soil of the dumpsite environs into the groundwater.

Table 3: Eigen-Value of Discriminant Function for the Vicinity of Abule-Egba Dumpsite for the Wet and Dry Seasons

Function	Eigen-Value	% Variance	Cumulative %	Canonical Correlation
1	0.732	100	100	0.650

Table 4: Wilks' Lambda Test of Discriminant Function for the Seasonal Variation in Groundwater Quality around Abule-Egba Dumpsite

Test of Function	Wilks'Lambda	Chi-Square	df	P level
1	0.577	13.729	6	0.033

Table 5: Canonical Discriminant Function Coefficients of Seasonal Variation in Groundwater Quality around Abule-Egba Dumpsite

Parameter	Function
pH	0.833
TDS	0.004
NO_3^-	-0.057
Cl^-	-0.004
Zn^{2+}	0.814
Fe^{2+}	1.890

Solous 1 and 2 Dumpsites

Table 4 shows that only one discriminant function accounted for the seasonal variation of groundwater quality around Solous 1 and Solous 2 Dumpsites in Igando. The single Discriminant function explains 100% variance between the wet and dry seasons. As can be inferred from the canonical correlation statistic of 0.749 (Table 6), 56.10% (% of squared canonical correlation) of the inter-seasonal variation in groundwater quality is explained by the model. The group means of the groundwater quality parameters are statistically significant as indicated by the Wilks' Lambda statistic of 0.439 at $p = 0.002$ in Table 7.

Table 6: Eigen-Value of Discriminant Function for the Vicinity of Solous 1 and Solous 2 Dumpsites for the Wet and Dry Seasons

Function	Eigen-Value	% Variance	Cumulative %	Canonical Correlation
1	1.280	100	100	0.749

The relative contribution of the groundwater quality parameters (Table 8) to the seasonal variation in groundwater quality around the dumpsites as expressed by the Discriminant function whose equation is:

$$Z = 0.396pH + 0.001TDS - 0.019NO_3^- - 0.004Cl^- + 0.560Zn^{2+} - 0.250Fe^{2+} \qquad (2)$$

This results in a relative contribution to the seasonal variation in groundwater quality in the order of:

$Zn^{2+} > pH > TDS > Cl^- > NO_3^- > Fe^{2+}$

The higher relative contribution of Zinc to the seasonal variation in groundwater quality around the dumpsite is traceable to its higher concentration during the wet season. The implication of this for groundwater resources management around the dumpsite is that treatment of groundwater for elevated concentration of Zinc may be needed at some of the locations with high concentrations in order to ensure conformity to drinking water quality standards.

Table 7: Wilks' Lambda Test of Discriminant Function for the Seasonal Variation in Groundwater Quality around Solous 1 and Solous 2 Dumpsites

Test of Function	Wilks'Lambda	Chi-Square	df	P level
1	0.439	20.605	6	0.002

Table 8: Canonical Discriminant Function Coefficients of Seasonal Variation in Groundwater Quality around Solous 1 and Solous 2 Dumpsites

Parameter	Function
pH	0.396
TDS	0.001
NO_3^-	-0.019
Cl^-	-0.004
Zn^{2+}	0.560
Fe^{2+}	-0.250

CONCLUSION

With regards to dumpsites as point sources of groundwater contamination, the potential exists for the continued leaching of contaminants from waste deposited at the dumpsites to reach concentrations that may impair the quality of the groundwater beyond acceptable standards. As a consequence, further purification of the groundwater may be required before consumption because the concentration of some of the hydrochemical parameters exceeds the WHO standard for drinking water quality. In the light of what this portends for groundwater quality around the dumpsites, Discriminant analysis has proved to be a useful tool in identifying the contaminants that play major roles in the observed variation of groundwater quality around the dumpsites. Furthermore, Discriminant analysis has also revealed that the seasonal variation in groundwater quality is significant, with Iron and Zinc being responsible for most of the variation at Abule-Egba and Solous Dumpsites vicinities, respectively.

In order to ameliorate the impact of these dumpsites on groundwater quality, environmental safeguard measures such as the construction of upstream diversion channels and leachate collection facilities should be incorporated as part of the groundwater management measures. This is not only to minimise the volume of leachate generated at the dumpsites, but also to reduce the volume that may potentially percolate into the groundwater especially during the wet season. In recognition of the fact that some of the water quality parameters exceeded stipulated drinking water quality standards, existing laws on discharge and disposal of waste should be properly implemented in order to mitigate some of the impacts of the dumpsites on groundwater quality.

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Cost Optimization Model for Effective Solid Waste Management in Minna, Niger State, Nigeria

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ABSTRACT

This study examines the application of a cost-optimizing mode for effective solid waste management in Minna, Niger State, in view of the limited funds at the disposal of the State Environmental Protection Agency charged with solid waste management in the state. For this purpose, the town was divided into six zones and waste collection within the zones was monitored for six weeks. A linear programming model was developed to optimize collection of solid waste from the zones to two disposal sites, one existing and one proposed. The basic input data are distances between sources and sink nodes, amount of waste generated, haul cost, equipment, operating and investment cost. The model was solved using Tutorial aid Optimization package software (TORA), a minimum objective value of N128,267.97 was obtained after 24 iterations. When tested with the existing disposal systems, a minimum value of N135,549.67 was obtained after 15 iterations. A total of N7,271.70 will be saved daily and N2,657,820.50 annually, if two disposal sites are used as proposed in the model. It is recommended that the model be adopted to minimize cost of waste disposal system in Minna.

Keywords: Optimization, Cost, Management, Effective, Solid waste, Model, Nigeria

INTRODUCTION

Management of solid waste has always been a huge problem for the managers. Indiscriminate disposal and dumping of waste has become a common practice in Nigerian. Solid waste may be defined as the organic and inorganic waste materials, produced by human and animal activities which have lost their value in the eyes of the owner (Ogwueleka, 2003). Solid wastes vary throughout the world because both the quantity and the constituents are determined by social customs and living standards. As a society becomes industrialized, the traditional domestic solid wastes are increased by industrial, commercial and agricultural wastes, each of which adds a new potential for nuisance (Fabbbricino, 2001) and sometimes a new threat to the health and welfare of human beings. The management of solid waste is intrinsically complex because it involves various connected problems and must achieve objectives which are often in conflict. In 1985, the Federal Government of Nigeria introduced a major initiative, the Environmental Sanitation Clean-up Campaign, whereby all residents are mandated to carry out compulsory clean up every last Saturday of the month. The initiative was good, but generated more problems as wastes from the exercise were dumped along roadsides instead of dumpsites designated for that purpose (Abel and Afolabi, 2007). The state of management of waste in most developing countries needs considerable improvement. Waste treatment plants can only be correctly planned when the amount of waste is known which is possible through a complete refuse collection system. The low level of financing for the agencies responsible for handling wastes in Nigeria has to a large extent affected performance. Very small amounts of revenue are realized directly from their services, as only a very limited fraction of the population is served by the house to house collection systems.

Minna is the capital of Niger State in the North-Central region. It is facing solid waste problems similar to many other urban cities in Nigeria. The current waste management system has generally failed to address a wide range of waste disposal problems. Only about 33% of wastes generated in Minna are collected through government approved collection sites (NPC, 2006) and only major streets within the town are covered during waste collection by the authorities. Wastes are littered everywhere, in open dumps and in drainage channels as shown in plates 1 and 2. Indiscriminate dumping of refuse in drainage channels is the major cause of flooding which is often experienced in the town. The effect of flooding is enormous, most times leading to loss of lives and properties. Aesthetic standards are abused in this era of environmental consciousness. The State Environmental Protection Agencies are continually grappling with limited funding, it is therefore necessary to operate the collection system such that the total haul cost is minimized for effective waste collection. Private collectors were contracted in 2008 and 2009 by government but were frustrated due to non payment. This clearly shows the difficulty in solid waste management. This paper presents a cost optimization model to optimize the collection of solid wastes in Minna metropolis with a view of reducing cost, thus providing an effective waste management system for the metropolis.

MATERIALS AND METHODS

Study area

The study site is located in Minna, the capital city of Niger state. Niger state is located in the North Central Geo-Political Zone of Nigeria. Minna town was divided into six collection routes (NISEPA, 2008) as shown in Figure 1. For the purpose of this study, the six collection zones were extensively covered. The six zones are:-

Zone 1: Kpakungu roundabout – Secretariat roundabout - Eastern bye pass – Chanchaga bridge

Zone 2: Secretariat roundabout – Tunga roundabout - ADP roundabout Maitumbi

Zone 3: Tunga roundabout – ABSS roundabout - ADP roundabout Maitumbi

Zone 4: ABSS roundabout – Maikunkele.

Zone 5: Mobil roundabout – AP Kpakungu roundabout through Dutsen Kura, Government house and Bosso (low cost)

Zone 6: AP Kpakungu roundabout – Kpakungu roundabout including Shiroro road.

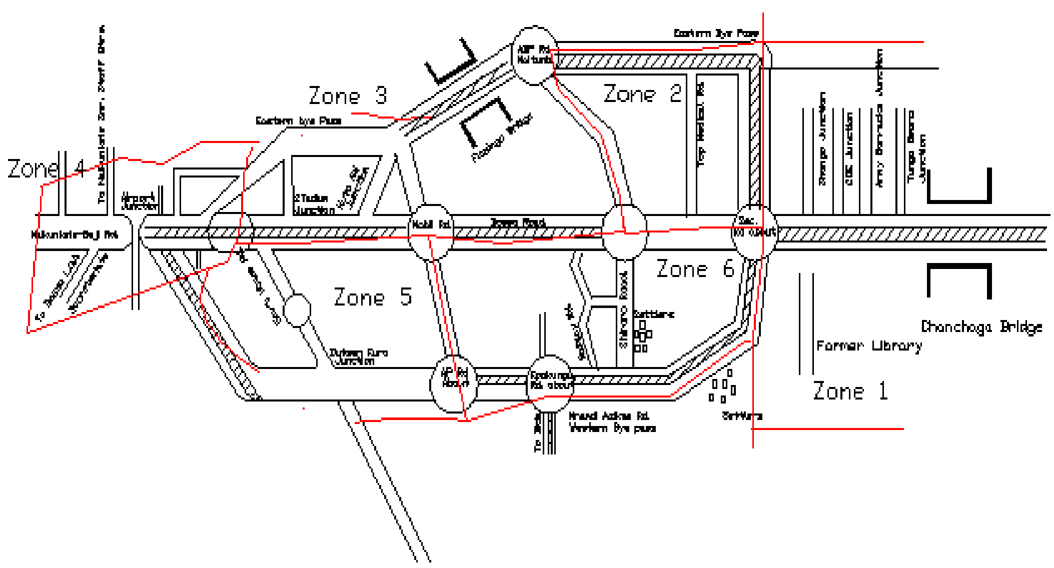

Figure 1: Waste Collection zones in Minna
(Source; Niger State Environmental Protection Agency, 2008)

Disposal Site 1 is existing while Disposal site 2 is proposed. The quantity of waste generated in Minna was estimated as 0.41 kg/p/d; which is within the range 0.3 – 0.6 kg/p/d (NEERI, 2006 and Ugwu, 2009) for developing countries. Based on the population of the zones, the quantity of waste generated is summarized in Table 1. The distance of each zone to the disposal site is presented in Table 2. The operating cost of waste collection vehicle was estimated to be ₦200/km for fuel, ₦10,000/day for vehicle maintenance and ₦8,000/day for wages. The cost of haulage of waste generated per zones is presented in Table 3 while Table 4 shows daily cost of hauling the waste generated from the zones to the disposal sites.

Table 1: Quantity of waste generated in each zone

Zone	Population	Quantity of waste generated (tonnes/day)
1	24,329	9.97
2	60,823	24.91
3	72,988	29.93
4	48,658	19.95
5	42,575	17.46
6	54,740	22.44

Table 2: Distance from each zone to disposal site.

Zone	Disposal site 1 (km) Existing	Disposal site 2 (km) proposed
1	7.5	17.0
2	10.0	11.0
3	14.3	5.5
4	16.3	7.2
5	10.3	16.8
6	6.0	15.6

Table 3: Haul cost per day

Zone	Disposal Site I ₦	Disposal Site 2 ₦
I	21,000.00	24,800.00
2	22,000.00	22,400.00
3	23,800.00	20,200.00
4	24,520.00	20,880.00
5	22,120.00	24,720.00
6	20,400.00	24,240.00

Table 4: Daily Cost per tonne of refuse.

Zone	Disposal site 1 ₦	Disposal site 2 ₦
1	2,100.00	2,480.00
2	883.00	899.60
3	796.00	674.91
4	1,229.07	1,046.62
5	1,226.90	1,415.81
6.	909.09	1,080.21

Model Formulation

Using the characteristics of the study area, the model formulation is represented by a set of linear equations. The model has three basic components.

a. Decision variables to be determined.
b. Objective (goal) that needs to be optimized (maximize or minimize).
c. Constraints that the solution must satisfy.

The aim of the optimization model is to estimate the optimum waste haul routes (or paths) from the source nodes, namely the waste production nodes (WPN) to the sink nodes (landfills). Waste produced at the WPN is transported by local waste collection vehicles (WCV), open trucks. Waste from each WPN is hauled to one landfill only.

The model has a total of 13 variables and 20 constraints. The decision variables are the amount of waste to be transported from source of generation to disposal sites. Constrains imposed by the activities are represented in equation 1.

$$\sum_{k=i}^{2} y_{ik} = w_i \quad i=1\ldots\ldots.6 \qquad (1)$$

where w_i = daily solid waste generation at zone i.
Y_{ik} = amount of daily solid waste to be removed from zone i to disposal site k.
These constraints ensure that all solid waste generated in zone i are removed to disposal site k (equation 2).

$$Y_{ik} - M_{dk} \leq 0 \quad i=1\ldots6;\ k=1,2 \qquad (2)$$

where d_k = Disposal sites 1 and 2, and M represents "sufficiently large number which will make the constraints non binding whenever $d_k = 1$.

The constraints ensure that amount of solid waste sent to each disposal site will not exceed the processing capacity of that site.

In the process of formulating this model, the following assumptions were made.

a. Solid wastes from generation sources are carried directly to disposal sites.
b. Fuel and maintenance costs are proportional to the distance travelled and to the amount of solid waste removed.
c. Collection cost is proportional to trip duration and to the amount of solid waste removed.

Objective function

In this model, one type of cost is considered:- Investments and operating cost from zones to disposal sites. The objective function Z (equation 3) is

$$Z = \sum_{k=1}^{2} G_k d_k + \sum_{i=1}^{6} \sum_{k=1}^{k} U_{ik} Y_{ik} \quad k=2,\ i=6 \qquad (3)$$

where Z = Objective function that needs to be optimized

G_k = Daily operating and investment Cost of disposal site, k=2 and i=6

U_{ik} = Cost of carrying one tonne of solid waste from zone i to disposal site k.

Given that:

$\sum_{k=1}^{2} Y_{ik} = W_i \quad i = 1 \text{------} 6$

$\sum_{i=1}^{6} Y_{ik} \leq U_k \quad k=1, 2$

$Y_{ik} \geq O, \ i = 1 \text{------} 6 \quad k=1,2$ (4)

The objective function to be optimized is given as equation (5)

$$\text{Min } Z = G_k d_k + U_{ik} Y_{ik} \tag{5}$$

This equation can be written in full

$$\text{Min } Z = G_k d_k + U_{11}Y_{11} + U_{12}Y_{12} + U_{21}Y_{21} + U_{22} Y_{22} + U_{31}Y_{31} + U_{32}Y_{32} + U_{41}Y_{41} + U_{42}Y_{42} + U_{51}Y_{51} + U_{52}Y_{52} + U_{61}Y_{61} + U_{62}Y_{62} \tag{6}$$

Subject to

$Y_{11} + Y_{12} = W_1 = 10$

$Y_{21} + Y_{22} = W_2 = 25$

$Y_{31} + Y_{32} = W_3 = 30$

$Y_{41} + Y_{42} = W_4 = 20$

$Y_{51} + Y_{52} = W_5 = 18$

$Y_{61} + Y_{62} = W_6 = 23$

$Y_{11} + Y_{21} + Y_{31} + Y_{41} + Y_{51} + Y_{61} \leq d_1 = 130$

$Y_{12} + Y_{22} + Y_{32} + Y_{42} + Y_{52} + Y_{62} \leq d_2 = 130$

$-Md_2 + Y_{11} \leq 0$

$-Md_2 + y_{12} \leq 0$
$-Md_2 + Y_{21} \leq 0$
$-Md_2 + y_{22} \leq 0$
$-Md_2 + Y_{31} \leq 0$
$-Md_2 + y_{32} \leq 0$
$-Md_2 + Y_{41} \leq 0$
$-Md_2 + y_{42} \leq 0$
$-Md_2 + Y_{51} \leq 0$
$-Md_2 + y_{52} \leq 0$
$-Md_2 + Y_{61} \leq 0$
$-Md_2 + y_{62} \leq 0$ (7)

$Y_{11}, Y_{12}, Y_{21}, Y_{22}, Y_{31}, Y_{32}, Y_{41}, Y_{42}, Y_{51}, Y_{52}, Y_{61}, Y_{62}, > 0$
$1000d_2 + 2100Y_{11} + 2480Y_{12} + 883Y_{21} + 899.6Y_{22} + 796Y_{31} + 674.91Y_{32} + 1229.07\ Y_{41} + 1046.62\ Y_{42} + 1266.9\ Y_{51} + 1415.81\ Y_{52} + 909.09\ Y_{61} + 1080.21\ Y_{62}$
(8)

RESULTS AND DISCUSSION

Linear Programming Output Summary

This equation was solved using TORA optimization software and the result obtained is shown in Tables 5 and 6. Table 5 shows the linear programming output summary for existing system. The analysis shows that with the existing system, Y12, Y22. Y32, Y42, Y52 and Y 62 = 0. This means that all wastes are sent to disposal site 1. The equation was solved after 15 iterations and the objective value was ₦135, 549. 47. Table 6 shows the linear programming output summary for the system. Table 7 shows that under the proposed system, waste collected from zones 1,2,5 and 6 will be sent to disposal site 1 whereas waste collected from zones 3 and 4 will be sent to the proposed disposal site 2. The equation was solved after 24 iterations and the objective value was ₦128. 267.97

Table 5: Linear Programming Output Summary for existing system.

Variable	Value	Objective Coefficient	Obj.Val.Contribution
X1: d2	0.30	1000.00	300.00
X2 : Y11	10.00	2100.00	21000.00
X3 : Y12	0.00	2480.00	0.00
X4 : Y21	25.00	883.00	22075.00
X5: Y22	0.00	899.60	0.00
X6: Y31	30.00	796.00	23880.00
X7 : Y32	0.00	674.91	0.00
X8 : Y41	20.00	1229.07	24581.40
X9 : Y42	0.00	1046.62	0.00
X10 : Y51	18.00	1266.90	22804.20
X11 : Y52	0.00	1415.81	0.00
X12 : Y61	23.00	909.09	20909.07
X13 : Y62	0.00	1080.21	0.00

Table 6: Linear Programming Output Summary for proposed system.

Variable	Value	Objective Coefficient	Obj.Val.Contribution
X1: d2	0.30	1000.00	300.00
X2 : Y11	10.00	2100.00	21000.00
X3 : Y12	0.00	2480.00	0.00
X4 : Y21	25.00	883.00	22075.00
X5: Y22	0.00	899.60	0.00
X6: Y31	0.00	796.00	0.00
X7 : Y32	30.00	674.91	20247.30
X8 : Y41	0.00	1229.07	0.00
X9 : Y42	20.00	1046.62	20932.40
X10 : Y51	18.00	1266.90	22804.20
X11 : Y52	0.00	1415.81	0.00
X12 : Y61	23.00	909.09	20909.07
X13 : Y62	0.00	1080.21	0.00

Comparison of optimal results with existing results.

The above model equation was solved using a computer program, since solving it manually is tedious and time consuming. TORA optimization system was used, 13 variables and 20 constraints defined in the model formed the basis for input data. A minimum objective value of ₦128, 267.97 was achieved after 24 iterations. Presently, there exists just a disposal site, the model was tested with just the existing site by sending all the wastes to the site, ie d_2=0, d_1 = 130. A minimum objective value of ₦135, 549.67 was achieved after 15 iterations.

A total of ₦7281.70 will be saved daily, and ₦2, 657,820.50 will be saved annually if the second disposal site is introduced as proposed in this research. Also introducing the second disposal site will reduce time spent since time is a function of distance as shown in the output summary. Wastes collected from zones 1, 2, 5 and 6 should be disposed at the existing disposal site 1, whereas wastes collected from zones 3 and 4, should be taken to the proposed disposal site 2. The model can only be used where the source nodes and the sink nodes are fixed. The model when adopted will reduce cost in waste collection, and cost which is a major factor militating against effective waste management when reduced will encourage private collectors to partner with government in this regard. This is because the private collectors who have been contacted twice by government could not continue due to high cost involved and government's unwillingness to pay such huge fees.

Conclusion

The model was used to determine the optimum cost of waste collection from the six waste collection zones of Minna to the two disposal sites. One disposal site (1) is existing but the second disposal site (2) is proposed between zones 3 and 4, about 5 km from zone 3 and 7 km from zone 4. The existing disposal site 1 should be moved about 4 km from its present position due to development of residential buildings to the site. Transfer stations are not required as distance from production nodes to disposal sites do not exceed 20 km. The linear programming model presented in this work can be used to optimize MSW haul and disposal systems provided that the locations of the source and sink nodes are fixed. Therefore, it is recommended that the model developed should be adopted by the government as a way of improving solid waste management in Minna with special reference to cost and time minimization in waste collection.

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Groundwater Prospecting using Geoelectrical Resistivity Method in Abeokuta Metropolis, Southwest Nigeria

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ABSTRACT
Aquifers in the hard rock terrain of Abeokuta metropolis and environs in southwestern Nigeria are characterised, using geoelectrical resistivity method with Schlumberger Vertical Electrical Sounding (VES) technique. The study provides insight into the nature of groundwater occurrence, which can guide groundwater exploration and thereby minimise the rate of the occurrence of abortive wells in the study area. Thirty locations were investigated and the VES curves obtained were interpreted and categorised into geoelectric models and type curves for aquifer characterisation. The H, KH, HKH and HAK type curves were obtained. Groundwater occurs, in the study area, within the weathered basement and fractured basement aquifers, which can be as deep as 33 m. A well designed borehole, constructed with appropriate technology, may be crucial for a successful well completion in the study area and areas with similar geology.

Keywords: Basement complex, aquifer characterisation, VES, geo-electrical resistivity, Abeokuta

INTRODUCTION

The water resources in Nigeria are enormous. The groundwater resources, estimated to be 50 million trillion ℓ/year (Akujieze *et al*., 2002), is by far greater than the surface water resources, estimated to be 224 trillion ℓ/year (Hanidu, 1990). In spite of the enormous water resources, however, only 48% of the inhabitants of the urban and semi-urban areas of Nigeria and 39% of rural areas have access to safe and reliable water supply (Federal Ministry of Water Resources, 2005; MacDonald *et al.*, 2005b). The inadequacy of safe water makes water and sanitation related diseases common. For example, diarrhea, more prevalent in the rural than the urban areas, is the second main cause of infant mortality after malaria, and caused between 150,000 and 200,000 deaths among children below 5 years (Federal Ministry of Water Resources, 2004). Across much of rural Nigeria, the only realistic water supply option is groundwater, through the construction of hand-dug wells, boreholes and spring development – alternative water resources may be unreliable or expensive to develop and maintain (MacDonald *et al*., 2005a). One of the constraints of developing groundwater, however, is the nature of its occurrence. Whereas in some areas, especially sedimentary, successful boreholes and hand-dug wells can be easily developed, in others, like the basement complex, however, appropriate methods of investigation are required to successfully site wells, as groundwater occurrence depends critically on hydrogeology.

The geoelectrical resistivity survey is the longest-established geophysical method used to site wells and boreholes throughout the world (MacDonald *et al.*, 2005a). There is a lot of robust equipment for the method and it can identify different resistivity changes with depth, a necessity for the identification of aquifers. In Nigeria, the survey method is the most popular and versatile for groundwater investigation in the basement complex areas (Olorunfemi, 2009). The most commonly used geoelectrical resistivity survey method is vertical electrical depth sounding, also known as VES (MacDonald *et al.*, 2005a). It has been used in different types of groundwater studies, such as the investigation of aquifer characteristics and groundwater potentials (Akaolisa, 2006; Bello and Makinde, 2007; Nejad, 2009; Omosuyi, 2010; Nkereuwem *et al.*, 2011), delineation of seawater intrusion and the boundary between saline and fresh water zones (Khalil, 2006; Sung-Ho *et al.*, 2007), groundwater quality and pollution studies (Karous *et al*., 1994; Arshad *et al.*, 2007; Abdullahi *et al.*, 2010), as well as in soil-water movements and precision agriculture (Johnson *et al.*, 2003; Corwin and Lesch, 2005). In this study, geological environments of groundwater occurrence are characterised, using VES technique, with the main aim of providing a guide to groundwater exploration, which can minimise the rate of occurrence of abortive wells in the study area and in areas with similar geology. As high as 70% of boreholes located in different parts of Nigeria have been reported as unproductive, with inadequate geological consideration and poor knowledge of groundwater disposition given as being responsible (Akujieze *et al*., 2002; Eduvie, 2006). Using borehole logs, Idowu and Ajayi (1998) classified aquifers in parts of the basement complex areas of southwestern Nigeria into (a) occurrences in the in-situ weathered materials overlying the fresh basement (b) occurrences in decomposed veins within the fresh basement (c) occurrences in the fractured basement and (d) occurrences in quartzite. The aquifer types are presented in Figs. 1 and 2.

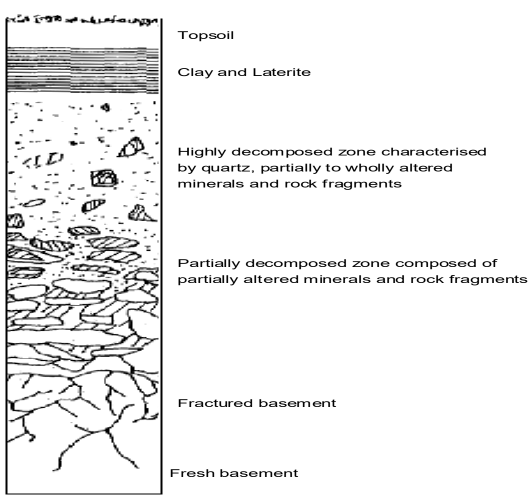

Figure 1: Mode of aquifer occurrence of weathered/fractured basement aquifer (Idowu and Ajayi, 1998)

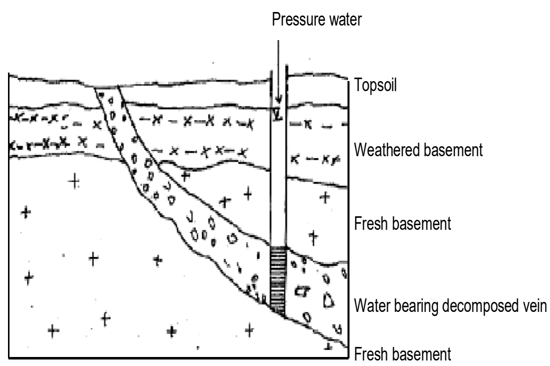

Figure 2: Mode of aquifer occurrence as a decomposed vein within the fresh basement (Idowu and Ajayi, 1998)

MATERIALS AND METHODS

The study area, Abeokuta metropolis, is located in southwestern Nigeria, between latitudes 7^0 5 ‘N and 7^0 20’ N and longitudes 3^0 17’ E – 3^0 40’ E (Fig. 3). It covers about 1,500 km^2 and it is the capital of Ogun State. Aquifers within the study area are constituted of rocks of the Precambrian Basement Complex of southwestern Nigeria, which comprise migmatitic and granite gneisses, slightly migmatised to unmigmatised parashists and metaigneous rocks, charnockites, Older Granites and unmetamorphosed dolerite dykes (Rahaman, 1988). The structural features exhibited by the basement rocks include foliation, lineation, folds, rock-rock contact, faults and joints. Abeokuta has an average annual rainfall of about 1,200 mm.

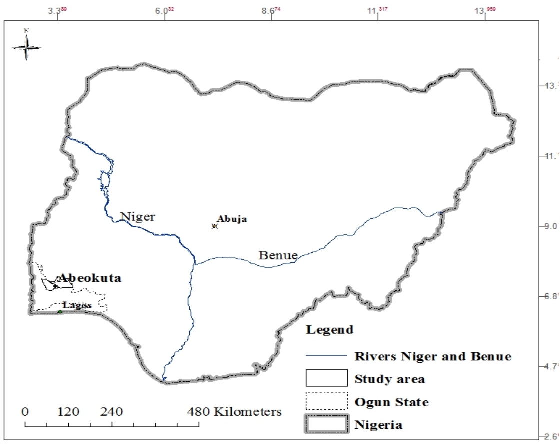

Figure 3: Nigeria showing the location of Abeokuta metropolis

Thirty (30) VES stations were investigated, using SAS 300C DC resistivity meter, with Schlumberger electrode array and a maximum current electrode spacing of 200 m. The locations of the VES, in terms of latitudes, longitudes and altitudes are presented in Table 1. The apparent resistivity, calculated from the measurement of resistance and geometric factor for Schlumberger configuration (Milsom, 2003), were plotted against half the electrode spacing to obtain VES curves, which were quantitatively interpreted using IPI2Win software for resistivity sounding interpretation (Bobachev *et al.*, 2003). The number of geoelectric layers, as well as their depths, thicknesses and resistivity values were obtained and used for identifying groundwater bearing zones (aquifers), taking into consideration the available logs of boreholes of the investigated locations. The VES curves were further categorised into typical geoelectric type curves as a way of further classifying the geological environments of groundwater occurrence in the study area.

RESULTS AND DISCUSSION

The results of the VES interpretations, as well as the categorisation of the VES curves into the geoelectric layer models, are presented in Table 1. Three classes of geoelectric layer models were obtained in the study area: 3-layer (37%), 4-layer (33%) and 5-layer (40%) models. H type curves constitute the 3–layer model, while KH (23%) constitute the 4 – layer model. The five–layer models consisted of HKH (37%) and AKH (3%) type curves. Representation of the different type curves are presented in Fig. 4. The model parameter values of the sounding point are represented in blue lines, while the theoretical sounding curve for the model parameter values is in red line, whereas the field curve is represented by circles.

In the 3 –layer model, the weathered basement, directly overlying the fresh basement rocks, constitute the aquifer (Fig. 4 a). The thickness of the weathered layer, therefore, is a determinant of how good or poor the aquifer is. The thickness of the layer ranges from 1.7 - 18.2 m in the study area. In the 4-layer model, two aquifer environments were encountered. One is constituted of a weathered basement overlain by a lateritic hard pan (Fig. 4b), while the other is constituted of the fractured basement sandwiched between fresh basement rocks (Fig. 4c). The first, typical of schist belts, range in thickness and depth from 14.5 – 27.1 m and 1.6 – 11.3 m respectively, with the resistivity range of 26 - 104 ohm-m. The second is typical of areas underlain by migmatites and has Aregbe and Adeloye Camp (Table 1) as examples. The thickness, depth and resistivity values range from 9.9 – 12.3 m, 3.2 -16.3 m and 51 – 359 ohm-m respectively. In the 5 – layer model, two aquifer types occur, viz: the weathered and the fractured basement. The former is separated from the latter by fresh basement rocks, with the latter confined within the fresh basement rocks (Figs. 4d and 4e). The thickness, depth and resistivity values of the weathered aquifer range from 2 – 9.6 m, 1 - 2.9 m and 12 – 586 ohm-m respectively. The ranges of thickness, depth and resistivity values of the fractured aquifer are 1 – 27.2 m, 5.4 -32.5 m and 71 – 735 ohm-m respectively. The difference between the HKH and AKH type curves of the 5-layer models is in the degree of weathering of the weathered aquifer. The results indicate that, in the study area, groundwater occurs not only within the weathered basement, usually lying above the fresh basement with varying degrees of weathering, but also within the fresh basement in fractured basement aquifers, which can be as deep as 33 m.

CONCLUSION

Three types of geoelectric models – 3, 4 and 5 layer models were obtained in the study area. Four VES type curves H, KH, HKH, and AKH were obtained, with indications of groundwater occurrence, not only within the weathered basement usually lying above the fresh basement with varying degrees of weathering, but also within the fresh basement in fractured basement aquifers, which can be as deep as 33 m. Appropriate drilling technology and well design, with due consideration for the actual nature of groundwater occurrence, may be crucial for a successful well completion in the study area and in a basement environment similar to that of the study area.

Acknowledgement

The authors wish to acknowledge the comments of Prof. M. O. Olorunfemi of the Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria.

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Table 1: Summary of results of VES interpretations

S/N	Location			Geoelectric Layer															Curve Type
	Name	Latitude	Longitude	1			2			3			4			5			
				Thickness (m)	Depth (m)	AR (ohm-m)	Thickness (m)	Depth (m)	AR (ohm-m)	Thickness (m)	Depth (m)	AR (ohm-m)	Thickness (m)	Depth (m)	AR (ohm-m)	Thickness (m)	Depth (m)	AR (ohm-m)	
1	Fajol	7.31833	3.31667	3.7	0	287	9.7	3.7	50	∞	13.4	1097							H
2	ECWA, Camp	7.25000	3.44639	1.6	0	1017	18.2	1.6	203	∞	19.8	475							H
3	Osiele	7.31444	3.47944	2.7	0	188	12.8	2.7	76	∞	15.5	488							H
4	Odeda	7.41667	3.53333	1.6	0	131	11.4	1.6	48	∞	13	132							H
5	FCE 1	7.310000	3.47987	2.7	0	183	12.8	2.7	76	∞	15.5	488							H
6	FCE 2	7.30000	3.47917	3.9	0	424	18.1	3.9	37	∞	22	256							H
7	Akala, Camp	7.30000	3.47806	3	0	104	8.7	3	23	∞	11.7	193							H
8	Eleweran	7.23472	3.30778	1.2	0	2787	15.4	1.2	71	∞	16.6	734							H
9	UNAAB 4	7.22860	3.43712	1	0	60	5	1	12	∞	6	4704							H
10	Oke, Camp	7.31667	3.45	1.5	0	2762	1.7	2.9	21	∞	9.6	10000							H
11	Olomore	7.18667	3.28778	1.2	0	802	1.9	1.2	35	∞	3.1	19560							H
12	Obantoko 1	7.30222	3.30583	0.5	0	53	1.1	0.5	370	27.1	1.6	104	∞	28.7	491				KH
13	Obamtoko 2	7.32306	3.46833	0.5	0	53	1.1	0.5	370	27.1	1.6	103	∞	28.7	491				KH
14	Aregbe	7.20222	3.30917	0.8	0	614	2.4	0.8	931	9.9	3.2	51	∞	13.1	1275				KH
15	Eweje	7.25167	3.43444	1.2	0	36	4.2	1.2	294	21.2	5.4	27	∞	26.6	600				KH
16	Olodo	7.28333	3.53611	4.5	0	90	6.8	4.5	369	39.5	11.3	61	∞	50.8	740				KH
17	Adeloye, Camp	7.32028	3.43333	6.7	0	908	9.9	6.7	2216	12.3	16.6	359	∞	28.9	815				KH
18	UNAAB 2	7.22845	3.43573	1.4	0	92	6	1.4	105	14.5	7.4	26	∞	21.9	1566				KH
19	UNAAB 5	7.22807	3.43801	2.9	0	342	9.3	2.9	38	20.3	12.2	460	12.5	32.5	301	∞	45	1244	HKH
20	UNAAB 1	7.23500	3.43644	1.3	0	1632	6.3	1.3	63	4.8	7.6	1000	27.2	12.4	735	∞	39.6	2047	HKH
21	UNAAB 7	7.22521	3.44014	1.7	0	1517	7.6	1.7	75	16.8	9.3	1075	6.4	26.1	636	∞	32.5	4400	HKH
22	Adigbe	7.12417	3.3175	1.3	0	10	2	1.3	21	2.1	3.3	767	1	5.4	474	∞	6.4	1436	HKH
23	Ibara	7.12528	3.33722	1.2	0	331	6.6	1.2	49	2.6	7.8	748	3.9	10.4	502	∞	14.3	6472	HKH
24	UNAAB 6	7.22912	3.438	1.6	0	766	9.6	1.6	34	10.3	11.2	865	3.1	21.5	483	∞	24.6	1995	HKH
25	UNAAB 3	7.22769	3.43368	1.8	0	353	6.1	1.8	31	21.8	7.9	824	2.8	29.7	418	∞	32.5	1387	HKH
26	Edun Gbonagun	7.22278	3.40222	1.1	0	499	3.7	1.1	12	17.2	4.8	961	19	22	71	∞	41	888	HKH
27	Oluga Kemta	7.38472	3.53833	1.2	0	181	6.1	1.2	41	7.9	7.3	900	7.9	15.2	450	∞	23.1	1000	HKH
28	Alimi Gbonagun	7.19806	3.4075	1	0	122	2	1	25	11.6	3	349	26.4	14.6	39	∞	41	249	HKH
29	Kotopo	7.19806	3.38806	1.4	0	553	5.4	1.4	140	8.1	6.8	718	17.9	14.9	164	∞	32.8	235	HKH
30	Tinrinmi	7.35306	3.57	1.1	0	121	3.9	1.1	586	9.6	5	906	24.6	14.6	440	∞	39.2	2608	AKH

AR- Apparent resistivity

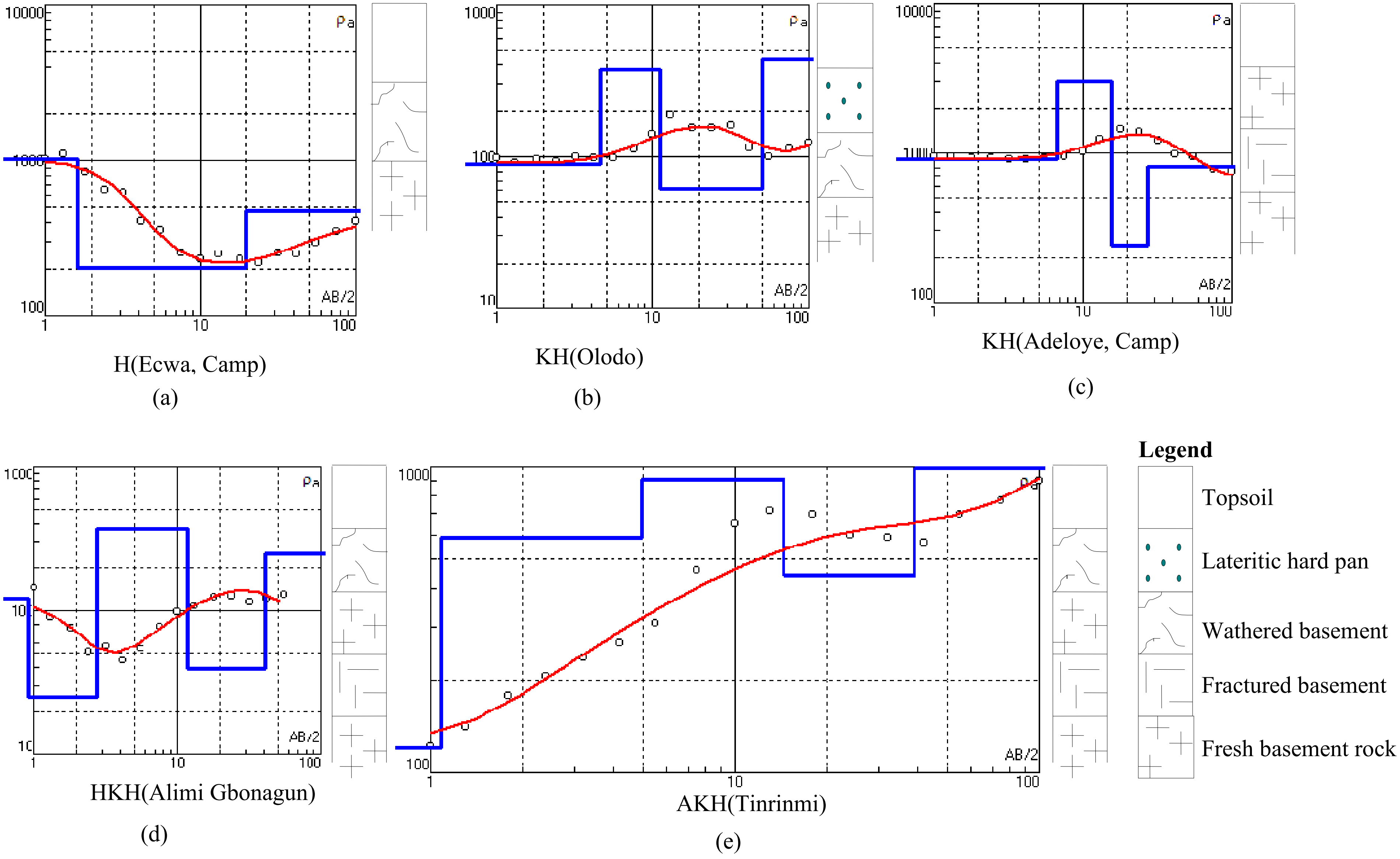

Figure 4: Geoelectric curves and sketches of logs obtained from the study area

Patterns of Groundwater Chemistry in Deep Aquifer Systems of the Niger Delta, Nigeria

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ABSTRACT

For this study, 57 groundwater samples from deep boreholes, (150- 450m) were analysed with a view to identifying major quality issues and their distribution contrary to pervious studies that were concerned with groundwater from shallow boreholes, less than 150 m in depth. The boreholes were scattered in 5 geomorphologic zones in the Niger Delta. The results revealed that three parameters namely, pH, Cl^- and Fe^{2+} stood out as constituting major groundwater quality issues even in deep aquifers. Values of pH range from 3.8 – 8.4 with 62% of the samples having values outside the NIS 554 permissible limits of 6.5 – 8.5. Slightly acidic groundwater is prevalent in the eastern part of the area including Port Harcourt. All the samples analysed indicated that values for iron ranged from 0.02 – 5.6mg/l with 71% of the samples containing iron in excess of 0.3mg/l which is NIS 554 highest permissible limit. The high iron concentrations occurred in boreholes drilled in the freshwater swamp/meander belt region. Chloride values vary from 5.6 -710mg/l with 18% of the samples showing Cl^- concentration in excess of 250mg/l recommended by NIS 554 as maximum permissible concentration in drinking water supplies. Chloride concentration is high particularly in the coastal areas and parts of Port Harcourt city bordering saltwater creeks and tidal channels which have influent relationship with the local groundwater table. Most other parameters fall within NIS 554 limits of acceptability. The study clearly showed that groundwater from even deep aquifers needs to be treated to correct the pH, Cl^- and Fe^{2+} concentration before it can meet NIS 554 standards for drinking water supplies.

Keywords: *Deep Aquifers, Groundwater, Chemistry, Quality, Niger Delta*

INTRODUCTION

Groundwater accounts for about 97% of the world's freshwater and it is fairly well distributed throughout the world (Buchanan, 1983; Bouwer, 2002). Although development of water supplies from deep wells requires relatively high cost of development, maintenance and operation, groundwater still enjoys a number of advantages over surface water sources. It involves little seepage losses. Treatment costs are less and less area of land is required for its development. It also has little or no evaporation problems, water logging, dam failure, silt elimination and creation of aquatic environment, which are usually associated with surface water development. Knowledge of the quality of groundwater is required because, the use to which water can be put depends on its quality.

Several research works have been carried out on the groundwater chemical characteristics in some parts of the Niger Delta (Etu-Efeotor, (1981), Amajor (1986, 1991), Amadi et al, (1989), Udom et al (1999), Mecon Geology and Engrg Services Ltd (2002), Ngah and Allen, (2006), Ngah, (2002), Ofoma et al, (2008). Specifically, the determination of water quality for human consumption has been the subject of many researches (e.g. Edet, 1993; Egbunike, 2007; Ige et al., 2008; 2009; Edet et al., 2011).

However most of the researches concentrated on the chemical characteristics of the shallow aquifers (not exceeding 150m in depth) since until very recently, terrain and logistics problems mitigated against successful drilling of deep water boreholes especially in the coastal areas. Provenance of host rocks and composition, origin and residence time of water in the sub-surface environment and geologic history are often different for shallow and deep aquifers. It is therefore necessary to examine the physic-chemical characteristics of groundwater from deep aquifer systems, bearing in mind the overall advantages of groundwater over surface water as a source of water supply and the fact that the only source of water supply in the coastal parts of the Niger Delta are deep water boreholes. This work therefore examines the quality of groundwater from deep aquifer systems in the Niger.

MATERIALS AND METHODS

Geology and Geomorphology of study locations

The Niger Delta (Fig.1) is a huge Sedimentary Basin. The present knowledge of the geology of the Niger Delta was derived from the works of the following researchers (Reyment, 1965; Short & Stauble, 1967; Murat, 1970; Merki, 1970) as well as the exploration activities of the oil and gas companies in Nigeria. The formation of the so called proto-Niger Delta occurred during the second depositional cycle (Campanian-Maastrichtian) of the southern Nigerian basin. However, the modern Niger Delta was formed during the third and last depositional cycle of the southern Nigerian basin which started in the Paleocene. In terms of litho-stratigraphy, the rocks in the Niger Delta are divided into the oldest Akata Formation (Paleocene), the Agbada Formation (Eocene) and the Youngest Benin Formation (Miocene to Recent).

The major aquiferous formation is the Benin Formation which is about 2100m thick at the centre of the basin and consists of coarse-medium grained sandstones, thick shales and gravels. The upper section of the Benin Formation consists of quaternary deposits about 40 – 150m thick and comprises sand and silt/clay with the later becoming increasingly more prominent seawards (Etu-Efeotor & Akpokodje, 1990). The formation consists of predominantly freshwater continental friable sands and gravel that have excellent aquifer properties with occasional intercalations of claystone/shales The Benin Formation is highly permeable and prolific and is the target of water boreholes in the Niger Delta. Akpkokodje (1987) identified five major geomorphologic units in the Niger Delta: the coastal plain sands (dry flatland and plain), the Sombreiro-WarriDeltaic plain (with abundant freshwater swamps), the freshwater swamps (backswamps,alluvial plainand meander belts), the saltwater or mangrove swamps and the active/abandoned coastal beaches (sand bars, beaches and bars).

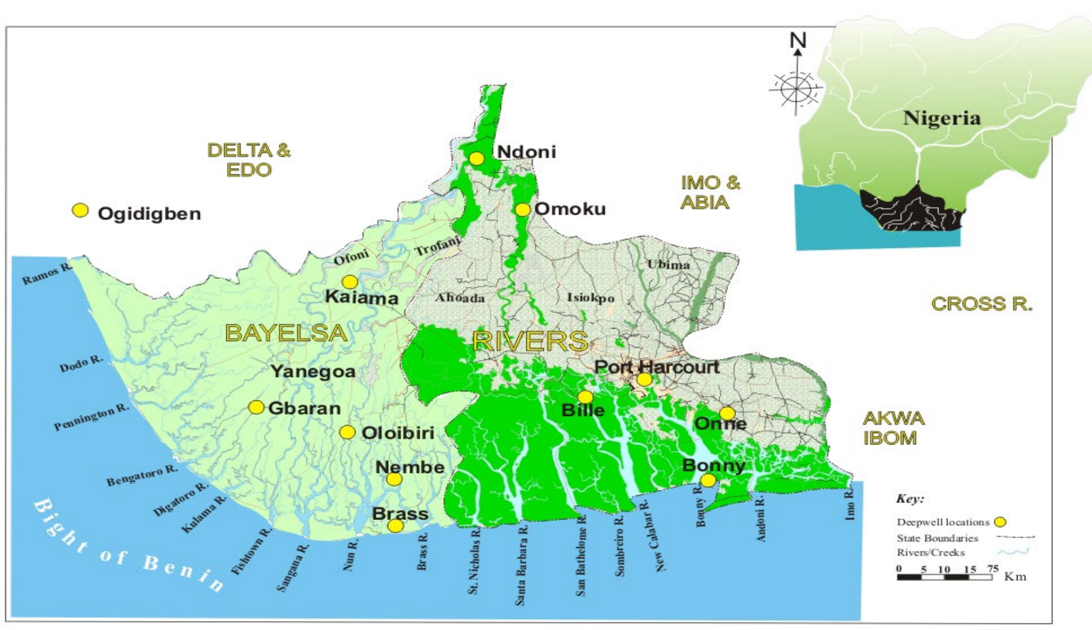

Fig.1: Location Map of the Study Area

Field Collection of Groundwater Samples

Although careful interpretation of down-hole geophysical logs can infer fluid chemistry, this is just to the extent of classifying the water as fresh or saline. The only means of evaluating the exact quality of water tapped by a well is an accurate analysis of a pumped sample. To achieve this, groundwater samples were collected from deep boreholes. To ensure integrity of samples and representativeness, many boreholes were sampled in each geomorphologic unit. Before a sample is taken, stagnant water is removed by pumping the well for about 30 minutes; Water samples were taken directly from the sampling tap at the well head and not along the flow line using 1.5litre polyethylene plastic bottle which had been properly rinsed with the water sample before collection. The samples were then properly labeled indicating location, water temperature at time of sampling, date, sample number, time, depth of screen and total borehole depths. To minimize sample deterioration, in-situ measurements were made of conductivity, pH and temperature.

Analyses of the samples were carried out at the laboratory of the Institute of Pollution Studies, Rivers State University of Science and Technology, Port Harcourt. Parameters tested for were the physio-chemical properties of the water as indicated in the results. The results of the analyses were then compared with the NIS 554 (2007) for drinking water quality.

Available Data and accuracy checks

A total of 69 samples from various geomorphological units were collected and analyzed. The samples were assumed to represent water quality at the depth at which the screens were set in the wells since water in the borehole represents the water from the screened intervals. Accuracy checks were undertaken on the results of the water analysis by watching out for certain known regularities in the dissociation of major inorganic constituents in groundwater. Out of a total of 69 datasets, only 57 passed the accuracy tests.

RESULTS AND DISCUSSION

The results of the analyses and distribution of the samples in geomorphologic units are shown in Table 1. These data were used to generate isopach maps of various parameters, especially parameters that occur in objectionable concentrations in the study area. Groundwater quality in deep aquifers in the study area shows considerable variation with local geology, depositional environment and degree of use and abuse. Being situated within the deltaic plain mega-depositional environment, the southern part of the study area comprises swamps, creeks, tidal channels, rivers and their distributaries and lakes. Brackish water resulting from tidal influx dominates the coast in the shallow aquifers.

Table 2 is the Nigerian Standards for Drinking Water Quality (NIS 554, 2007). A comparison of the results of this study and the WHO guidelines indicates that some quality issues really exist even in the deep aquifers. The trends amongst relevant chemical parameters are discussed hereunder.

Table 1: Groundwater Quality Data from the Different Geomorphic Zones of the Niger Delta

S/No	Geomorphic zone	Borehole Location	Depth (m)	Iron (ppm)	Chloride (mg/1)	Salinity (mg/1)	Conductivity (µS/cm)	pH	Alkalinity (mg/1)	Hardness (mg/1)
1.	CPS	Ogbo	186	0.3	25.0	40.0	250.0	6.8	11.8	10
2.	"	Edeocha	185	0.5	10.0	150.0	21.0	6.1	12	8
3.	"	Joinkrama	176.	6.2	5.6	136.6	400.0	6.3	-	13.3
4.	"	Ndoni	382	0.8	54	241.0	540	7.9	16	24
5.	"	Mbiama	175	5.6	6.4	48.9	141.5	6.6	-	16
6.	"	Onne	264	0.06	7.0	210.0	19	6.2	19	2.5
7.	"	Kula	183.0	0.7	68.5	113	170	6.2	18.5	66
8.	"	Umuechem	152	0.30	11	100	36	6.7	18.0	6.0
9.	"	NDBDA	170	0.1	16	26.4	600	7.2	24	16.5
10.	"	Onne Port	176	0.6	24.7	63.7	70	6.0	18	11.0
11.	"	Moscow Road	180	0.04	63.9	95.3	300	5.4	4.0	13
12.	"	Central Police Stn	176.	0.02	408.25	672.75	150.0	6.0	12.0	125
13.	"	Rumuokoro	152.0	0.03	10.64	17.55	140	6.0	16	13
14.	"	Rumuodamaya	168.0	0.1	12.06	19.82	50	6.2	16	24
15.	"	Elelenwo	171.8	0.05	35.0	60.0	21	5.3	-	16
16.	"	Iriebe	163.0	0.01	38.0	50	23	5.9	-	20
17.	FWS	Ogbia	101	0.4	109.8	180.0	367.5	6.9	15	9.5
18.	"	Amakalakala	160.	1.9	119.0	98.6	552.6	6.4	-	20.4
19.	"	Peretorugbene	211.0	0.2	30	30	40	7.2	30.5	55
20.	"	Ekeremor	202	1.5	58	150	130	6.5	19	41
21.	"	Toru Ndoro	211	4.5	68	30	300.0	3.8	0.12	74
22.	"	Torofani	165	3.5	0.14	150	-	6.8	-	69
23.	"	Ofoni	186	0.8	55	105	-	6.2	-	15
24.	"	Toro Anjiama	215	1.0	68	50	-	7.7	38	84
25.	"	Forupa	215	0.5	34	60	-	6.0	-	121
26.	"	Asamabiri	81.0	0.8	7.0	50	40	6.5	-	45

S/No	Geomorphic zone	Borehole Location	Depth (m)	Iron (ppm)	Chloride (mg/1)	Salinity (mg/1)	Conductivity (μS/cm)	pH	Alkalinity (mg/1)	Hardness (mg/1)
27.	FWS“	Amarata	180	3.0	50	82	-	6.8	35	2
28.	“	Ukubie	85.3	0.4	14	240	500	6.7	30	142
29.	“	Tebidaba	171.0	0.6	12	355	540	7.4	32	135
30.	“	Aguobiri	79	3.0	19	511	200	6.9	22	20
31.	“	Okolobiri	75	2.0	4.5	30.4	-	6.2	-	27.5
32.	“	Amassoma	180	2.0	4.3	181.4	352.3	6.5	-	11.2
.33.	“	Agudama-Epie	242.67	2.4	4.5	163.4	465	6.3	-	32
34.	“	Oporoma	42.7	0.5	108.5	116	398.6	6.8	-	25
35.	“	Peremabiri	300	4.5	132.0	50	200	7.4	35	110
36.	“	Amatolo	161.0	0.7	5.7	85.9	675.1	6.2	-	8
37.	“	Yenagoa	185.34	4.5	48.4	49.3	172.9	6.3	29	8
38.	“	Oyorokoto	180	3.6	-	-	-	-	-	-
39.	“	Otuoke	215	0.8	108	355	86	6.8	-	16
40.	“	Gbaran – Ubie	250	0.8	132	82	138	7.4	41	18
41.	SWS	Bassambiri	250	0.4	233.0	500.0	99	7.5	35	14.5
42.	“	Atubo	193	0.7	104.0	872.0	500	7.3	38	10
43.	“	Nembe	193	0.6	13	21.0	80	6.2	12	14
44.	“	Kanana	186	0.4	34	500	125	6.7	12	38
45.	“	Okrika Mainland	320	0.3	35.5	58.5	19	6.2	10.40	20
46.	“	Ibuluya-Dikibo	180	0.4	32.0	18.0	20.0	4.5	2	21
47.	CBR	Brass	192	1.6	710	116.0	250	5.5	3	28
48.	“	Kalibiama	281	0.9	10	202.0	440.0	8.4	-	488
49.	“	Bonny	304	0.8	265	186	140	5.9	-	78
50.	“	Gbokokiri	176	0.40	300	192.0	-	6.6	20	18
51.	“	Ikuru	190	1.3	351	242.0	-	6.7	-	70
52.	“	G.R.A. P.H	170	0.1	26	50	7	5.3	2	6
53.	“	Creek Road	170.0	0.2	390.5	643.5	150.0	5.8	3	135
54.	“	Potts Johnson	180.0	0.2	401	661	160	5.8	3	135

S/No	Geomorphic zone	Borehole Location	Depth (m)	Iron (ppm)	Chloride (mg/1)	Salinity (mg/1)	Conductivity (µS/cm)	pH	Alkalinity (mg/1)	Hardness (mg/1)
55.	CBR	Twon Brass	280	0.9	710	116	21	5.5	-	28
56.	“	Dema-Abbey Bonny	250	1.1	280	181	180	6.4	-	77
57.	“	Akiama Bonny	434	0.4	233	163	82	6.8	36	79
58.	“	Oguede Bonny	450	0.5	201	142	38	6.2	43	78
59.	“	Life Camp, Bonny	260	0.9	261	184	57	6.4	-	86
60	“	BRT, Bonny	260	0.9	283	198	78	6.8	48	81

CPS = Coastal Plain Sands, FWS = Freshwater Swamp, SWS = Saltwater Swamp, CBR = Coastal Beaches and Ridges, SWP = Sombreiro Warri Deltaic Plain

Table 2: Nigerian Standards for Drinking Water Quality (NIS 554, 2007)

A) Physical / Organoleptic Parameters				
Parameter	**Unit**	**Maximum Permitted Levels**	**Health Impact**	**Note**
Colour	TUC	15	None	
Odour	-	Unobjectionable	None	
Taste	-	Unobjectionable	None	
Temperature	^{o} Celsius	Ambient	None	
Turbidity	NTU	5	none	
B) Chemical Parameters **Inorganic Constitutents**				
Aluminum (Al)	mg/L	0.2	Potential Neuro-degenerative disorders	Note 1
Arsenic (As)	mg/L	0.01	Cancer	
Barium	mg/L	0.7	Hypertension	
Cadmium (Cd)	mg/L	0.003	Toxic to the kidney	
Chloride (Cl)	mg/L	250	Note	
Chromium (Cr^{6+})	mg/L	0.05	Cancer	
Conductivity	µS/cm	1000	Note	
Copper (Cu^{+2})	mg/L	1	Gastrointestinal disorder	
Cyanide (CN^{-})	mg/L	0.01	Very toxic to the thyroid and the nervous system	
Fluoride (F^{-})	mg/L	1.5	Fluorosis, Skeletal tissue (bones and teeth) morbidity	
Hardness (as $CaCO_3$)	mg/L	150	Note	
Hydrogen Sulphide (H_2S)	mg/L	0.05	Note	
Iron (Fe^{2+})	mg/L	0.3	Note	
Lead (Pb)	mg/L	0.01	Cancer, interference with Vitamin D metabolism, affect mental development in infants, toxic to the central and peripheral nervous systems	
Magnesium (Mg^{+2})	mg/L	0.20	Consumer acceptability	
Manganese (Mn^{+2})	mg/L	0.2	Neurological disorder	
Mercury (Hg)	mg/L	0.001	Affects the kidney and central nervous system	

Nickel (Ni)	mg/L	0.02	Possible carcinogenic	
Nitrate (NO_3)	mg/L	50	Cyanosis, and asphyxia ('blue-baby syndrome") in infants under 3 months syndrome") in infants under 3 months	
Nitrite (NO_2)	mg/L	0.2	Cyanosis, and asphyxia ('blue-baby syndrome") in infants under 3 months	
pH	-	6.5 – 8.5	Note	
Sodium (Na)	mg/L	200	Note	
Sulphate (SO_4)	mg/L	100	Note	
Total Dissolved Solids	mg/L	500	Note	
Zinc (Zn)	mg/L	3	Note	
C) ORGANIC CONSTITUENTS				
Detergents	mg/L		Possibly carcinogenic	
Mineral oil	mg/L		Possibly carcinogenic	
Pesticides	mg/L		Possibly carcinogenic	
Phenols	mg/L		Possibly carcinogenic	
Poly Aromatic hydrocarbons	mg/L		Possibly carcinogenic	
Total Organic Carbon or Oxidisability	mg/L	5	Cancer	

Electrical Conductivity (Conductance)

Table 1 shows that the electrical conductivity of groundwater in the study area ranges from 7 – 837 μS/cm. NIS 554.(2007) stipulates 1000 μS/cm as the maximum permissible for this parameter. The electrical conductance, or conductivity, is the ability of a substance to conduct electric current. It is reported in μS/cm. It gives an idea of the amount of total dissolved solids (TDS) present in the water. Conductivity increases as the TDS increases and in general, the corrosivity of the water increases as TDS and electrical conductivity increase. Electrical conductance depends on temperature (taken as 25ºC) and types and concentration of different dissociated ions in the water.

Total Hardness

Figure 2 shows the pattern of distribution of hardness in groundwater in the study area. The hardness of water is the sum of the ions which can precipitate as hard particles from water, mainly Ca^{2+} and Mg^{2+}. This is regarded as Ca^{2+} + Mg^{2+}or Total hardness. It is usually expressed in meq/l. (Appelo and Postman 1993). It is assessed by the ability of the water to precipitate soap. This parameter is very important in manufacturing processes. Hardness values in the deep aquifers in the area range from 2.0 – 488mg/l. Sawyer and McCarty (1967), Todd (1980) classified hardness in groundwater as follows (Table 3):

Table 3:Classification of Hardness in groundwater

Hardness (mg/l)	Water classification
0 – 75	Soft
75 – 150	Moderately hard
150 – 300	Hard
>300	Very hard

Similarly, NIS 554 (2007) sets 150mg/l as the maximum permissible value. Therefore except for Kalaibiama with Hardness of 488mg/l, groundwater in deep aquifers in most parts of the study area is within the soft and moderately hard range. When the hardness is very low, ≤ 10 mg/l, the water becomes corrosive and can dissolve heavy metals such as iron causing corrosion and incrustation. Hardness is therefore not a major quality issue in groundwater from deep aquifers in the study area.

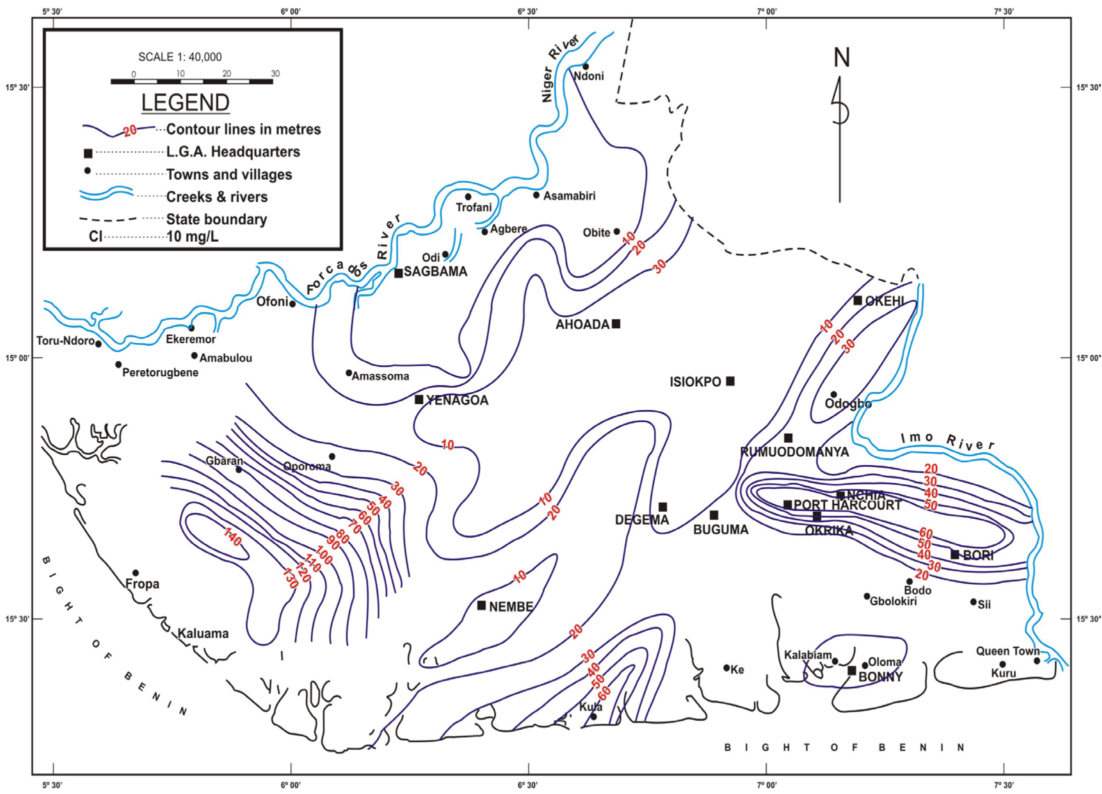

Fig. 2: Pattern of distribution of hardness in groundwater samples from deep

Alkalinity

The alkalinity in the study area range from 0.12 – 172mg/l. Sixty-seven per cent (67%) of the analysis returned values for alkalinity, 90% of these have values <75mg/l while 10% have values between 75 and 172mg/l. The alkalinity of a solution can be defined as the capacity of the solutes it contains to react with and neutralize acid (Hem 1989). It is reported in meq/l or mg/l of $CaCO_3$. It is the sum of titrable bases and a measure of an aggregate property of the water. It is therefore expected that the water will be chemically aggressive to iron and carbonate surfaces.

pH

Figure 3 shows the distribution of pH in the study area. From the figure, the western parts of the study area have groundwater with pH values between 6.5 and 7.5 acceptable to NIS 554 (2007) except for Toru Ndoro with pH 3.8. Values are much more irregular in the eastern part of the region. The areas around Ahoada, north of Isiokpo, north of Port Harcourt and south-east of Okrika have more acidic groundwater with pH values between 4.5 and 6.0.

pH represents the negative base-10 logarithm of the hydrogen-ion activity in water. It is measured in moles per liter. Even when no other solutes are present, a few of the H_2O molecules in liquid water will be broken up into H^+ and OH^- ions. This process of dissociation is a chemical equilibrium that may be written as

H_2O (l) = $H^+ + OH^-$

For neutral waters, H^+ equals OH^- = 7. Water is considered alkaline when OH^-ions > H^+ ions and pH > 7. When the $H^+ > OH^-$ and pH <7, the water is described as acidic. pH is therefore used to express the intensity of the acid or alkaline conditions of a solution. NIS 554 (2007) recommended a pH of 6.5 as minimum desirable and 8.5 as maximum permissible limits in drinking water supplies. The pH values for the samples range from very acidic (3.8 at Toru Ndoru) to permissible (8.4 at Kalaibiama). About 38% of the samples have values within NIS 554 (2007) while 62% have values outside the standards and on the acid side. Acidity in groundwater in the Niger Delta is suspected to be linked partly to long history of gas flaring from oil activities. The oil and gas activities release CO_2 which reacts with atmospheric moisture to form carbonic acid (H_2CO_2) which infiltrates the ground surface with rainfall and joins the groundwater systems. Thus, pH is a major quality issue even in groundwater from deep aquifers in the study area.

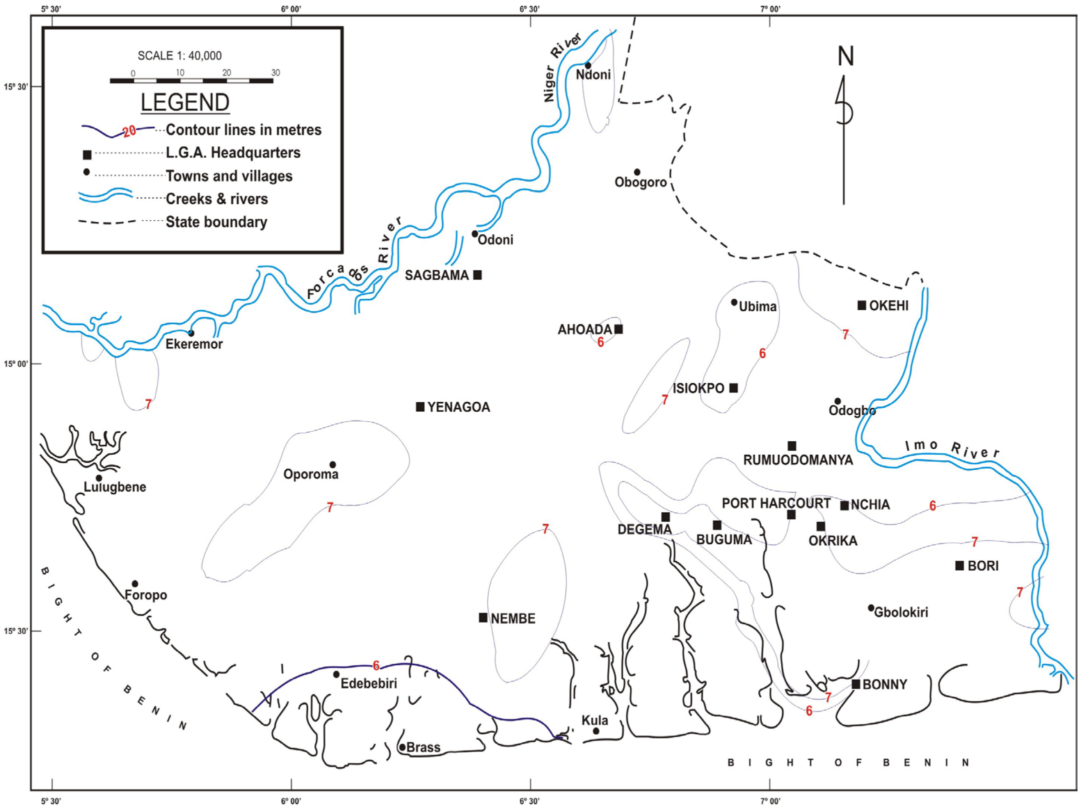

Fig. 3: Pattern of distribution of pH in groundwater samples in the study

Iron

The values range from 0 – 10mg/l. In 50% of the samples, the iron content is less than 0.4mg/l, 0.4 – 1.0 at 22% of the sites and >1.0mg/l at 20% of the sites. The highest value of 10.0mg/l occurs at Rumuokachi and Umuoji while the groundwater from Harry's Town has 8.0mg/l. NIS 554 (2007) recommended a value of 0.3mg/l as maximum permissible limit. The implication therefore is that most deep water boreholes in the study area deliver water with iron in objectionable concentration. Figure 4 shows the distribution of iron in the area. The locations north-east and south-east of the region have groundwater with iron in acceptable limits while locations south of these including the freshwater swamps/backswamps/alluvial plains/meander belt complex as well as the mangrove swamps and the coastal ridges have high iron contents in their deep groundwater.

Although iron is the second most abundant metallic element in the earth's crust, its concentration in water is small. The chemical behaviour of iron and its solubility in water

depends strongly on the oxidation intensity in the system in which it occurs. pH also has a strong influence (Mattheis, 1982). Iron is an essential element in the metabolism of animals and plants, but when present in water in excessive amount, it forms red oxy-hydroxide precipitate that stains laundry and plumbing fixtures. It therefore becomes an objectionable impurity in domestic and industrial water supplies. Hence iron determination is commonly included in chemical analysis. Nearly all the analysis in this study returned a value for iron.
Iron is therefore another major quality issue in groundwater from the study area. Several boreholes are known to have been abandoned in the area as a result of high iron content. In some cases, corrosion occasioned by the high iron content has weakened the fabric of mild steel structures used in borehole construction and pump installation resulting in 'sand pumping' and 'pump drop' or a drastic reduction of the lifespan of boreholes completed with mild steel and other corrosible materials.

Amajor (1987) explained the high occurrence of iron in groundwater in the area to be related to the geological history and source rocks of the deposits that constitute the aquifers in the Niger delta. According to him, the aquifers consist of sands with thick brown colouration due to iron oxide coatings and stains, most of the sands being second and/or third cycle sands with very long transport history. They may have originated from northern highlands of Kogi state where the sediments are usually rich in iron and may have contributed to the sediments that built up the delta. The high rate of deposition associated with the Niger delta may have preserved these iron-rich grains along with other iron minerals such as hematite, limonite and magnetite and incorporate them into geologic records. With slightly acidic and corrosive groundwater, the iron may have been leached from the iron minerals, stains and coatings and liberated into groundwater flow systems. Pyritic clay interbeds, organic matters and lignite which abound in the area may also have provided sources for the leaching of iron from sedimentary rocks into the groundwater systems.

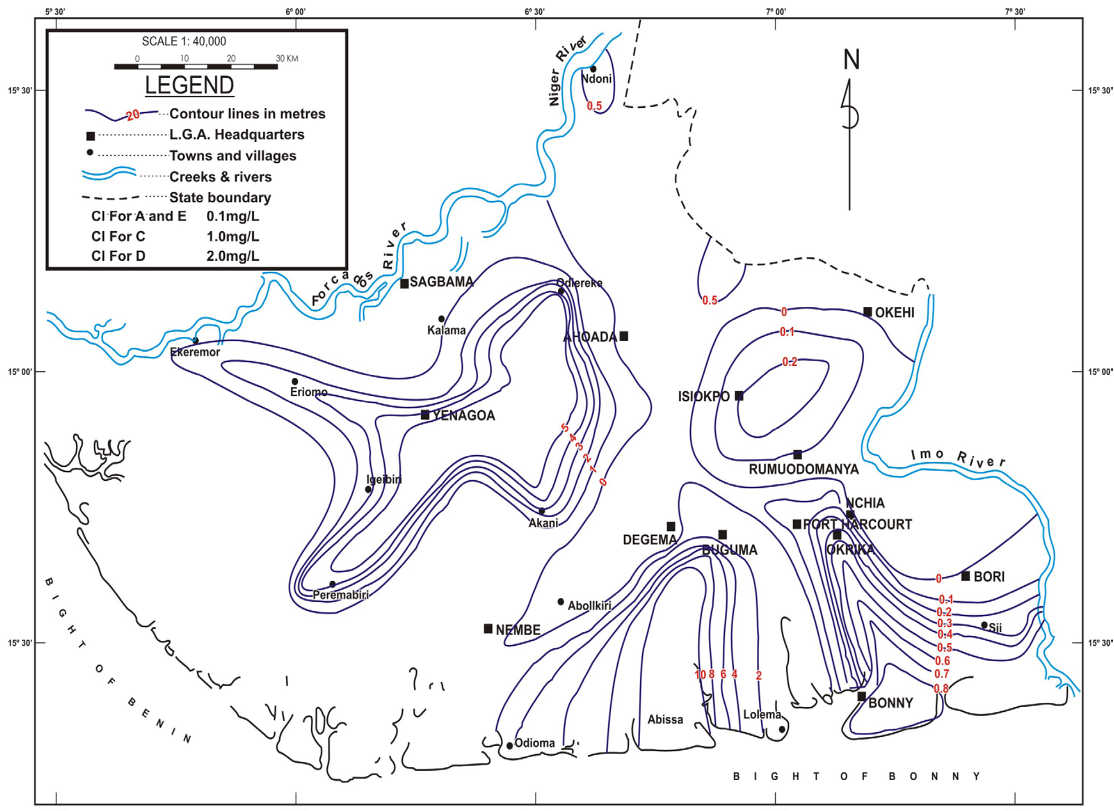

Fig.4: Pattern of distribution of iron in groundwater samples in the study area

Chloride

Chloride values were reported in all the samples analyzed. Their values range from 3mg/l – 810mg/l. NIS 554 (2007) specified 250mg/l as the upper limit of harmless tolerance. 68% of the samples have chloride concentration less than 48mg/l, 24% produced water with chloride concentration between 48mg/l and 250 mg/l while 8% produced water with chloride concentration greater than 250mg/l. The highest concentration of 801mg/l was obtained from a borehole at Oloma. Figure 5 shows a chloride distribution map of the study area. From the map, the chloride content in groundwater appears generally to decrease from north to south i.e. from the hinterland to the coast. The localized chloride enrichment around the Old GRA, Port Harcourt, Borokiri, Moscow road and Central Police Station in Port Harcourt could be as a result of brackish water invasion from nearby creeks and tidal channels. Chloride again is a major quality issue especially in groundwater in these areas as well as in the mangrove swamps and the coastal beaches and ridges.

Chlorine is the most abundant of the halogens. Its compounds with common metallic elements, alkali metals and alkali earth metals are readily soluble in water. Therefore, chloride is present in all natural waters but its concentration is lower than that of sulphates and bicarbonates especially in recharge areas. Generally, the most common type of water in which chlorine is the dominant anion is one in which sodium is the predominant cation. Amadi (2004) and Ngah (2009) noted that chloride produces salty taste in water which varies with quantity of sodium ions (Na^+). Predominance of Na^+ imparts highly noticeable salty taste even in small quantities of chlorine unlike when Ca^{2+} and Mg^{2+} predominate. Determination of chloride content is very important especially in coastal aquifers because the first sign of saline water intrusion is a progressive upward trend in chloride concentration in the water obtained from the affected boreholes.

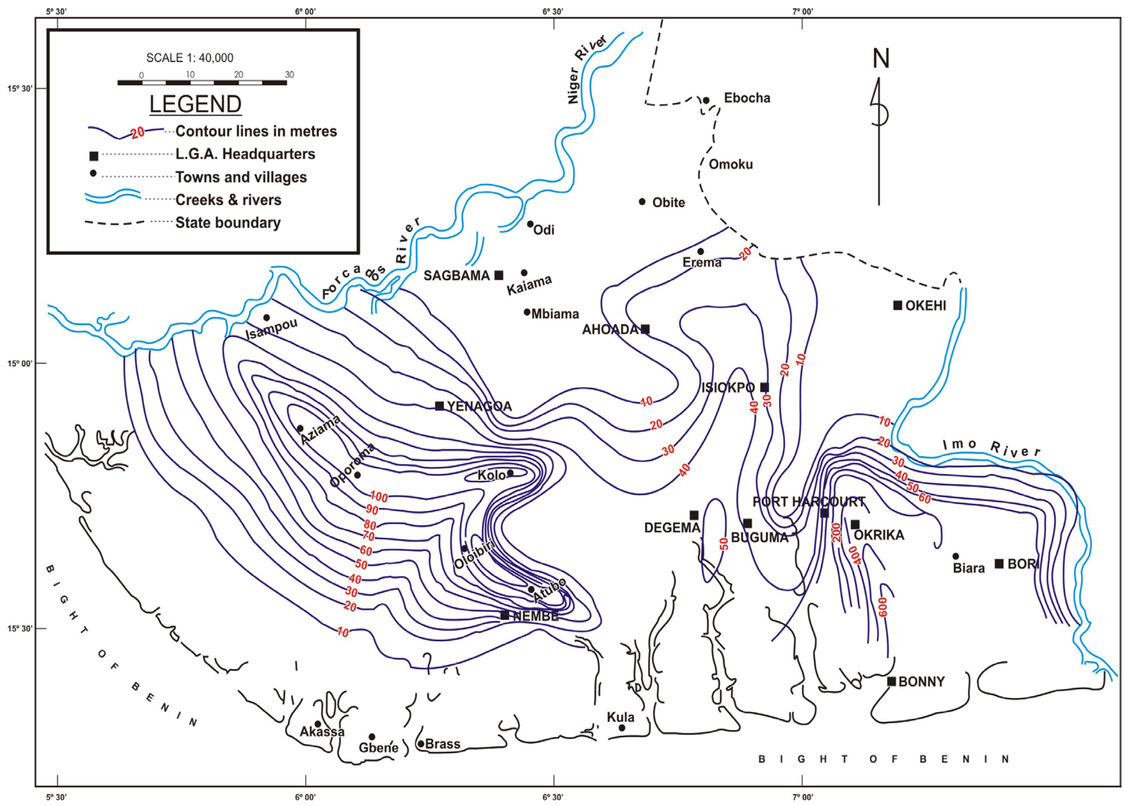

Fig. 5: Distribution of distribution of Chloride in groundwater samples in the study

CONCLUSIONS

From the above discussions, three parameters namely, pH, iron and chloride contents, form the main water quality issues in deep aquifers of the study area.

The problem of low pH and acidic water are more pronounced in the eastern parts of the area covering Ahoada, Isiokpo and Port Harcourt. Generally, the values range from very acidic (3.8 at Toru Ndoru) to permissible (8.4 at Kalaibiama). Iron is a more common problem in groundwater samples from the Freshwater swamps/Backswamp/Meander belt region, the Mangrove swamps and Coastal ridges. It may have originated from northern highlands from where sediments rich in iron which built up the delta originated. With the high rate of deposition associated with the Niger Delta, these sediments may have preserved their iron-rich grains along with other iron minerals and incorporated them into geologic records. The slightly acidic and corrosive groundwater prevalent in the area provided a suitable condition for iron to leach from the iron minerals, stains and coatings and thereby gain entry into the groundwater flow systems.

Chloride concentration is high particularly in the coastal areas and parts of Port Harcourt city bordering saltwater creeks and tidal channels which have influent relationship with the local groundwater table. The chloride originates from the nearby salt/brackish water bodies and from rain water especially in the coastal areas. Generally, the chloride content in groundwater appears to decrease from north to south i.e. from the hinterland to the coast. The localized chloride enrichment around a part of Port Harcourt and Borokiri could be as a result of brackish water invasion from nearby creeks and tidal channels. The study also revealed that most other chemical parameters show fairly tolerable concentrations in deeper aquifers of the area.

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Unsteady State Groundwater Flow in Semi-Finite Artesian Aquifer due to Water Level Changes in Bounding Channels

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ABSTRACT
In this paper, the flow of ground water induced by variation in water level in two channels bounding a confined aquifer was studied. The water level in each channel varies gradually over time and can be defined by exponential mathematical functions. Analytical solutions were sought to the problem using the Laplace transform method. The values of head were obtained in error functions which can be evaluated at various times and places in the aquifer. A numerical example problem was given in which head values at various places in the aquifer were computed at varying time intervals. Similar results were also obtained for various values of a delay constant introduced in the study and these were compared.

Keywords: unsteady state, finite artesian, groundwater, bounding channels

INTRODUCTION

In many instances, situations arise in the field in which a body of water in a channel interfacing an aquifer would constitute major sources of groundwater recharge. The water level in the channel can be subjected to different types of changes; either rapid or slow, depending on the event causing process. For instance, sudden release of water from remote sources due to water leakages or flood water resulting from intense precipitation falling over short period of time could generate large surface flow. This would lead to rapid build up of water level in the channel. Similar situations could also result from either pumping operations in irrigation fields, rapid withdrawal of water from storage reservoirs or sudden build up of water in reservoirs in pumped-storage hydropower generation plants.

Gradual change in water level on the other hand, could result from the drying up of lakes as a result of high evaporation processes. On global scale, sudden change in water level could result from freezing and de-freezing of polar ice due to climate change. In the case of coastal areas adjoining permeable rocks, flood waves generated by tidal oceans would induce ground water flow. Although the changes enumerated here could take place in remote areas, the effects are usually transmitted to all parts of the aquifer.

Problems of water level changes in channels, lakes and lagoons bounding aquifers have over the years received the attention of hydrologists and researchers. For instance, Hammad (1969) among earliest researchers studied the groundwater flow in African Saharan aquifer system; the results gave an idea of the pattern and general trend of ground water flow. Marino (1974) and Gill (1984) derived analytical solutions for groundwater flow problems in confined and semi-finite aquifers due to changes in channel water levels. Mustafa (1987, 1990) employed similar approach and in addition, introduced a practical dimension to the problems, by examining variations in groundwater flow induced by both surface infiltration and channel water level changes bounding aquifers.

Since the development of GIS system, 3-D groundwater flow modelling has, of recent, gained prominence as more information can be obtained on the nature, pattern and trend of groundwater flow in aquifers on regional scale. For example, Gossel et al (2004) applied the GIS-based groundwater flow modelling technique to study the long term groundwater flow in the Nubian sandstone aquifer in Eastern Sahara. The results of the studies indicated that the Nubian Aquifer groundwater system had been formed by infiltration during the 20,000 –

5,000 (BP). The studies further found that the aquifer system is a fossil aquifer and had been in unsteady state condition for the last 3,000 years.

Recently, the case of surface and subsurface water interaction generally observed in coastal areas, giving rise to moving water boundary, was studied by Kong et al .(2010). A moving water boundary was simulated by a linked groundwater and surface water 2-D model; an improvement over a 1-D model employed by previous researchers. The governing equations that were developed in the model were solved numerically, using finite difference methods.
Similarly, Hashemi et al. (2012) employed the MODFLOW-2000 ground water flow model under steady state conditions to determine the recharging system in the Gareh-Bygone Plain in southern Iran. The study used the flood water spreading system that was established to recharge the ground water. The results showed that without surface water inflow, the plain was recharged by the fault conducting water from the upper sub-basin.

The problem here is aimed at studying the effect of flow resulting from water level changes taking place in two channels bounding a semi-finite artesian aquifer which can be linked to a moving boundary. A mathematical representation of the problem is shown in Fig.1 for which analytical solution was sought.

MATHEMATICAL REPRESENTATION OF THE PROBLEM

In the study presented herein, a situation is visualized in which the water levels in both the LHS and RHS channels shown in Fig.1 were initially at the same level, the datum. Thereafter, they both change gradually, as to induce groundwater flow into the adjoining aquifer. A solution is sought on the nature and distribution pattern of groundwater flow under unsteady state conditions using the boundary conditions to be specified.

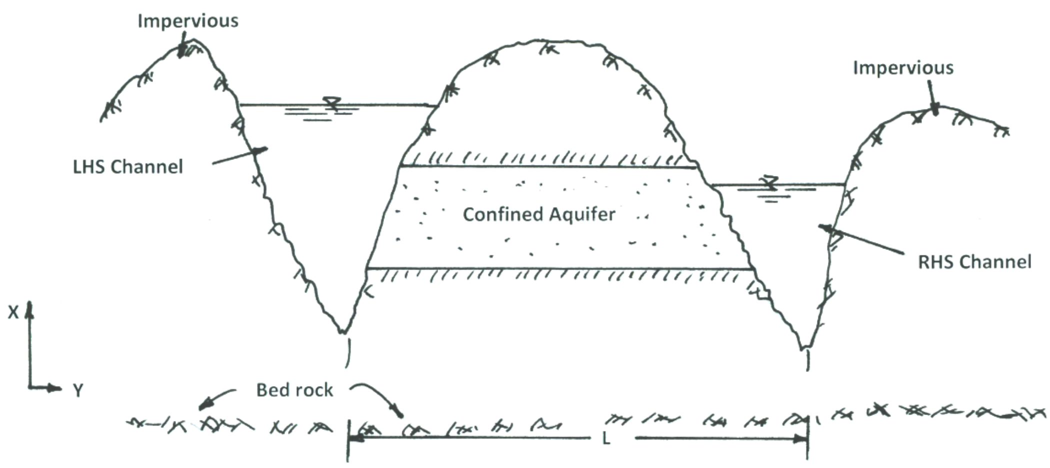

Fig. 1: Schematic representation of the problem

The one-dimensional unsteady state groundwater flow equation in confined aquifer is given by

$$\partial^2/\partial x^2 = \frac{1}{\alpha}\,\partial h/\partial t \qquad - \qquad (1)$$

Equation (1) is a Partial Differential Equation (PDE). In seeking solution to the PDE, either one of the three types of boundary conditions must be specified, in addition to the initial conditions. These boundary conditions are:

i) Drichlet's condition - the value of the solution at the boundary
ii) Neumann's condition - the values the derivatives take at the boundary
iii) Robin's (or Cauchy's) condition - weighted combination of Drichlet and Neumann conditions.

The nature of the problem studied here is of the Drichlet's class of problems. The following boundary and initial conditions apply herein.

$h(x,0) = 0, \quad t \leq 0$ (2a)

$h(0,t) = H_o e^{\theta t}, \quad t > 0$ (2b)

$h(L,t) = H_o (1 - e^{\theta t}) \quad t > 0$ (2c)

This means, the head h, in the channels at x = 0 and at x = L will change after time t > 0
For the stability of the solution to be maintained, time t is limited to say, t= τ, a finite value while, θ is the delay constant, a very small quantity. Indeed, θ is of the order of 10^{-6} t^{-1}
Let solution be sought by taking the Laplace transform of Eq.1, and Eqs.2 (a-c) thus:

L {h(x,t) } = h(x,p)

where p is the transform time

Hence, the solution for Eq.1 is put in the form:

$$h(x, p) = C_1\cosh(\varphi x) + C_2 \sinh(\varphi x) \quad (3)$$

where $\varphi = (p/\alpha)^{1/2}$ and C_1 and C_2 are constants

Now, from Eq. (2b), $h(0, p) = \frac{H0}{p-\theta}$ (4a)

and from Eq. (2c), $h(L, p) = H_0(\frac{1}{p} - \frac{1}{p-\theta})$ (4b)

Putting these into Eq.3, the values of the constants are obtained as

$$C_1 = \frac{H0}{p-\theta} \text{ and } = H_0 \{(\frac{1}{p} - \frac{1}{p-\theta}) - \frac{\cosh(\varphi L)}{(p-\theta)}\}\frac{1}{\sinh(\varphi L)} \quad (5)$$

Finally rearranging Eq.3 after putting the values of the constants C_1 and C_2,

$$h(x, p) = H_0 \{ \frac{\sinh \varphi(L-x)}{(p-\theta)\sinh(\varphi L)} + \frac{\sinh(\varphi x)}{p\sinh(\varphi L)} + \frac{\sinh(\varphi x)}{(p-\theta)\sinh(\varphi L)} \} \quad (6)$$

Now, using Binomial series expansion and after some algebraic rearrangement of Eq.6 gives for the term,

$$\frac{\sinh \varphi(L-x)}{\sinh(\varphi L)} = \sum_{n=0}^{\infty}[\exp -\varphi(2nL + x)] + \sum_{n=0}^{\infty}[exp - \varphi(2(n+1)Lx)] \quad (7a)$$

and

$$\frac{\sinh(\varphi x)}{sinh(\varphi L)} = \sum_{n=0}^{\infty}[\exp -\varphi(2nL + L - x)] + \sum_{n=0}^{\infty}[exp - \varphi(2nL + L + x)] \quad (7b)$$

For brevity, let us define the following space variable as,

$\mu_1 = 2nL+x$

$\mu_2 = 2nL+2L-x$

$\beta_1 = 2nL+L-x$

$\beta_2 = 2nL+L+x$

Thus, Eq.6 can be expanded as,

$$h(x,p) = H_0\{ (1/(p-\theta)) \{ \sum_{n=0}^{\infty} \exp(-\varphi\mu_1) + \sum_{n=0}^{\infty} \exp(-\varphi\mu_2)\}$$
$$+ (1/(p)) \{ \sum_{n=0}^{\infty} \exp(-\varphi\beta_1) + \sum_{n=0}^{\infty} \exp(-\varphi\beta_2)\}$$
$$- (1/(p-\theta)) \{ \sum_{n=0}^{\infty} \exp(-\varphi\beta_1) + \sum_{n=0}^{\infty} \exp(-\varphi\beta_2)\} \} \quad (8)$$

The total solution is now obtained by taking the inverse Laplace transform, one by one of all the summation terms in Eq.8. That is,

$$h(x,t) = L^{-1}\{h(x,p)\}$$

Replacing φ by $\sqrt{\alpha t}$, and putting the values of μ_1, μ_2, β_1, and β_2 accordingly, the resulting solution, giving the head in the aquifer at various places and times,

$$h(x,t)= H_0 \{ \sum_{n=0}^{\infty} 1/2[\exp(\theta t)]\{\exp\text{-}(2nL+x)\sqrt{\theta/\alpha})\ \mathrm{erfc}\ ((2nL+x)/2\sqrt{\alpha t} - \sqrt{\theta t})$$
$$+ \sum_{n=0}^{\infty} \exp((2nL+x)\sqrt{\theta/\alpha})\ \mathrm{erfc}\ ((2nL+x)/2\sqrt{\alpha t} + \sqrt{\theta t})\}$$
$$+ \sum_{n=0}^{\infty} 1/2[\exp(\theta t)]\{\exp\text{-}((2nL+2L-x)\sqrt{\theta/\alpha})\ \mathrm{erfc}\ (\text{-}(2nL+2L-x)/2\sqrt{\alpha t} -$$
$$\sqrt{\theta t})$$
$$+ \sum_{n=0}^{\infty} \exp(\sqrt{\theta/\alpha})\ \mathrm{erfc}\ ((-(2L+2L-x)\ /2\sqrt{\alpha t} + \sqrt{\theta t})\}$$
$$+ \sum_{n=0}^{\infty} \mathrm{erfc}((2nL+L-x)/2\sqrt{\alpha t}) + \sum_{n=0}^{\infty} \mathrm{erfc}((2nL+L+x)/2\sqrt{\alpha t})$$
$$- \sum_{n=0}^{\infty} 1/2[\exp(\theta t)]\{\exp\text{-}((2nL+L-x)/\sqrt{\theta/\alpha})\ \mathrm{erfc}\ ((2nL+L-x)/2\sqrt{\alpha t} - \sqrt{\theta t})$$
$$- \sum_{n=0}^{\infty} \exp((2nL+L-x)\sqrt{\theta/\alpha})\ \mathrm{erfc}\ ((2nL+L-x)/2\sqrt{\alpha t} + \sqrt{\theta t})\}$$
$$- \sum_{n=0}^{\infty} 1/2[\exp(\theta t)]\{\exp\text{-}((2nL+L+x)\sqrt{\theta/\alpha})\ \mathrm{erfc}\ ((2nL+L+x)/2\sqrt{\alpha t} - \sqrt{\theta t})$$
$$- \sum_{n=0}^{\infty} \exp(\sqrt{\theta/\alpha})\ \mathrm{erfc}\ ((2nL+L+x)/2\sqrt{\alpha t} + \sqrt{\theta t})\}\} \quad (9)$$

where,

erf(x) = 1 – erfc(x) and erf(x) $=\frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt$ (10a)

The values of the function can be obtained in standard mathematical handbooks.
Using Taylor series expansion and integrating the error function, gives

$$erf(x) = 1-\frac{1}{\sqrt{\pi}}e^{x^2}\{1/x - 2/x^3 + (1.3)/(2^3x^5) - (1.3.5)/(2^3x^7) + \ldots\} \quad (10b)$$

From Abramowitz and Stegun (1992), an approximation of the function is

$$erf(x) = 1 - 1/(1 + a_1x + a_2x^2 + a_3x^3 + a_4x^4)^4 + e(x) \quad (10c)$$

Such that, $|e(x)| \leq 5 X 10^{-4}$

Constants a_1, a_2, a_3 and a_4 are obtained from rational fitting of weights thus:

a_1= 0.278393, a_2= 0.23030389, a_3 = 0.000972 and a_4 = 0.078108
The error function complimentary takes special values at
erfc(0) =1 ; erfc(∞) =0 and erfc($-\infty$) =2

DISCUSSION OF RESULTS
Suppose, the delay constant θ=0, Eq.9 reduces to

$$h(x,t) = H_0 \{ \sum_{n=0}^{\infty} erfc\frac{(2nL+x)}{2\sqrt{\alpha t}} + \sum_{n=0}^{\infty} erfc\frac{(2nL+2L+x)}{2\sqrt{\alpha t}} \} \quad (11)$$

This is identical to the solution obtained by Gill (1984) for groundwater flow due to sudden rise of water in one channel only. This means, the flow situation is due only to water level changes in the left hand side channel.

A numerical example is given for the solution in which typical aquifer values and constants were assigned to parameters in Eq.9.

To obtain the head distribution in the aquifer at various time intervals, the distance between the channels is set at, **L**= 1000m.

Time t is practical time in days and set at, t = 1 day, 2 days, 5 days, 10, days, 50 days, . . etc
The head causing flow is fixed at, 10m. This value is sufficient to generate determinable flow in the aquifer system.

Using a typical aquifer parameter $\boldsymbol{\alpha}$ = 12,000m^2/day, the value for the delay constant at a start was put at $\boldsymbol{\theta}$= 5 x 10^{-5} t^{-1} which was gradually increased to $\boldsymbol{\theta}$ = 5 x 10^{-3} t^{-1} .

Using MS- EXCEL, the various heads were calculated at distances fixed at x = 10m, 20m, 50m, 100m, . . 600m from Eq. 9, using the approximation formula obtained for the error function given in Eqs.10 (a-c).

Head values at time t= 1 day, 5 days,10 days, 20 days and 30 days were determined and plotted for varying values of the delay constant $\boldsymbol{\theta}$ and shown in Figs.2 - 6.

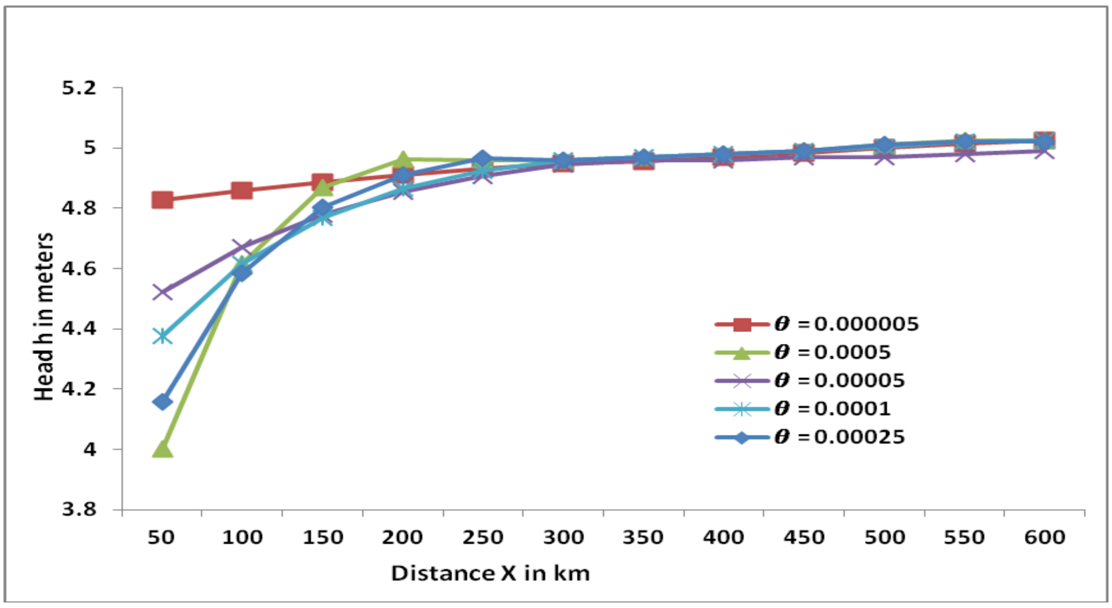

Fig. 2: Variation of head for varying θ at time t=1 day

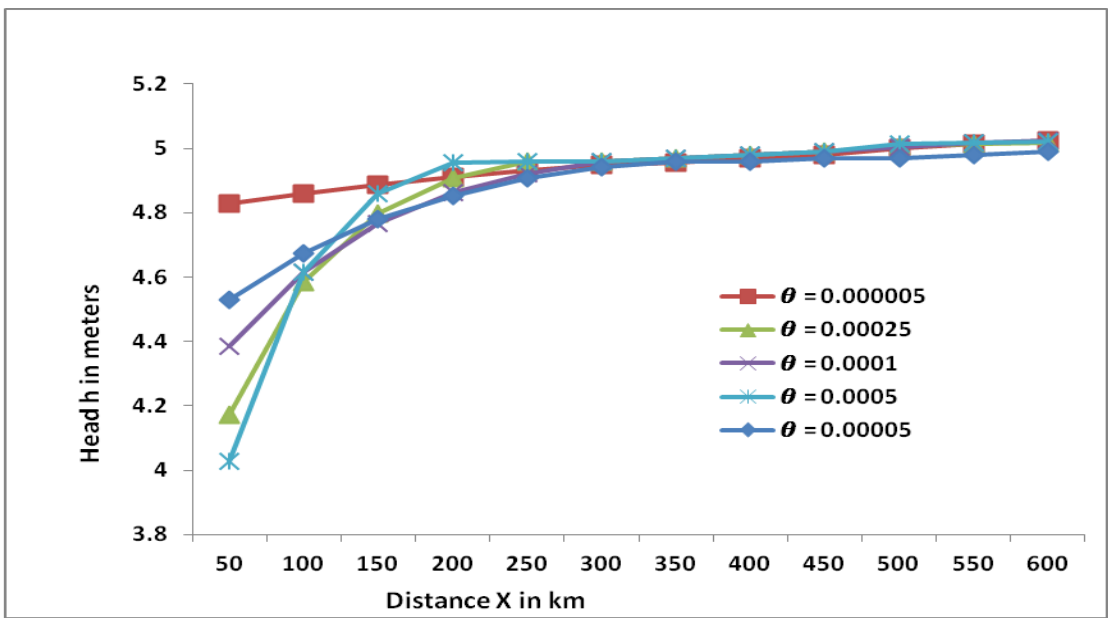

Fig. 3: Variation of head for varying θ at time t=5 days

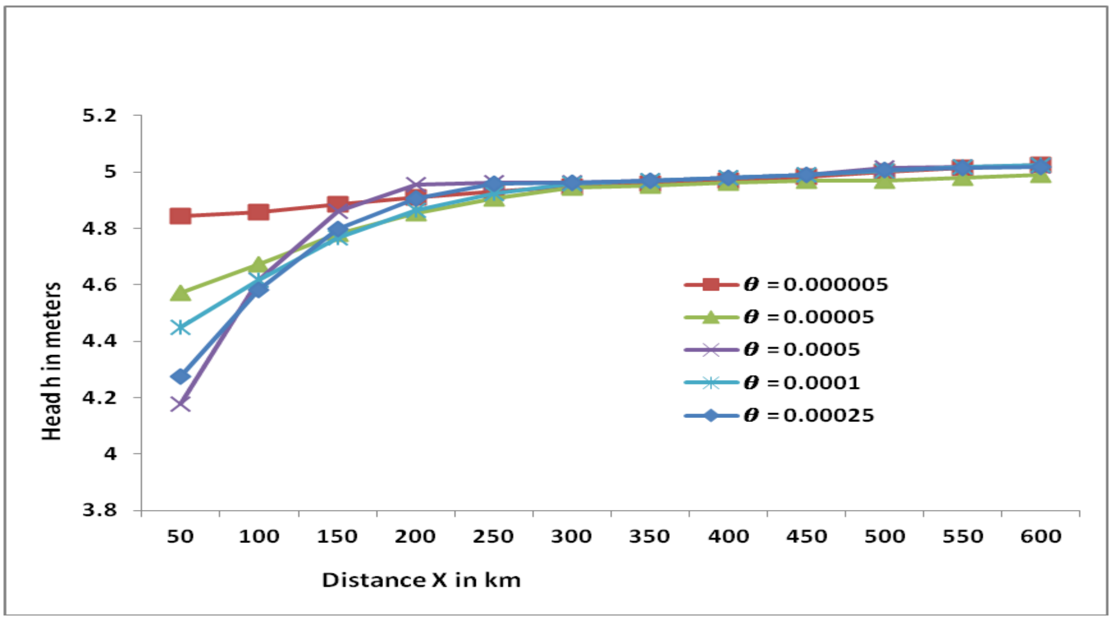

Fig. 4: Variation of head for varying θ at time t=10 days

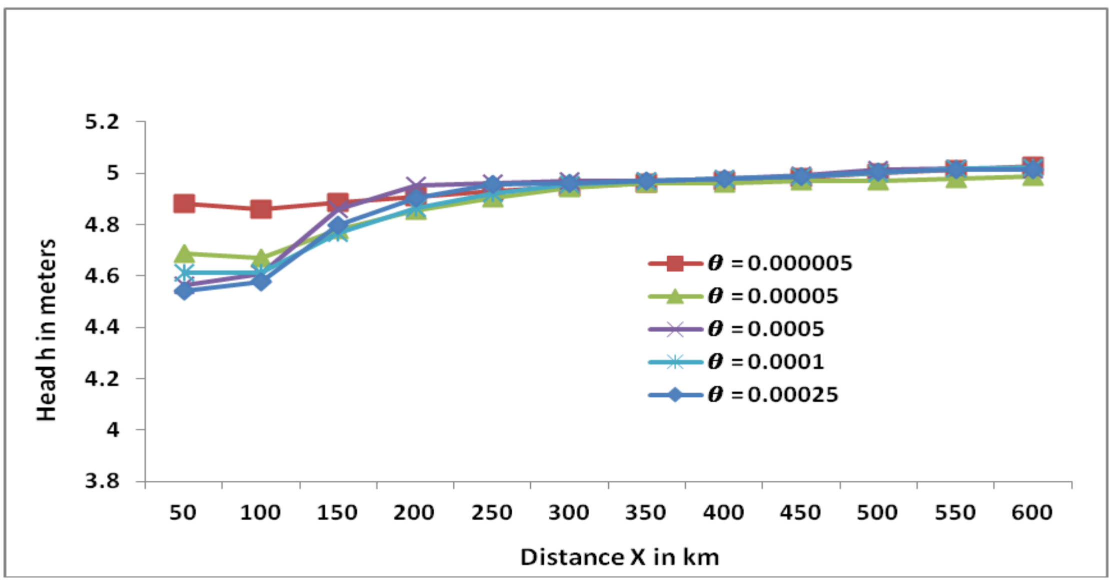

Fig. 5: Variation of head for varying θ at time t=20 days

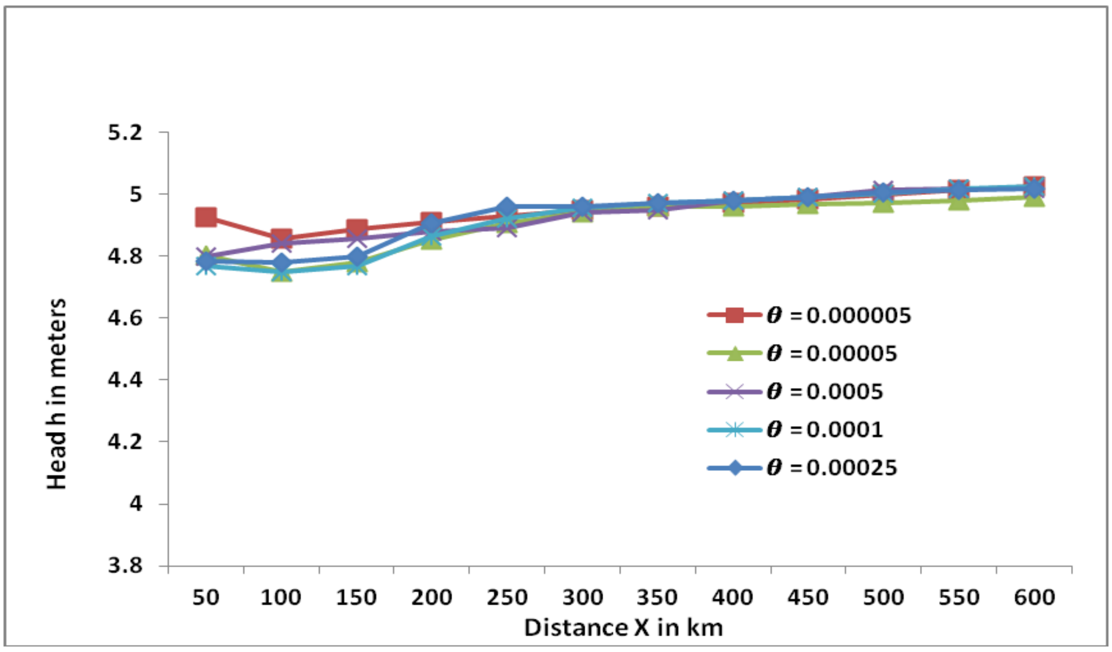

Fig. 6: Variation of head for varying θ at time t=30 days

The values of head at start which were not fixed are clearly shown at the start. There were changes as expected in the head distribution albeit, not much, as the delay constant θ was increased. The head causing flow is from the boundary on the right to left due to higher rise in head in the former than in the latter. The pattern has remained the same with time although there is appreciable variation from one time period to another. The effect of increasing the delay parameter θ was not that pronounced in the head distribution as expected however, it has changed the flow pattern.

CONCLUSION

The problem of flow situation in finite artesian aquifer in which the level of water in two channels bounding an aquifer change was investigated. The change takes place gradually, over time, defined by mathematical functions; for which, solutions were obtained, using Laplace transform method. Analytical solutions for the problem studied were given in error functions. A numerical example was given in which at various time intervals the head distribution in the aquifer at different places was calculated using MS-Excel computer program. These solutions would help to understand the nature of ground water flow resulting from sudden inflow of surface water, such as caused by flood water, or tidal waves generated in coastal areas.

Acknowledgement
The assistance received from Professor Gregory M. Wajiga of the Department of Computer Science, Modibbo Adama University of Technology, Yola towards the computation of the numerical example problem, using MS-Excel 2010 is greatly appreciated and hereby duly acknowledged.

Notations

H_0, h = head in aquifer - (L)
α =T/S - (L^2T^{-1})
T = transmissibility - (L^2T^{-1})
S= Storativity of the aquifer - (storage coefficient; dimensionless)
$\varphi = (p/\alpha)^{1/2}$ - (L^{-1})
p = parameter in Laplace transform - (T^{-1})
L = distance separating the two bounding channels - (L)
θ= delay parameter - (T^{-1})
***t, τ*= time - (T)**
μ_1, μ_2, β_1, β_2 = space variables, f(x,L) - (L)
C_1 and C_2 are constants – (LT)

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Village Level Operation and Maintenance (VLOM) of Hand Pumps: A Concept for Sustainability of Rural Water Sources in Nigeria

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Abstract

The objective of this paper is to present successes achieved in the field by building the capacities of community members, using the Village Level Operation and Maintenance (VLOM) of hand pumps concept document developed by the Federal Ministry of Water Resources.. Activities carried out in 17 selected states in Nigeria included training on maintaining current, valid and up to date data on hand pumps in the states. Other activities included establishing the roles of stakeholders, capacity building for community members on repair and rehabilitation of hand pumps and the establishment of an effective supply chain. Results achieved in the participating states showed that the capacity of the artisans was enhanced. In addition, about 486 non functional hand pumps were rehabilitated, 540 'Water Sanitation and Hygiene Committees' (WASHCOMs) were established during the community mobilization and 22 Spare parts outlets were established. Two states achieved a complete inventory of water sources in the states during the exercise and five of the states achieved wide participation of Local Government Areas (LGA) on capacity building of local mechanics. The paper recommends that VLOM components should be integrated in all new water supply projects and in the implementation of relevant policies.

Keywords: Village Level Operation and Maintenance, Sustainability, Capacity Building, Access, Community Mobilization.

INTRODUCTION

Nigeria had a population of 140,431,790 in 2006 with an annual growth rate of about 3.2% over a total land area of 923,768 km^2 (NPC Report, 2009). The 2008 Demographic and Health Surveys (DHS) report estimated that about 54% of the population has access to improved source of drinking water. The DHS (2008) also estimated that about 31% of the population use improved sanitation facilities. Access to improved water supply in rural areas is defined in this paper as the availability of at least 30 litres of improved safe water per person per day within 250 m of the dwelling of the users (National Water Supply and Sanitation Policy, 2000). Sources of such water include pipe, borehole, rainwater harvesting, protected well and protected spring. Safe water also refers to water, which is free of any significant risk to health over the lifetime of consumption. Drinking water is also defined in this paper, based on the Nigerian Standard for Drinking Water Quality definition as, water in its original state or after treatment, intended for drinking, cooking, food preparation or other domestic purposes, regardless of its origin and whether it is supplied from a drinking water system, or a tanker, or taken from a private well (NIS 554, 2007). The National Policy on Water Supply and Sanitation (2000) puts the percentage of those having access to safe water in rural Nigeria at about 39 percent and for the small towns (semi-urban) at about 42 percent. The national average was put at 53.4 percent in 2006, which increased slightly to 54.2 percent in 2008 (NDHS, 2008).

Meeting the MDG goals is a professed long-term objective in Nigeria. However, the translation of the objective into reality requires a substantial number of new water sources, majority of which can be expected to be installed in areas with least access figures, that is, in the rural areas, where boreholes with hand pumps and the rehabilitation of non functional water sources are considered most viable. Efforts towards increasing access to safe water in rural areas have led to the promotion of hand pumps in such settings. The extent to which the interventions and new services will continue to operate satisfactorily and generate benefits over their planned life is termed as sustainability. Sustainable development concerns environmental sustainability, an issue beyond individual projects but towards which projects can contribute (Smout, 2008). Sustainable development is such that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Maintenance, which is a major factor of sustainability, is often viewed by institutional players in the sector as a "burden", without considering the fact that meeting maintenance needs is inevitable as soon as a new water source is constructed. In view of the stated fact, the concept of VLOM was introduced and the concept document developed for Nigeria by the Federal Ministry of Water Resources in 2010 (FMWR, 2010).

The objective of this paper therefore is to present successes achieved on application of VLOM documents in 17 states in terms of:

- Capacity building of community members on the maintenance of hand pumps towards enabling communities to own and manage the operation and maintenance of their drinking water sources.
- Establishing effective supply chain for communities and artisans to access spare parts and maintenance services.
- Building the capacity of Government institutions at Federal, State, LGA and community levels to support VLOM.

VILLAGE LEVEL OPERATION AND MAINTENANCE (VLOM) DOCUMENTS

The Dublin principles are a very useful point of reference in developing strategies for progress in any water supply scheme. The principle (www.gwpforum.org/servlet,1992) states that

1. Fresh water is a finite and vulnerable resource, essential to sustain life, development and environment. (Effective management of water resources therefore demands a holistic approach.)
2. Water development and management should be based on a participatory approach, involving user, planners and policy makers at all levels. (Means that decisions should be taken at the lowest appropriate level)
3. Women play a central part in the provision, management and safeguarding of water.
4. Water has economic value in all its competing uses and should be recognized as an economic good.

In response to the need for training documents, the Village Level Operation and Maintenance (VLOM) Concept document was developed by the Federal Ministry of Water Resources (2010). VLOM is to address the challenges of maintenance experienced in the field because planned and coordinated means of Operation and Maintenance of hand pumps did not previously exist in the country. The VLOM concept document and training manuals were developed taking into account key strategies of meeting the challenges of ensuring the sustainability of existing and new facilities, the 'community management' strategy.

Community management of rural water sources includes ownership and responsibility for operation and maintenance.

VLOM concept document was put together from field experiences of many states which have operated installed hand pumps for a period of time (especially states of over 10 years operational experience) and also the fact that VLOM had been a major maintenance culture in India where the use of hand pumps is very common.

The process of the establishment of VLOM may be categorized into achieving the following milestones:

1. Assessment of Institutional Capacity
2. Inventory of Water Sources
3. Creating Ownership – Establishing the Role of Stakeholders
4. Community Mobilization
5. Capacity Building
6. Repair and Rehabilitation of dysfunctional hand pumps
7. Handover of functional Installations
8. Establishing an effective Supply Chain
9. Monitoring of VLOM establishment

The application of the Dublin principles has played a key role in decision making in the VLOM initiative and a strategic focus on the principles will further play a key role in the way forward on the initiative.

METHODOLOGY

A survey was conducted between 2007 and 2011 with UNICEF support to assess Milestones 2 to 9 using 17 participating states in Nigeria. The states are Benue, Borno, Cross River, Ebonyi, Ekiti, Enugu, Gombe, Imo, Jigawa, Kano, Katsina, Kebbi, Kwara, Ogun, Osun, Yobe and Zamfara.

Milestone 2: In the 17 states, questionnaires were developed on data collection and staff members from the Rural Water Supply and Sanitation Agencies (RUWASSA) were trained on data collection, updating and maintaining current and valid data base on all hand pumps in the states.

Milestone 3: All selected states except Zamfara State participated in workshops (participants made up of personnel in each state ministry of water resources, development partners and representatives of participating LGAs) where the roles of stakeholders were articulated and agreed upon during the initial VLOM training. The communiqué developed by each state at the end of the workshops detailed out the role of the stakeholders.

Milestone 4: Community mobilization was achieved by initiating the mobilization from the Water, Sanitation and Hygiene (WASH) Department of the participating Local Governments. The WASH officers then led WASH teams to communities where hand pumps were installed; various manuals were available for use in the visited communities for mobilization. Communities, fully mobilized, led on hand pump maintenance.

Milestones 5, 6 and 7: Capacity building and repairs were achieved by the use of training Manuals from the Federal Ministry of Agriculture and Water Resources (2008a, 2008b, 2008c and 2008d) at various hand pump locations. To this end, hand pumps were practically dismantled and repaired/rehabilitated following the instructions in the manuals. The manuals that were used include:

- Installation & Maintenance of RUWATSAN I Hand pumps
- Installation & Maintenance of RUWATSAN II Hand pumps
- Construction of Platforms and Drains for Hand pumps
- Preventive Maintenance of RUWATSAN I and India Mark II hand pumps

Trainings were conducted for local area mechanics to build their capacity as the technical contacts for repairs and rehabilitation of hand pumps in communities; Training of Trainers (ToT), training of caretakers and artisans on preventive maintenance of hand pumps were carried out. The repaired/rehabilitated hand pumps were handed over to the communities for ownership. Results achieved by LGAs are presented in Table 1.

Milestone 8: Rehabilitation of hand pumps cannot be achieved without availability of spare parts. Therefore, supply chain is a critical component of VLOM. Seed stock of spare parts was made available to communities with support from UNICEF. The stock are sold and replaced with a reasonable profit margin. Benefiting States and LGAs are presented in Table 1.

Milestone 9: Monitoring, which is a compulsory process was initiated. Monitoring and Evaluation (M&E) is designed to be a continuous process. At the end of the above activities, a case study was conducted in Benue State on the impact of VLOM in the state using the flow chart (Fig. 1).

RESULTS AND DISCUSSION

Trend in the Use of Hand Pumps in Nigeria

The Standards Organization of Nigeria had produced Standards for two brands of hand pumps for the country, namely the NIS 326 parts I and II for RUWATSAN I (similar to the India Mark III hand pump) and RUWATSAN II (similar to the Afridev hand pump) in conjunction with stakeholders (NIS 326, 2009). The hand pump Standards were approved by the Council of Standards Organization of Nigeria for quality assurance of hand pumps and accessories for the sustainability of the water sources.

The survey conducted in 2011 with UNICEF support on inventory of water points in four states of Benue, Katsina, Bauchi and Jigawa showed that Bauchi State has 608 hand pump equipped boreholes (HPBH), Benue has 341 HPBH, Jigawa State has installed a total of 1174 HPBH while Katsina State has 340 HPBH. Similarly, data on other states with hand pump equipped boreholes show that Ogun State has 250 in different Local Government Areas (LGAs). Information showed that usage of hand pumps was established in Ogun State in the 1990s during the Guinea Worm eradication programme. The construction of hand pump equipped boreholes in the state has contributed to the low levels of water borne diseases currently in the state. The state currently has 'zero Guinea Worm disease' case (WHO, 2013). The maintenance of the hand pumps had been a major challenge until recent times when the VLOM concept was adopted. The need for constant training of artisans on the maintenance of hand pumps is also achieved by the use of the developed manuals. For example, it was found that in the 33 LGAs of Oyo State, 2,233 boreholes were equipped with hand pumps and motorized pumps as at December 2010. The need for quality assured spare parts and tools, and the need for capacity building in various aspects of maintaining the water sources has also been established in the state. Similarly, Ebonyi State has about 2,077 hand pumps in 12 LGAs. The issue of training and re-training of local artisans and mechanics is a consistent need to date.

Table 1: VLOM Activity in Seventeen Participating States in Nigeria

S/N	States	LGAs	Output	Milestones reached towards achieving VLOM	Results Achieved
1	Benue	Guma	2 Local Area Mechanics (LAMs) and 36 Local artisans trained on hand pump (HP) maintenance, 44 WASHCOMs(Water, Sanitation and Hygiene Committees) formed	2,3,4,5,6,7,8,9	42 non functional hand pump (HP) boreholes rehabilitated
		Tarka	2 LAMs trained	5	
		KatsinaAla	2 LAMs trained	5	
		Agatu	2 LAMs trained	5	
		Obi	2 LAMs trained	5	
		Ushongo	2 LAMs trained	5	
2	Borno	Gwoza	2 LAMs trained per LGA, 50 WASHCOMs formed in the state, 2 spare parts outlets set up in Gwoza and Bama LGAs	2,3,4,5,6,7,8	50 non functional Hand pump boreholes rehabilitated
		Bama		2,3,4,5,6,7,8	
		Other LGAs with HPs	2 Local Area Mechanics Trained from each	5	
3	Cross River	Abi	2 LAMs trained per LGA, 50 WASHCOMs formed in the state, 3 spare parts outlets set up in Abi, Obudu and Yala LGAs	2,3,4,5,6,7,8	50 non functional Hand pump boreholes rehabilitated
		Obudu		2,3,4,5,6,7,8	
		Yala		2,3,4,5,6,7,8	
		Other LGAs with HPs	2 Local Area Mechanics Trained each	5	
4	Ebonyi	Onicha	2 LAMs trained per LGA, 50 WASHCOMs formed in the state, 2 spare parts outlets set up in Onicha and Ikwo LGAs	2,3,4,5,6,7,8	50 non functional Hand pump boreholes rehabilitated
		Ikwo		2,3,4,5,6,7,8	
		Other LGAs with HPs	2 Local Area Mechanics Trained each	5	

S/N	States	LGAs	Output	Milestones reached towards achieving VLOM	Results Achieved
5	Ekiti	Ekiti West	2 LAMs trained per LGA, 50 WASHCOMs formed in the state, 3 spare parts outlets set up in Ekiti West, Odi -Ois and Gboyin LGAs	2,3,4,5,6,7,8	50 non functional Hand pump boreholes rehabilitated
		Odi – Ois			
		Gboyin			
		Other LGAs	No LAM trained	5	
6	Enugu	Aninri	Inventory of Water Sources in Aninri LGA	2,3,5	Hand pump Database established in 1 LGA
7	Gombe	Akko	2 LAMs trained per LGA, 50 WASHCOMs formed in the state, 3 spare parts outlets set up	2,3,4,5,6,7,8	50 non functional Hand pump boreholes rehabilitated
		Dukku			
		Shongom			
		Other LGAs	2 Local Area Mechanics Trained each	5	
8	Imo	Ohaji/Egbema	Creating Ownership by Stakeholders workshop at state level, inventory of water sources at 1 LGA, 5 LAM trained	2,3,5,6	3 non functional Hand pump boreholes rehabilitated
9	Jigawa	Buji	Creating Ownership by Stakeholders workshop at state level, inventory of water sources at 3 LGA, 10 LAMs trained, 9 TOT for community mobilization trained	2,3,5,6	Non functional Hand pump boreholes rehabilitated
		Guri			
		Taura			
10	Kano	Takai	10 LAMs trained, 36 Artisans/ caretakers trained, 47 WASHCOMs formed,	2,3,4,5,6,7,8,9	Community mobilization and Capacity building achieved
				5	

S/N	States	LGAs	Output	Milestones reached towards achieving VLOM	Results Achieved
	Kano	Minjibir	2 LAMs trained per LGA, 50 WASHCOMs formed in the state, 3 spare parts outlets set up	2,3,4,5,6,7,8	50 non functional Hand pump boreholes rehabilitated
		Kumbotso		2,3,4,5,6,7,8	
		Gaya		2,3,4,5,6,7,8	
		Other LGAs with HPs	2 Local Area Mechanics Trained each	5	
11	Katsina	State level	Inventory of Water sources completed in the state, creating ownership, WASHCOMs formed, ToT of HP mechanics	2,3,4,5,6,7,8	Comprehensive Hand pump Data Base available in the State
		All LGAs	Inventory of Water sources completed	2	
12	Kebbi	Fakai	2 LAMs trained per LGA, 50 WASHCOMs formed in the state, 3 spare parts outlets set up	2,3,4,5,6,7,8	50 non functional Hand pump boreholes rehabilitated
		Dandi		2,3,4,5,6,7,8	
		Other LGAs	No LAM trained	5	
13	Kwara	Asa	2 LAMs trained per LGA, 50 WASHCOMs formed in the state, 3 spare parts outlets set up	2,3,4,5,6,7,8	50 non functional Hand pump boreholes rehabilitated
		Edu		2,3,4,5,6,7,8	
		Other LGAs	No LAM trained	5	

S/N	States	LGAs	Output	Milestones Reached towards Achieving VLOM	Results Achieved
14	Ogun	Odeda	Creating Ownership by Stakeholders workshop at state level, inventory of water sources at 1 LGA, 8 LAM trained	2,3,5	Hand pump Data base established in 1 LGA
15	Osun	Ejigbo	2 Local Area Mechanics (LAMs) and 38 Local artisans trained on HP maintenance, 49 WASHCOMs formed	2,3,4,5,6,7,8	41 non functional Hand pump boreholes rehabilitated
16	Yobe	Geidam Nguru Bade	Creating Ownership by Stakeholders workshop at state level, inventory of water sources at 1 LGA, 9 ToT for LAMs trained, 9 ToT for Community mobilization trained, HPBHs rehabilitated in Jigawa during training	2,3,5,6	Hand pump Database established in 1 LGA
17	Zamfara	AnkaBakura	Inventory of Water Sources completed in Bukkuyum, B/Magaji, Gusau, Gummi, K/ Namoda, Maradu, Maru, Shinkafi, Tsafe, T/ Mafara, Zurmi	2	Comprehensive Hand pump Data Base available in the State

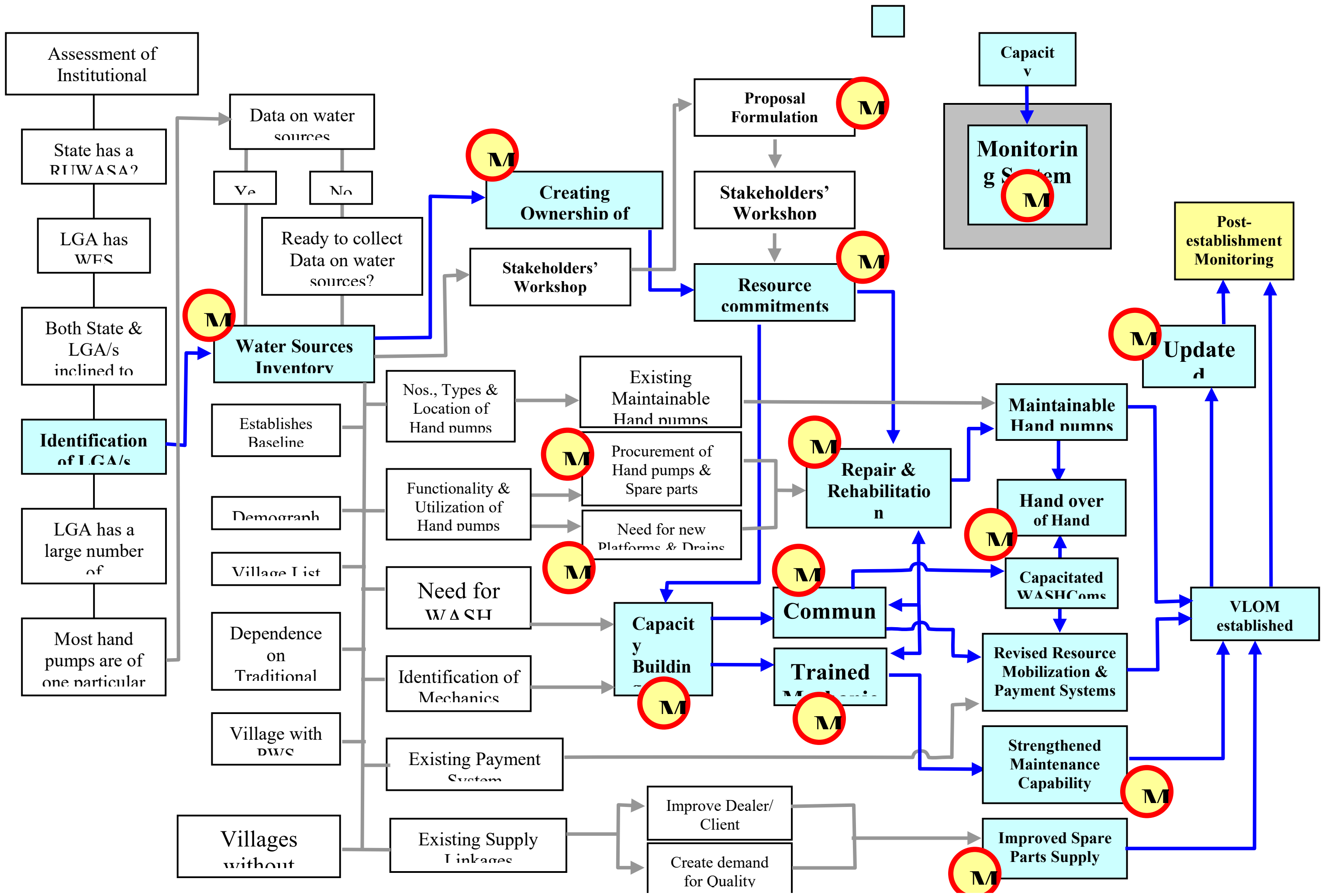

Fig. 1: Process of VLOM Establishment showing points for Monitoring (adopted from FMWR, 2010)

Project Ownership at Various Levels

Results achieved from the seventeen states that participated in the exercise are presented in Table 1. Only two states (Katsina and Zamfara) out of the 17 participating states had a comprehensive database of installed hand pumps as shown in Fig. 2. It is encouraged that other states should be committed to achieving state wide inventory of hand pumps in their states. Strengthening of VLOM has to be in critical areas such as project ownership, from

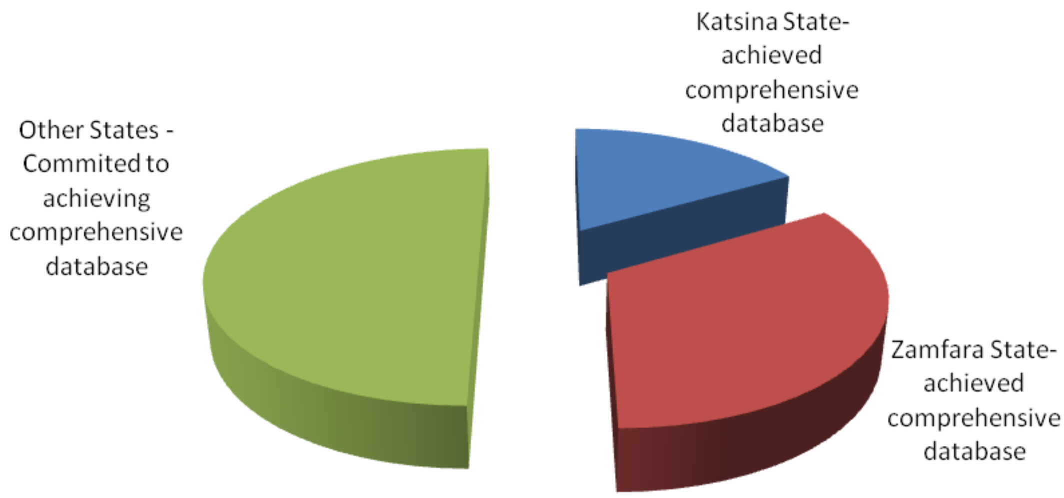

Fig. 2: Inventory of ownership at State level

Available Technology for Operation & Maintenance (O&M) in Rural Areas

It was found that various technology options installed in the field ranged from solar powered submersible pumps to Rain Water Harvesting (RWH) and hand pump equipped boreholes. In Benue State, RWH accounted for 14.64% of all improved water sources in the state and hand pump equipped boreholes accounted for (82.28%). The most common improved water source found in all the states surveyed in the rural areas is the hand pump equipped boreholes. Motorized systems (using generators) were found to account for 15.24% of the technology options in all the states. The maintenance for this high number of hand pumps installed in rural areas was found to be un-planned and un-documented. This was the situation that had earlier provoked the development of the VLOM concept document and training manuals. Thus, the survey conducted in 2011 also buttressed the relevance of developed documents, particularly in view of the high number of installed hand pumps.

In assessing the impact of the work done in participating states (M & E of VLOM documents), a case study of Benue State shows that as at 2011, the state had a total of 341 hand pumps with 70% functional hand pumps. Rehabilitation of a total of 42 hand pumps in the state improved the functionality status from 58% before the exercise to 70%. The impact of the VLOM is positively seen in the state.

Coverage and access to improved water sources in rural areas

The WHO/ UNICEF Joint Monitoring Programme report*,* shows that the use of improved drinking water sources in rural areas in Nigeria as at 2010 stands at only 43% (JMP, 2012) while the National Policy on Water Supply and Sanitation (2000) puts the percentage of those having access to safe water in rural Nigeria at about 39%. This slow increase of 4% over a period of ten years cannot support the achievement of the Millennium Development Goals by 2015. Coverage and access for improved drinking water sources in the rural areas need to be increased by strengthening VLOM in the rural areas. A total of 486 non functional hand pumps were rehabilitated during the exercise, 540 'Water Sanitation and Hygiene Committees' (WASHCOMs) were established during the community mobilization and 22 Spare parts outlets were established and five of the states achieved Local Government Area (LGA) wide participation on capacity building of local area mechanics. The application of the VLOM concept has contributed strongly to the increase of functional hand pumps in the selected states.

CONCLUSION

This paper noted poor project ownership at various levels and concludes that ensuring sustainability of both the existing and new water sources is a major concern in any planned, on-going or completed project. Coverage of and access to improved drinking water sources in the rural areas need to be increased by strengthening VLOM in the rural areas. There is also an urgent need to close the coverage and service gap that exists in the rural areas by promoting VLOM. Similarly, adopting the VLOM concept should improve the current water supply coverage in Nigeria. The assessment shows that VLOM is critical to sustainability of installed water sources in rural areas.

Finally, the paper recommends that:

- VLOM components should be integrated with all water supply projects.

- Implementation of relevant policies needs to become a state-owned strategy
- On the issue of poor ownership at community level:
  - Creation of new water sources should be demand-driven
  - Community contribution towards the cost of water source should be ensured in accordance with existing policies
- There is a need for Government to assess and build a critical mass of capacitated personnel at all levels towards achieving the sustainability of rural water sources.
- Selection criteria should be formulated for all trainees participating in capacity building towards establishing VLOM (including local area mechanics).
- An effective mechanism for monitoring of the progress in establishing VLOM should be put in place in all participating states.

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The Management of urban self-supply wells in Abeokuta, Nigeria: An assessment and redefinition of roles for water safety planning

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ABSTRACT

This paper describes source management practices of self-supply wells in Abeokuta, Nigeria, through a descriptive case study involving semi-structured interviews with open ended questions. The paper detailed perception of users as per source management, the management problems, and factors influencing the identified problems. A major problem is lack of co-operation among resident users. The resident users are further highlighted as managers of self-supply systems. The highlighted role of the resident users showed one of the unique management features of self-supply sources - that is, systems owned by one but managed by many. This management feature is different from communal systems – owned and managed by the community or the public water systems, which are largely owned and managed by the Government. The paper identifies possible solutions, and argues the need for appropriate role definition in water safety development and implementation for the systems in view of the fact that self-supply owners qualify as self-supply sources yet the existing management practices becloud their role definition in water safety plans.

Keywords: Self-supply systems, source management, water safety, water supplier, urban.

INTRODUCTION

Water safety guidance has been developed for large scale water utilities and small community water systems (Davison et al., 2005; Godfrey and Howard, 2005; Donlon, 2004; Mahmud et al., 2007). Water safety plans development for both types of systems is possible because the responsibility to develop and comply with water safety guidance is placed on source owners

(Davison *et al.,* 2005; Schmoll *et al*., 2006). The ownership of both the public water utilities and community water sources are usually entrenched in governmental and/or non-governmental institutions. These institutions claim responsibilities for provision (and/or funding of public water suppliers), management, and in the case of public utilities, for maintenance and operations. In the wake of water safety plans, some institutions have called for and are involved in ensuring safety measures in the large scale water networks and the community systems. Presently however, water safety guidance for privately owned water sources is yet to be seen.

Two factors may be associated with the current non-emergence of water safety guidance for self-supply sources. The first factor is the type of ownership that surrounds self-supply sources – individual or private. The second factor is the lack of an established institution to claim responsibility for the general management of individually owned water sources. In terms of ownership, many owners or operators of self-supply sources lack the technical expertise or the competence of developing and ensuring water safety management of their sources. Many of these individual source owners also lack the skill to initiate the actions needed in water safety plans. The recognition of the lack of technical expertise of source owners leaves the fate of water safety planning for self owned sources with the second factor; which is the need for an appropriate established institution to oversee and develop water safety guidance for self-supply sources.

Water Safety Plan approach is a preventive risk management approach, where risks to drinking-water safety are identified, prioritized and managed to protect drinking-water quality from source to consumer. Application of this approach leads to the development of a Water Safety Plan (WSP), which is a record of the process and practice of providing safe water.

Presently, there is no known established institutional set-up for self-supply systems, particularly, in Nigeria, where this study was conducted. The absence of an established institution to initiate, co-ordinate, and develop water safety plans for self-supply systems may thus represent and remain a major obstacle to ensuring safety of water from such sources. Arguably, existing water safety plans could be adapted to suit the needs of any systems and technology type (Schmoll *et al*., 2006). The management structure of self-supply sources in the study location however clouds the process of water safety planning for the sources -

hence the need to understand the management practices, which surrounds self-supply systems for an appropriate adaptation.

Generally, Source or system management relates to the action taken in normal operation or incident conditions. Source management also includes systems upgrade and improvement. This paper sets out source management definitions as perceived by source owners and users, existing management practices, challenges confronting source management, and factors influencing the identified challenges. The paper also highlights source maintenance and improvement measures, specified roles and responsibilities, and the lessons learnt with implications for water safety planning.

METHODOLOGY

This study is premised within a wider research, in which a total of 105 semi-structured interviews with open ended questions were conducted between March and July 2007, towards an apt water safety plans for self-supply sources. Sixty of the 105 respondents commented on source management practices. The 60 respondents comprise Source Owners, SO (30%), Resident Users, RU (65%), and Non-Resident Users, NRU (5%). Seventy two percent of those interviewed had formal education ranging from basic (primary) to higher education.

It is important to state that the criteria used to select self-supply wells in the wider research located wells but did not pre-empt the socio-economic class or status of self-supply well owner/user among the respondents. It was however important to retain the owner/user of sampled wells as research subjects for the purpose of triangulation so that interview results could be triangulated with findings from researcher's observation of the well handling and the results from the quantitative sanitary inspections and water quality analysis conducted on sampled wells. Triangulation in research facilitates validation of data through cross verification from usually more than two information sources. All the responders are however self-supply water users and hence qualify to comment on source management and practices. Similarly, the sample size of respondents that commented on source management arguably may be seen as not large enough to establish generalized statements, the opinions expressed are however validated with onsite observation within and during the wider research.

Transcripts of interviews were made from the original taped conversations which were played back for the purpose. Interviews made in vernacular were first translated, hand written and typed. The translation aimed at clear rather than verbatim transcripts. Grammatical corrections were made where necessary for further clarity without changing or influencing the meaning. Details of the raw data were subsequently coded (Neuman, 2003; Richards, 2006). The process started with open coding generating many initial codes from the data. At the initial stage, the total numbers of codes or themes were high to maintain a wide range of codes to choose from. Consequently, similar codes were merged into higher or lower level codes. Interview responses associated with coded themes were then examined to identify related and/or contrast views, and to understand the factors or perceptions that are being expressed. Data descriptions and interpretations eventually followed within each major theme.

Source management practices, users' interpretation of source management and the challenges to hand-dug well management are many and diverse. To capture the diversity, results were grouped into six major themes. The themes are presented and discussed in sub-sections. The number of respondents in each theme is presented within the theme. Excerpts of actual responses during the interview are presented in appropriate Boxes in Appendix 1.

RESULTS AND DISCUSSIONS

Users' interpretation of source management

Source management is interpreted by water users in six ways (Box 1 in the Appendix). The definitions are:

- Source protection from contamination - examples include use of dedicated versus multiple buckets or well lining
- Maintaining source structure – involves building a well cover
- Hygiene check of source operators - example include prevention of standing with shoes on well-head
- Cleaning the well area
- Supervision of operation - involves control of the time of operation or locking the well cover
- Overseeing access to source, especially access for non-resident users

Source Management Practices, Rules and Sanctions

Seven source management practices are identified (Table1). Judging from the frequency of occurrence (from interviews), access control via key collection, locking of wells and time management are the popular management practices. The most common practice is however access control through key collection. Access to lock-up wells is gained only when the owners or RU open the well for use. In the key collection approach, NRU can have access to wells on demand by asking for the keys.

Two observations are however apparent from Table 1. The first is that five (1, 2, 3, 6 and 7) of the specified management practices are a form of access control. The second observation revealed that users are being controlled (4 and 5). The people being controlled are in the following text referred to as the Controlled group. By implication therefore, the main source management approach is Access management.

Time management as an access control option is noted by four respondents (Box 2). Hand-dug wells are opened for operation within a given time. On an average, the specified time is between 5am and 7pm (Box 2). The time period suggests that access to well water is permitted only during the day. Various reasons are given for the identified access time. The most referred reason however is the concern for the safety of source and water (Table 2).

Table 1: Self-supply Hand-dug well management practices in Abeokuta, Nigeria

	Source management practices	Frequency
1	Access to source via key collection *,[a]	8
2	Locking of dug wells [a]	5
3	Time management [a]	4
4	Prevent child operators [b]	2
5	Deny access to non-resident users [b]	2
6	Deny access when water level is low [a]	1
7	Access through tap stands	1

[a] Form of access control; [b] The Controlled group; *: Access on demand by asking for the key; N^1 = 23

Table 2: Reasons for day time access to Self-supply hand-dug wells

Reasons for day time access to wells	No. of respondents
Un-fenced well [a]	1
Prevent night time water pollution [a]	3

Security reasons	1
Prevent household break-in	1
Prevent animals and birds [a]	1

[a] Associated with source and water safety

The day time access hours appears to suit users' water collection preferences. Table 3 shows four categories of preferred water collection times; on demand, strictly morning, morning and evening, and morning and on-demand. Judging by the frequency of preference, 50% of the users are in favour of the chance to be able to access hand-dug wells on demand. Water collection on demand is favoured to avoid usage of the water for un-approved purposes.

The remaining 50% however prefer to access water at least in the morning (Table 3). Assuming that morning may also be inclusive in 'on demand', Table 3 suggests that 100% of the users prefer to collect water at least in the morning. The preference of morning water collection is supported by the general argument that the water might become dirty and unsettled due to subsequent higher traffic of users. Other stated reasons include household cleaning before start of daily occupation. Users are at home in the morning and morning also represents bathing time (Box 3).

Table 3: Water users preferred collection times

Preferred water collection times	Frequency	% Frequency
On demand	6	50
Strictly morning [a]	2	17
Morning and evening [a]	3	25
Morning and on demand [a]	1	8
	12	100

[a] Clearly include preference for morning

Access management via the locking of wellhead cover implies that especially NRU can access wells only when the supervision of source operation is intended. The implication is that absence of source owners could prompt nonchalant user attitude. Further allusion suggests that access is denied unless the condition of supervision is met. The strategy of 'No supervision, no access' thus limits deviant behaviour of users.

On the other hand, restricting access to wells due to low water level clearly occurs only when low water level is experienced. Thus, while access control through the locking of wellhead cover is condition-based (i.e. supervision requirement must be met) management approach, access limitation due to low water level is an event-based (management style is informed by the event of low water level) management strategy.

Access to well water via tap stands is the fifth and one of the least mentioned. The access option is not common because it is more expensive than the first four options (Table 1). The cost involved in access via key collection for instance includes the cost of padlocks with keys, and bucket and rope. Usually, the cost of padlocks with keys, and bucket and rope is about one thousand Naira (National Currency) or £4. The cost implication of the fifth access control strategy is more because the option involves the installation of some form of water lifting devices, for example, dedicated motorized pumps. Motorized pumps typically cost about N12, 000 (£48). To avoid the problem of the Controlled groups around the wells, distribution lines are set-up with tap stands provided outside the fence for the NRU. The access option represents the best available practice in the study area. The access option is better because water collection activities are limited to the tap stands away from the self-supply wells.

Box 4 highlights four rules that source owners and/or RU apply in the management of hand-dug wells. The rules include prohibition to climb on well head with shoes or slippers on (1 R); prohibition of having chewing stick in mouth during source operation (2 R); prohibition of individual bucket – i.e. strict adherence to the usage of owner's dedicated bucket and rope (1 R); and the rule of No talking while fetching (1 R). Box 5 on the other hand spots three sanctions that are being applied to enforce the stated management rules. The sanctions include banning the usage of un-authorized bucket (1 R); Banning of non-compliant users (3 R), and/or Subjection of non-compliant users to public embarrassment: '*Scream at people*' (1 R).

The general inference from the respondents view point as illustrated in Boxes 4 and 5 suggests that the establishment and promulgation of source management rules are the prerogative of the SO. Enforcement of sanctions is also the responsibility of the SO.

Major problems to Source Management

Hand-dug well management in the study area is faced with six notable problems (Table 4). Three (problems 1, 2, and 3), of the six challenges account for more than 80% of the frequency, all the six problems are nonetheless important to well management (Table 4). The challenges are presented and discussed in turn.

Table 4: Challenges to Self-supply hand-dug well management

	Challenges to source management	Frequency	% Frequency
1	Problems of non-resident users	16	49
	▪ Destructive tendencies	10	
	▪ Difficult access control	6	
2	Lack of co-operation between owners and resident users	7	21
	▪ Conflict on source maintenance	5	
	▪ Conflict on access control	2	
3	Unhygienic behaviour around the wells	4	12
4	Lack of co-operation among Resident users	3	9
5	Problems of children as source operators	2	6
6	Recovery of loose buckets	1	3
	Total	33	100

Source Owners and particularly the RU are confronted with problems associated with the NRU. The responders generally decry the destructive tendencies of the NRU and with strong negative comments described the problematic activities of the NRU towards access control. Three objects of destruction are noted (Box 6); damages to well cover, damage and/or carting away of bucket and rope, and misuse of the well area. Also three consequences of damage to well cover are highlighted (Box 6); conflict between SO and RU over asset control (1 R). Usage of hand-dug well water restricted to non-drinking purposes (1 R). And stoppage of well cover provision or repairs (1 R).

The second major challenge to source management has to do with lack of co-operation between SO and RU. Findings reveal that the SO exercises the right of ownership on access control (2 R) while the RU shows recognition of their non-ownership status by shying away from asset repairs and maintenance (Box 7).

The third challenge involves the supervision of hygiene behaviour around the wells. Water related household activities like laundry, bathing, and toileting activities are reported while poultry pen, litters and refuse drops are noted as common sights within well areas (Box 8). The comments of three of the four responders who reported the hygiene management issue imply that maintaining the well area is the responsibility of the RU (Box 8). The fourth respondent however attributed the unsanitary state of the well area to NRU. Invariably, where there is no co-operation among RU coupled with in-ability to control the activities of NRU, source management relating to hygiene behaviour near the wells becomes a serious problem. Also by inference, apart from access control, hygiene management represents another branch of hand-dug well management.

The fourth dilemma to source management is attributed to the lack of co-operation among the RU. Referring to Box 8 and with additional evidence in Box 9, lack of co-operation among RU makes hygiene management a particularly difficult task. Hygiene management is particularly difficult because RU exhibit diverse hygiene levels, which are informed by different water-use priority for hand-dug well water. The influence of water-use priority on hygiene levels is discussed further below.

While some RU try to take responsibility for maintaining the hygiene of well areas (which represents a common or joint owned area); other RU either discredit such hygiene initiatives or discourage the individual effort (Box 9). Lack of co-operation as noted particularly, in Box 9 may however, have grave implication for water safety plans. The seriousness of the implication is rooted in two factors. The first is that shared residential houses are common practice in the study area. Shared houses come either as blocks of flats or as blocks of single unit rooms. The most common however are blocks of single unit rooms. The second factor, which is inferred from the first factor, is that RU will usually be a significant stakeholder in hand-dug well management. As noted in Box 9 therefore, there is the need to seek co-operation among RU on source management to ensure source and water safety plans of hand-dug wells.

Handling of well operation by children is observed as the fifth problem. In Box 10, children as well operators is noted as a common feature in the study area (3 R); Children abuse hand-dug wells (3 R); Children play around wells (1 R), and prevention of children as well operators is considered a safety measure in terms of human, source and water safety (2 R). The fifth issue can be viewed in three ways; the first point relates to child well operators as common practice. The second identifies the children operation activities that require supervision or control. And the third involves access denial for safety reasons. The observation made - children as source operators a common practice - corroborates established knowledge. Loughran and Pritchett (1997) remarked that children often have an important role in performing household tasks such as water collection. Guarcello et al. (2004) also noted the responsibility of children as water collectors in five different countries of the world. Observations made in the field for this research also confirm that children as water collectors are common in Nigeria.

Identification of children activities, which require control, is however critical to self-supply well management and water safety. For instance the "*...dirt in water*" mentioned, and bucket misuse reported in Box 10 shows that children operation activities represent one of the critical operation actions around hand-dug wells. Bucket related activity is particularly critical because bucket related threat represents a Very High Risk problem to hand-dug well water safety (Oluwasanya, 2013). Critical operation activities by implication deserve critical control actions. Children operation activities around hand-dug wells therefore represent Very High Risk and a Critical Control Point in well management and water safety development.

To deny children access to wells for safety reasons is debatable. On the one hand, human, source and water safety are good grounds to deny access to wells. Denying children the access to wells may not however be a feasible or sustainable source management option. Denying children the access to wells may not be feasible because of the generally perceived role of children as water collectors (Loughran and Prichett, 1997; Guarcello et al., 2004). Consideration of setting a minimum age limit for well operation may however be a meeting point between the two sides of the debate. The recommendation of minimum age limit should nonetheless be tested with water users prior to any possible adoption or implementation in source management and water safety planning.

Bucket recovery problem is identified in Box 10. The problem is associated with children operation activities and suggests that there is no standard bucket recovery tool made available to children. Lack of standard bucket recovery practices is not verified in this study. However, usage of an improvised bucket recovery devise was witnessed during the field visit (Figure 1). In the event that there is no standard bucket recovery tool or system, development and usage of standardized user friendly bucket recovery tools and practices is recommended for hand-dug wells with bucket system operations.

Figure 1: Bucket recovery exercise

Factors Fuelling Source Management Problems

Challenges to source management are influenced by four factors, namely insult (name calling) from NRU, perception of water as common good, absence of SO or property Care taker, and water use priority.

The impact of insults on source management activities is noted by four RU (Box 11). Offensive words and derogatory statements are examples of abusive language that represents insults to the intended. The respondents described two source management efforts which were started but eventually discontinued due to name calling (Box 11). One cited access control via locking of well while two respondents described stoppage of hygiene management efforts. Insults or name calling by NRU also discourage a RU from further getting involved with source management initiatives (Box 11). Insult is thus, capable of driving source management initiatives and invariably water safety plans activities to a halt. Name calling may also deter key source management personnel from implementing administrative functions. It should be recalled that the RU were earlier identified as hand-dug well managers. The consequences of name calling suggest that passing insults on Source Managers is a limiting factor to source management and by extension, to water safety planning. Name calling by the Controlled groups in hand-dug well management also signify a social hazard to contain. The social hazard should not however be allowed to derail source management and/or water safety plans.

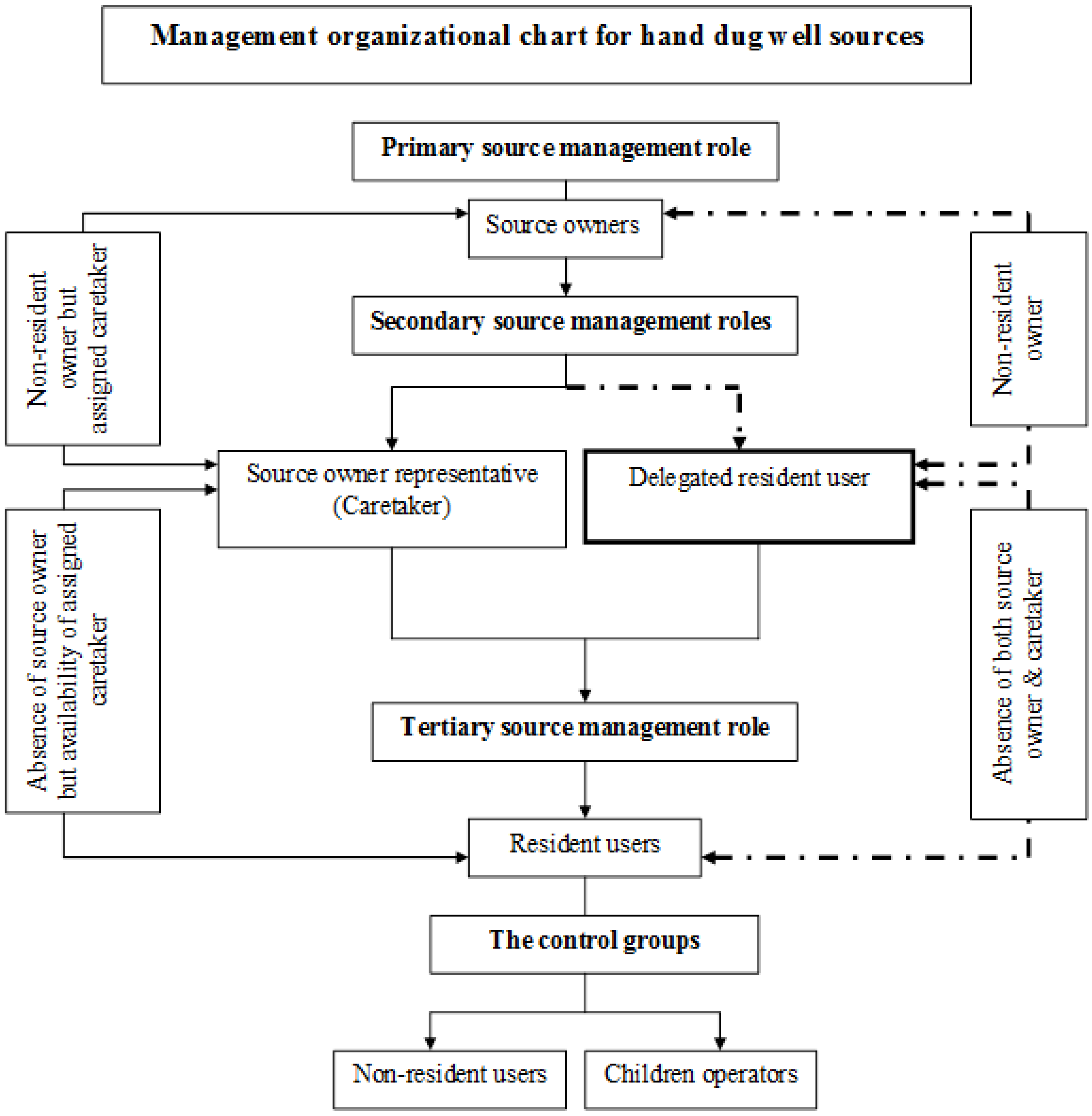
The second factor; water perceived as common good is indicated by four RU (Box 12). An observation that is common to the remarks of the four responders is that free access is tied with perception of water as a common good. Free access to hand-dug wells however encourages limited or no management practice. Another observation in Box 12 is that the perception of the SO equally aligns with that of the RU. In the event that SO and RU share the same perception of water a public good as indicated above, the source may be in danger of limited or no management. Where Owners and RU however share contrasting views on water as public good, source management may lead to conflict between the parties. A limited or no-management approach would not ensure safe water. Conflict between SO and RU would not impact positively on source management and/or water safety activities. Either way, appropriate enlightenment is necessary to mitigate the influence of water as a common good on source management and invariably on water safety interventions.

The third factor is concerned with the absence of SO. The factor is reported by three respondents (Box 13). Absence of SO is engineered in two ways; absence as a result of non-residency (2 R) or via the demise of the SO (1 R). Aside from the SO, the remarks of R33 and R41 reveal another actor in hand-dug well management - the Caretaker (Figure 2). The responder's statements suggest that Caretakers are assigned representatives of property Owners, invariably the SO. And the duties of Caretakers include rent collection and asset (property and water source) management. Asset management will hereafter be used interchangeably with source management.

The views of the respondents in Box 13 again reveal that in the absence of the SO and/or the Caretaker, asset management reverts to the Residents. Asset management by residents however is difficult because there are usually many RU; who may not always agree to effect repairs and maintenance on behalf of the SO, subsequently indicating an issue of managing many residents, and the problem of lack of consensus. To reach a consensus among many RU in the absence of SO is tricky, since residents perceive asset management as the responsibility of the Owners. To regard source or asset management as the responsibility of the SO is however a perception rooted in ownership. Source ownership status dictates where the primary source management role lies, and that is with the SO (Figure 2). Source ownership thus represents a critical factor in self-supply system management.

Another management difficulty that is identified is that when source management becomes the responsibility of the RU, the problem of a source with many managers ensues. This management difficulty suggests that in the absence of the primary Owner and/or the secondary Owner (primary owner representative/Caretaker), source management role become un-delegated as the role reverts to the RU. Absence of SO and/or owner representative thus exposes the result of un-delegated management role in source administration on one hand and the ownership responsibility on the other hand. In the absence of the SO and/or owner representative therefore, delegated source management may be the answer to achieve consensus or cooperation among the RU (Figure 2).

Absence of SO is generated in two ways: non-residency or demise. In the event of a non-resident SO, the Delegated Resident User may be required to liaise with the SO. In the case of the demise of the SO and/or unavailability of any secondary owner, source management responsibility reverts to RU but under the supervision of a delegated RU (Figure 2). Consideration for delegation may however be based on voluntary appointment or on the RU with the longest tenancy.



NB: The highlighted box is a recommended role. The broken arrows are recommended links

Figure 2: Management organizational chart for self-supply hand-dug wells (Is this a proposal? If so, state it.)

The fourth identified influencing factor on source management in the study area is the water use priority. The priority that any user assigns to water from a particular source can be linked to the hygiene behaviour the user exhibits around the source. The link between water use priority and hygiene behaviour is illustrated in a source management feud recounted by R41. A user who perceives water from a dug well to be good enough only for non-ingested purposes will not, for example, hesitate to draw water with an unhygienic bucket and rope. The reverse may however be the case, if the source is the drinking water source. Water use priority is a function of the perceived source water quality. The influence of water use priority on hygiene management can thus be eliminated or at least be minimized if safe water quality is ensured. Safe water quality of hand-dug wells can however be ensured through water quality management or essentially through the development of water safety plans.

Source Maintenance and Improvement Measures
Respondents are able to identify nine source maintenance and improvement measures. Five of the nine measures are however mentioned more often than the others. All the measures with the corresponding frequency of mentioning in parenthesis are: Re-digging of well hole (13), Well cover repairs (5), Source water treatment with chemicals (5), and Maintenance of well area (4). The others are Provision of dedicated bucket (2), Installation of well lining (1), Cleaning of well hole (1), Pump repairs (1) and Education of resident users (1).

While many of the listed measures are self explanatory, source water treatment with chemicals is worth noting. The measure is fairly popular with hand-dug wells in the study area. Four of the five respondents (Box 14) specified the use of alum for source water treatment. Another two respondents mentioned the usage of Water Guard and chlorine. Water Guard is a brand name for hypochlorite packaged for household water treatment. The danger identified with the practice of the use of chemicals lies in the dosage. Source water treatment involving the use of chemicals like chlorine is arguably expected to be carried out under the supervision of or with the instruction of skilled personnel. Use of chlorine in the form of hypochlorite packaged in brands like Water Guard specifically for household purposes is however recommended. Water Guard is nevertheless intended for household water treatment and not for treatment of water within the well.

Five source improvement conditions that need to be met for maintenance to be achieved are prescribed. The identified conditions with corresponding number of respondents include:

Agreement between users (3), Maintenance cost contribution by Resident Users (2), Funds availability (2), Seasonality (2), and Adequate power supply (2).

Three respondents believed that consensus especially, between the RU is a precondition for source improvement. And consensus could only be reached by dialogue. According to two other respondents a major point to agree on is the maintenance cost contribution; a precondition that is rather difficult to achieve. Another related precondition is availability of funds. Some well maintenance activities are best carried out in the dry season thereby making seasonality a precondition for the relevant source improvement actions. Examples of the season based improvement activities are well lining and re-digging. The last referred precondition is availability of power source. Source improvement works like the repairs of metallic well cover requires welding. Welding works are usually based on the supply of some form of power. Electricity generated power is the most common in the study area but very erratic.

Self-supply Source Management: Implications for Water Safety Planning

The problems confronting self-supply well management in the study area as shown in this study are diverse with varied implications for source management and water safety plans. The need to seek co-operation among RU dictated by the problem – lack of co-operation among RU – highlighted RU as managers of self-supply systems, and showed one of the unique management features of self-supply systems. That is, systems owned by one but managed by many. This management feature is different from communal systems – owned and managed by the community or the public water systems, which are largely owned and managed by the Government. The involvement of RU in the management of hand-dug wells justifies the need for an appropriate expanded role definition in an apt water safety plans for such systems.

Similarly, the existing WHO water safety plans expects the management and especially the development of water safety plans to reside with the water providers. Water providers in the context of self-supply systems are Source Owners. Resident users are however seen from this study as key stakeholders in the management of the systems. The managerial role of the RU should be recognized and given the appropriate consideration it deserves. The recognition calls for the inclusion of at least a delegated RU in water safety planning. The involvement of an established institution to initiate, coordinate, and facilitate the development of water safety plans together with the identified source management team is also recommended.

Access and hygiene management are identified as the basic source management approaches adopted for hand-dug wells in the study area. Of the existing practices, the management options that could be included in water safety guidance for the sources are: 1) Installation of pumps (dedicated and motorized) with well and provision of dedicated 1 to 2 tap stands for NRU. This represents the best available practice. 2) Keep well under lock and key with absolute non-access to NRU. 3) Keep well under lock, but allow access during Owners/RU time of operation. Resident SO and/or RU can then supervise operations and other operators. 4) Keep well under lock but allow monitored access through key collection and return.

The various source management challenges also suggest the need for modification of existing access control and hygiene management strategies. The following new concepts are recommended. 1) Introduction and display of source access time-table and operation rules. 2) Introduction and enforcement of the usage of dedicated bucket and rope. 3) Introduction and enforcement of minimum age limit. 4) Enforcement of operation rules through sanctions such as banning the usage of un-authorised bucket. 5) Introduction of supporting programs: training of SO and/or delegated RU on how to set up and enforce source and water safety rules. 6) Introduction of government regulation to enforce source management and safety.

Finally, the primary actors to be engaged with the identified roles and source management responsibilities are illustrated in Table 5.

Table 5: Responsibilities and Identified Actors

	Roles/Responsibility	**Actors**
1	Introduction of well management rules	Resident Source Owners (RSO)
2	Supervision of access to hand-dug wells	RSO
3	Enforcement of well management rules	RSO or delegated Resident User
4	Source maintenance	RSO or shared responsibility of Resident Users in the event of deceased or non-resident Source Owner

CONCLUSIONS

The management of urban self-supply wells in the town appears simple but complicated. It is however important to understand the management custom to develop effective and efficient water safety measures suited for the systems. The main source management approaches are access and hygiene management strategies. Aside the resident source owners, resident users are highlighted as managers of self-supply systems, especially in the absence of source owners. The highlighted showed one of the unique management features of self-supply systems; sources owned by one but managed by many. The involvement of RU in the management of hand-dug wells justifies the call for an appropriate expanded role definition in an apt water safety plans for self-supply systems.

The involvement of an established institution to initiate, coordinate, and facilitate the development of water safety plans together with the identified source management team is also recommended.

ACKNOWLEDGEMENT

The authors acknowledged the Commonwealth Scholarship Commission, United Kingdom, for the sponsorship of the program that led to this research.

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Appendix 1: Interview excerpt

(Source: Field data; I: Interviewer; R: Respondent)

R_5:	*'…. but we don't allow people to bring drawer bucket from outside*
R_8:	*'…we build a cover on it and put it under lock*
R_{39}:	*I don't allow people to even come close with their shoes. I put a lot of restrictions on people who fetch the water.*
R_{41}:	*'…to sweep and tidy the well area. It is just something I have made my responsibility*
R_{74}:	*The owners do not allow any other person put their own drawer in the well*
R_{83}:	*If I am not around, I can not see what people are doing. But most of the time I am around and I see the way the people use the well. If need be I scream at people and even ask them not to come back again. So it is either I do not leave the well open or I monitor it.*

Box 1: Source management interpretations

I:	*Who authorizes the use?*
R_{83}:	*The owners.* ***Once we open the well by 5 a.m. people are allowed to fetch water till 7 p.m. in the evening.***
I:	*Why 5 a.m. to 7 p. m.?*
R_{83}:	*Because of the people to prevent wicked people who may want to contaminate the water or drop dangerous things into the well. Since we could not fence it round*
I:	*How do you look after the well?*
R_{84}:	*We lock the well every night.* ***The well is usually opened between 5a.m and 6p.m*** *every day and residential users will take water first and lock up in the evening.*
I:	*Why do you lock it at night?*
R_{84}:	*You know that anything can happen at night so for security reasons, we lock it at night.*
I:	*Things like what?*
R_{84}:	*People are very wicked; there was a case whereby somebody got killed and the body was dropped into the well of a neighbour and got all the neighbours' residents in trouble. So to avoid such, it's better to lock up. Secondly, we lock up to prevent animals and birds from flying in.*
I:	*What time of the day do you draw water from the well?*
R_{89}:	*Morning to evening.* ***We lock the well by 7 pm***
I:	*Why is that?*
R_{89}:	*To prevent people from throwing dirt or contaminate the water at night*
I:	*What time of the day do you draw water from the well?*
R_{91}:	***The well is open between 7a.m to 5p.m.***
I:	*Why don't you allow fetching beyond those times?*
R_{91}:	*The elders say that ''it is dangerous to fetch water from the well at night''. In fact, there is a myth that "if you allow the fetching of water in the evening, the household will split".*

Box 2: Operation time management; an access management strategy

I: Why do you prefer that time of the day?
R_{81}: *Its better in the morning, once other user comes around the water becomes unsettled and dirty*

I: *What time of the day do you normally fetch water?*
R_{84}: *Usually morning and evening because I have my bath before leaving for work and before retiring for bed.*
R_{88}: *In the morning because we need to do household chores before we leave for school*
R_{94}: *Morning and evening. We go to work during the day; these are the times we are at home*

Box 3: Reasons for choice of water collection time

R_{39}: *I (source owner) don't allow people to even come close with their shoes. I put a lot of restrictions on people who fetch the water.*

R_{47}: *I (source owner) told them that they can not come with chewing stick around here or do any dirty things around the well and we don't allow them to use dirty drawer.*

R_{62}: *I (source owner) don't allow people to talk or use chewing stick beside the well or talk beside it. It's me that knows how much I am spending and have spent on the well.*

R_{74}: *No, they (source owners) do not allow individuals to use other buckets*

Box 4: Existing source management rules

R_4: *'… whosoever will not be allowed to use other buckets ….*

R_9: *'… anyone who is not comfortable with it (source management) can go else where.*

R_{83}: *If need be I (source owner) scream at people and even ask them not to come back again.*

R_{94}: *'…the person will not be allowed to fetch water another day*

Box 5: Sanctions for the enforcement of source management rules

Damages to wellhead cover

R_8: *On several occasion they have broken and removed the zinc cover on the well.*
I: *So you are saying that there is no way that you owners can handle this people?*
R_8: *There is no way.*
I: *But I think we should be able to control them.*
R_8: *We may be able to control people within the house what about the outsiders, particularly during dry season when there is no tap water, how many people are we going to talk to?*

R_{39}: *'… but the people around are very wicked. They broke the cover and damage those things.*

R_{40}: *See, the construction was done recently. The people of this neighbourhood just derive pleasure in destroying things.*

R_{42}: *It's our people; some of them are bad, they broke the cover; that's why we stop using the well water for cooking and bathing.*

R_{90}: *'… users hardly ever allow cover to stay on the well. Any time the well cover is fixed, by the night, it is removed, so we stopped providing cover for the well.*

Problems with Buckets

R_1: *It is not that we cannot tie a drawer to the well but the people around here are destroyers; they are destructive. It is good as you said it but if we tie one there they will use it badly.*

R_4: *What makes individual to have their own drawer is that most people are careless when using it and it may drop into the well.*

R_{62}: *That is what I have been doing but people when they come for water sometimes they go away with the drawer*

Problems with Well area

R_8: *'….some after fetching water will turn it down here on the ground and if we complain they would say that it will flow away'*

R_{51}: *We have talked so much but our people are not yielding. I however feel that if the government comes in now and arrest some people all this throwing and dumping of refuse will stop. We are not police or sanitary inspector; there is nothing we can do. We have been arrested before and if they (the police) come again we shall take them (the police) to every of their (refuse dumpers) door steps.*

Box 6: Non-resident users: major challenge to hand dug well management

R_1:	*We have done it before, the landlord instructed us to be locking it….when we took action based on what he said and the people rebelled, he still shifted the blame on us. He said did we rent the house because of water?*
I:	*Ok, what can you do if your reason for not drinking the water is because of what people are throwing into the well to fetch water? What can you do to control that?*
R_{78}:	*There is nothing we can do except to repair the cover and we can not ask them not to fetch water because the landlord will allow them*
R_{17}:	*As tenants there is nothing we can do. We can't do it on our own*
I:	*What about if you talk to the landlord?*
R_{18}:	*We have about 4 landlords in this place. What I will say is that let every man fetch his water and treat it. If you come back in the next 3 years you'll meet the well the same way it is now.*
R_{34}:	*I can agree with you but if we tell the Landlord this water is not good, he will not do anything.*
I:	*Is the Landlord living here?*
R_{34}:	*No*
I:	*You are the one living here and using the well can't you call yourselves together?*
R_{34}:	*It is not possible*
I:	*I understand that it is not your water because you are not the owner but you use it any way and since you use it, you and not the landlord is been affected by the water….*
R_{34}:	*Yes it's not affecting the Landlord*
I:	*Then are you going to do something about the well?*
R_{34}:	*Do you people want to help us to repair it?*
I:	*It is the same thing I said about the Landlord. We do not live here, so it is not our responsibility to do anything shouldn't you be able to repair it?*
R_{34}:	*I can not agree who will pay and repair water for the landlord?*
I:	*Does everybody see repairing of well as the landlord's duty?*
R_{34}:	*Yes, I ask someone to contribute to repair light (electricity) and he told me that there is no electricity in the village, he can do without electricity!*

Box 7: Remarks reflecting lack of co-operation between source owners and resident users

R_{19}:	*Why I ask you to be called is that this place nothing should be washed here (the well area). In my own space I know that my hens sleep over there and I have decided that they will be moved away. If I do that, then this container also should be removed. And also we should clear this (the well area) place.*
R_{20}	*It is for the benefit of all we would make an end of it, all this rubbish must be parked away.*
R_{41}:	*When you saw me this morning trying to sweep and tidy the well area, it is not that I knew that you were coming. It is just something I have made my responsibility. I left it (well area cleaning) because of the careless use of the residents. Just yesterday again, I did thorough cleaning and this morning the whole place is all mess. Before I swept this place this morning, you would have asked if people that live here are able to sleep. A relative of the owner came around sometime ago wondering why the whole area is left un-kept. I told him that I purposely left it for him to see. You will find excretes and urination almost everywhere.*
R_{51}:	*On the environment I've told you that there is nothing we can do, but when you come again, if you want to talk to those who are using this place I can take you to their houses and whatsoever you want to say you can say it to them directly.*

Box 8: Hygiene behaviour around well area

R_{40}:	*'…our neighbour here fight me over the well that's why I left the well unattended to. I know that everybody knows that I have tried in getting them (residents) to do the right things about the well, but they do not comply*
R_{41}:	*'To make our surroundings clean is something that we want, I take it as my job to do so. We were taught to wake up in the morning and clean our surroundings and we do so, but nowadays, some people just live in the house, they even claim that they can not sweep, pride that will not get them anywhere...*
I:	*So, there is no way that you can agree*
R_{41}:	*No way*
R_{75}:	*'…. if others will cooperate, and will not accuse others of anything, because if a person does it, it may be a problem on him/her. Like when my husband ask one of our co-tenants to close the gate one night, the person refused to answer my husband that night that it really turned to a big problem. I expected the landlord to come out and judge the case, he didn't come out at all instead he went to the other party who is wrong and started begging them.*

Box 9: Respondents comments reflecting lack of co-operation among resident users

R_{41}:	*'……because I scolded a child for being dirty with the water….'*
R_{78}:	*'…but you know the children, they will loose the bucket into the well. When they fetch too much water, they will throw the bucket into the well and they will also try to get the bucket out by themselves when no one is at home*
R_{82}:	*The cover was spoilt by the rain so children are not allowed to fetch from the well to prevent dirt in the water.*
R_{86}:	*'…. We also prevent children from fetching or playing by the well side*

Box 10: Children as hand dug well operators

R_1:	*We have done it before, even the landlord instructed us to be locking it then but the bad word from people prevented us from locking it further*
R_2:	*They said, 'you are tenants when you are ejected carry the well along with you' those are their words.*
R_{40}:	*They always abuse us if we complain of their bad usage.*
R_{41}:	*It has been war over the well. With all what we did the other time the well was repaired, they made it very difficult for us and insulted us throughout. The caretaker's wife did a lot when we complained about their hygiene but they destroyed everything.*
	There was a situation, which resulted because I scolded a child for being dirty with the water, he went and called his father. The old man opposite called me a crazy woman and I had to ask him to stop insulting me. I explained that my concern for the well is for everybody's benefit and not only for myself, but they do not appreciate it. This other woman too takes everything negatively. She once told me that 'where are the well owners, are they not all dead' (implying that you don't need to kill yourself over what you do not own)!
	I am sorry but on the case of this water, I do not guarantee its safety in my hands. The insults are too much and think of the fact that it is for their safety

Box 11: Name calling by non-resident users

I:	*Did people yield to your instructions on the well?*
R_1:	*No they did not*
I:	*Why, don't you lock it up?*
R_1:	*We don't hoard water or keep people from the well*
I:	*Who authorizes access to people from outside?*
R_{84}:	*No one really*
I:	*Why is that?*
R_{84}:	*Because it is a natural resource*
I:	*Who do the people seek permission from to use the well?*
R_{87}:	*No one, the well is free for all*
I:	*What about the landlord, does he live here?*
R_{87}:	*He does but the well is left for any one who wants water*
I:	*Are they all rightful users of the well?*
R_{88}:	*We can say that because the landlord constructed the well for public use*

Box 12: Water perceived as common good

R_{33}: There is always this type of problem in a house where the Landlord is not staying with them. It is the caretaker that comes here to collect money, the landlord and his son may not come for months. We are many here. Any house which is not a flat is difficult to manage.

R_{34}: '…if we tell the Landlord this water is not good, he will not do anything.
I: Is the Landlord living here?
R_{34}: No
I: You are the one living here and using the well can't you call yourselves together?
R_{34}: It is not possible
I: I understand that it is not your water because you are not the owner but you use it any way and since you use it, you and not the landlord is been affected by the water….
R_{34}: Yes it's not affecting the Landlord
I: Then are you going to do something about the well?
R_{34}: I can not agree who will pay and repair water for the landlord?
I: Does everybody see repairing of well as the landlord's duty?
R_{34}: Yes, I ask someone to contribute to repair light (electricity) and he told me that there is no electricity in the village, he can do without electricity!

I: What about the owner?
R_{41}: The owner is dead
I: Is there no one who can take responsibility for the well?
R_{41}: The only person who used to be in charge after the death of the owner are the traders in the shops opposite us, but she is also dead and the shops have been taken over by new tenants. We the residents are supposed to look after the well now
I: So can't the resident users agree on taking proper care of the well?
R_{41}: At all; the people of this neighbourhood do not agree on anything that will benefit them

Box 13: Impact of the absence of source owners on source management

R_{81}: '…. And we poured some chemicals into the well

R_{83}: The water was dirty when the well was first constructed. We bought alum and poured it into the well

R_{88}: At times the well water will be coloured that is why we do add alum to the water

R_{93}: I use water guard or alum
I: Oh, you know about water guard?
R_{93}: Yes, I know water guard
I: What is the difference between Water guard and alum?
R_{93}: Water guard is a chemical that is well measured while alum is one aspect of treatment!

R_{96}: 'We use to call some retired officers from the Water Corporation to treat the water. They normally pour alum and chlorine in large quantity into the well. But what I noticed was that the water foams when you put to boil as if you added soap into the water. And many times, the chlorine is too much. We figured that the dosage was not proportionate to the water quantity. So we asked them to stop coming to treat the well.

It however took 2 years before the effect of the chemicals wore off. Ever since, we stopped making any effort to treat the well.

Box 14: Source water treatment practices

Rainfall Variability in Sections of the Benin-Owena River Basin, Nigeria, and its Implication for Rain-fed Cultivation

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ABSTRACT

Rainfall variability and vulnerability to extreme climatic event of drought and flood peaks in sections of the Benin-Owena River Basin was analyzed using a 50-year (1961-2010) long-term rainfall data. Time series data for 50 years was generated and the numbers of wet and dry years were determined after the double mass curve technique was used to verify the consistency of the rainfall data. Benin had 2300 mm annual rainfall compared with a threshold of 1727 mm while the other stations had less. The study reveals that Benin had the most satisfactory rainfall regime with the station being vulnerable to high flood peak and only two (2) of the 50 years under consideration being vulnerable to drought (1972 and 1977), while Akure was found to be the most vulnerable station to extreme climatic failure of drought events as forty-seven (47) of the 50 years experienced unsatisfactory rainfall events lower than the minimum threshold rainfall value for the area. Ado-Ekiti with the lowest rainfall events had 41 years of unsatisfactory rainfall or failure conditions (drought) and Ondo had 37. Apart from Benin, most of the stations had rainfall below the minimum threshold value. The implication here is that the basin is prone to drought hence too risky for rain-fed agriculture. Akure, Ado-Ekiti and Ondo are located in the northern part of the basin where rainfall reliability is low and the risk for failure or vulnerability to drought is high. The highest rainfall ever of 2827.2 mm was recorded in Benin in 2010 season.

Key Words: Rainfall, reliability, risk, flood, drought, vulnerability.

INTRODUCTION

The most striking feature of rainfall pattern in Nigeria is the extreme variability in its geographical distribution and variability in the monthly and mean annual rainfall observed. The real nature of this extreme variation in rainfall pattern in terms of its resilience and vulnerability to extreme climatic events across Nigeria, especially in the Niger Delta, is scarcely discussed in the literature (Oluleye, 2009; Eludoyin et al, 2009; Grist and Nicholson, 2001; Tarhule and Woo, 1998; Adelekan, 1998; Anyadike, 1993; Adedoyin, 1989). Precipitation data as often used in studies of climate variation is usually restricted to the analysis of mean annual rainfall values, or that of other relevant climatic factors. In this paper historical rainfall data (1961-2010) were used to evaluate the vulnerability of rainfall patterns to climate change and variability in the study basin. This study stem from the need to investigate the variability of average monthly rainfall and its vulnerability to climate change impacts in line with afore-mentioned studies. Besides, IPCC (1996) has in its global concerns on climate matters made it imperative for studies to be carried out at local, regional and global scales for data to be gathered so that definite statements can be made on climatic issues. Rainfall is a critical climatic index relevant to the hydrologists, climatologists, agriculturalists, civil engineers amongst others (Ikhile and Ikhile, 2011). A statistical analysis of this index of climate is very relevant in the current global climate debate. This study is objective in that it uses the average monthly rainfall to extrapolate climatic conditions over this portion of the basin for the period of time.

The Study Area

The study area has been detailed in the works of Ikhile (2007a and 2007b). It is situated in South-West Nigeria and lies between latitude 7^{o} 00’ and 8^{o} 03’N and longitude 4^{o} 50’ and 6^{o} 00’E (Figure 1). This includes parts of Edo, Ekiti and Ondo States of Nigeria. The climate is the tropical continental type with alternating wet and dry seasons of varying duration. The seasons correspond to the periods of dominance of the wet tropical continental air masses.

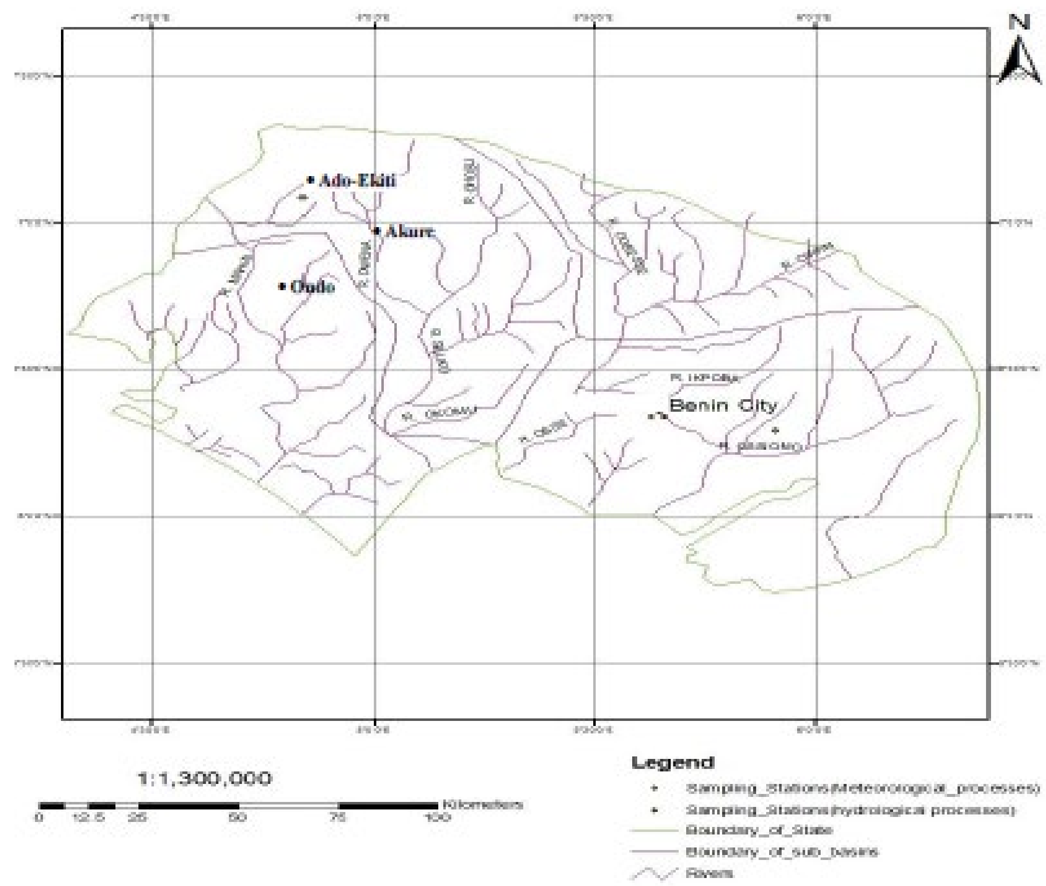

Figure 1: Spatial Extent and Drainage of Benin-Owena River Basin

The seasonal distribution of rainfall follows the direction of the Inter-Tropical Discontinuity (ITD) and varies almost proportionally with distance from the coast. The wet season occurs within seven months from April to October while the dry season lasts from November to March. There is usually a break in rainfall in August. Specifically, this area has the annual mean rainfall ranging from 500 to 2, 780 mm. About 90% of the rain falls in six to seven months of April to October. The mean annual temperature ranges between 24ºC-33ºC. The mean number of hours of sunshine is 5-7 depending on the season. The rate of evaporation is high being the continental interior. The relative humidity is between 60%-80% per annum depending on the season of the year (dry or rainy). The mean atmospheric pressure is about 1013mb.

METHOD

Long term rainfall data from 5 stations spanning 50 years (1961 - 2010) were acquired from the Federal Ministry of Aviation, Meteorological Services (FMAMS) Oshodi, Lagos, and the Benin City Synoptic Station in Edo State. Records of the rainfall data stations network show that Ado-Ekiti meteorological station has been operational as early as 1953, while that of Akure was commissioned in 1980 giving a rainfall data span of 31 years (1980 - 2010), a data period that is sufficient to provide a reliable estimate of climate change scenario (Gobo and Abam, 2006; Miller, 1961). Thus, a 50-year rainfall data for Ado-Ekiti, Ondo, Benin and a 30-year rainfall for Akure were used to compute the vulnerability of the basin to drought or flood events. Rainfall data were analyzed to establish whether there exists evidence of trends in frequency of monthly and annual rainfall of various magnitude; wet years were compared with dry years with respect to rainfall frequencies and the frequencies were compared between stations of different average annual rainfall.

Natural variability in the climate system is generally examined using the movement of the ITCZ or the squall lines (Omotola, 1983). The index is given by the April to October average of this pressure difference. Rainfall depth was used as the major determinant of extreme climatic events (wet or dry years) and computations of climate change variability in the study basin. A dry year was defined as a year with rainfall less than some threshold value defined by the long-term annual average rainfall for that particular station, while a wet year is a year with rainfall greater than the same threshold value for the station (Hashimoto, 1982a; Tsheko, 2003). The Double Mass Curve technique was used to verify the consistency of the rainfall data prior to the above analysis.

RESULTS AND DISCUSSION

Long-Term Rainfall Variability and Climate Change Scenarios

Figure 2 presents the long-term mean monthly seasonal variation in rainfall (1961-2010) over the study area. From Figure 2 a clear correlation can be observed between the movement of the ITCZ and the mean monthly rainfall depths. The wettest months are April to October with a break most often in August, while the drier months are November to March. The analysis for the Benin-Owena basin as a whole reveals that the coastal towns of Port Harcourt, Warri and Benin City had higher rainfall than Akure, Ado-Ekiti and Ondo that are further inland. The study further reveals that in the segment of the basin under consideration, only Benin and Ondo experienced rainfall value above the long-term mean monthly threshold rainfall of 144mm in the entire wet season months of April to October, while Akure and Ado-Ekiti had slightly higher mean rainfall than the threshold rainfall value for a shorter period of May to September in the 50-year period (Figure 2). The months of November to March with observed mean monthly rainfall values below the long-term threshold figure could be said to be experiencing drought conditions in the dry season. Similarly, rainfall pattern for Benin and Ondo exhibited a double maxima regime with peaks in July and September, while Akure and Ado-Ekiti were observed to have a single rainfall peak in the month of September (Figure 2).

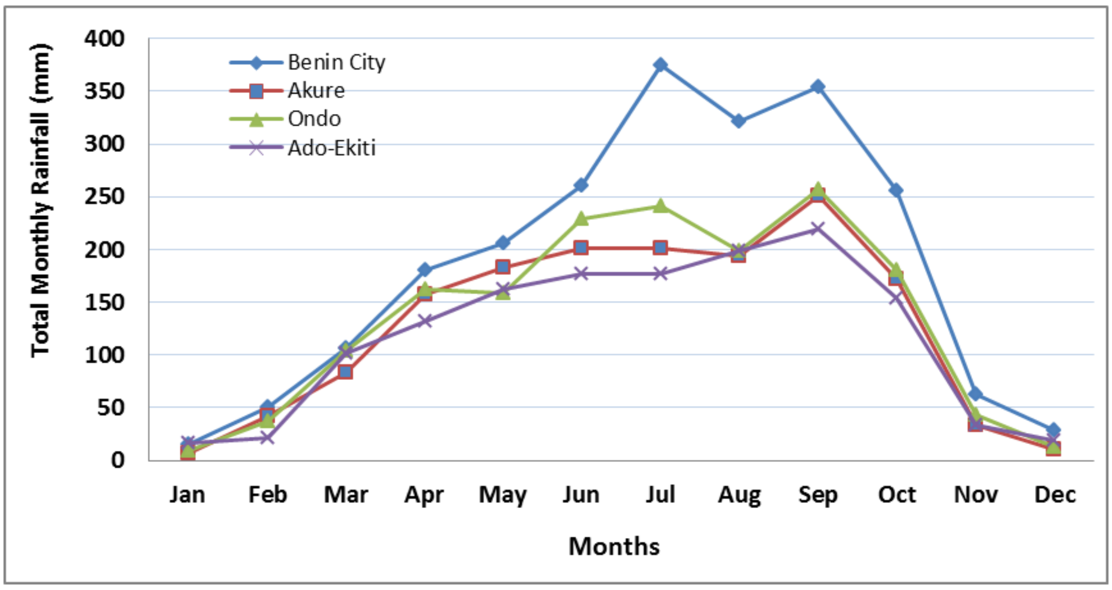

Fig.2: Mean Monthly Variation of Rainfall in the Study Area (1961-2010).

The long-term mean annual rainfall threshold for the section of the Benin-Owena River Basin under study was found to be 1727mm. Figure 3 presents the distribution of mean annual rainfall at the station around the long-term mean annual rainfall threshold. The figure shows that observed rainfall values for Benin was generally higher than the long-term threshold value of 1727mm, with only two years, 1972 (1702mm) and 1977 (1716mm) in the 50-year period under consideration having rainfall below the threshold mean value. These years could be described as drought years with recorded rainfall values below the minimum threshold. This period was in the decade 1971-1980 when Benin experienced her lowest decadal mean rainfall value of 2234.1mm (Table1), a value that was, however, higher than the threshold mean annual rainfall figure.

Rainfall in Akure was found to be the poorest in the area when compared with the minimum threshold rainfall value of 1727mm as only three (1991, 1995 and 2008) of the 50-year under investigation were observed to have recorded higher rainfall than the minimum threshold figure with mean annual rainfall of 1853.4mm (1990), 1913.6mm (1995) and 2848.8mm (2008). Ado-Ekiti and Ondo were slightly better in terms of reduced number of years vulnerable to drought conditions. Ado-Ekiti has 9 mean annual rainfall events above the minimum threshold value, i.e. 1963, 1968, 1994, 1997, 2001, 2004, 2006, 2009 and 2010, while in Ondo there were 13 recorded rainfall events above the minimum threshold as observed in the following years –1963, 1868, 1975, 1978, 1979, 1980, 1985, 1991, 1994, 1995, 2003, 2008 and 2010. It is imperative to note that Akure station experienced an exceptionally high rainfall in 2008 with 2848.8mm of rainfall, a figure that was the fourth highest observed rainfall in the study area in the 50-year period (see Figure 3). In contrast, Ado-Ekiti was observed to experience the lowest rainfall with the driest years being 1964 and 1977 with mean rainfall values of 634.5mm and 604.3mm, respectively.

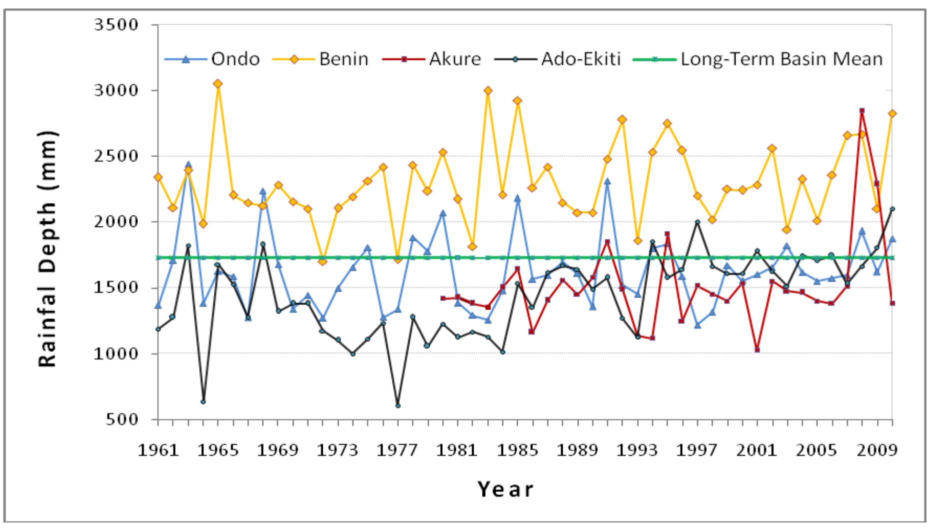

Fig.3: Trends in Long-Term Rainfall Regime in the Study Area

Trends in Long-Term Seasonal Rainfall Variability (1961 – 2010)

Seasonal Rainfall Variability for Akure

Table 1 presents the decadal rainfall variability in the study area. The table reveals that the long-term mean annual rainfall value for Akure was 1562mm and only the decade 2001-2010 had rainfall higher than this long-term threshold at the station. However, this figure was lower than the minimum threshold rainfall value (1727mm rainfall) for the section of the basin under consideration. This signifies that Akure was vulnerable to extreme weather condition of drought in the decades 1981-1990 and 1991-2000.These decades can be said to be failure years as the observed rainfall amounts in the station were lower than the long-term minimum threshold rainfall value for the station. Fig.4 shows the distribution of decadal mean rainfall about the long-term threshold rainfall value for the study.

Table 1: Decadal Rainfall (mm) Distribution of the Basin (1961-2010)

Decade	Ondo	Benin	Akure	Ado-Ekiti	Basin Mean
1961-1970	1664	2477	N.A	1444	1862
1971-1980	1603	2234	N.A	1417	1751
1981-1990	1541	2355	1445	1387	1682
1991-2000	1627	2493	1486	1391	1749
2001-2010	1686	2374	1633	1722	1853
1961-2010	1624	2300	1562	1439	1727

N.A= Not Available, Station Records begin in 1980 in Akure

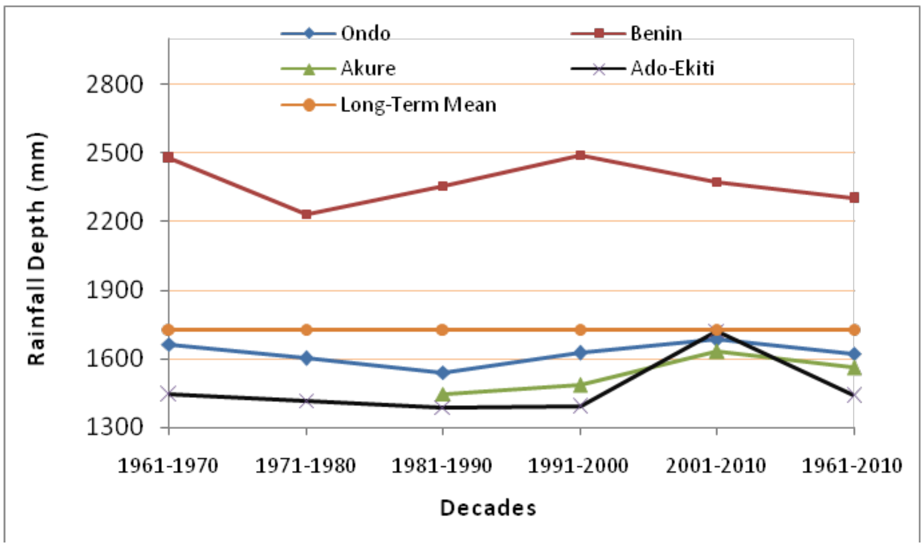

Fig.4: Decadal Mean Rainfall Depth for the Study Area

In the decade (1981-1990), total rainfall was 14,452mm and the decadal mean was 1,445mm for Akure. January was dry in all years except 1988, which was a rather wet year with rainfall in all the months. A value of 18mm (highest in the decade) was recorded in January 1988. However, the month of November in 1988 was an exception as there was no rain in that month, giving a total rainfall figure of 233mm for the month of November for the decade, the lowest observed for the month in all the decades. Rainfall was experienced for four years in December (1983, 1987, 1988 and 1990), with a total of 143mm for the decade. February was wet with a total decadal rainfall of 406mm, but in 1984, 1985 and 1989 there was no rainfall in February. In March, the decadal total was 936mm, while it was only 1990 that experienced dry year. In this decade, there was no "break" in August rather it recorded higher rainfall than July (1,924mm and 1,822mm respectively). There was a single peak in September (2,313mm). The decadal wet season total and mean were 12,699mm and 181.4mm as against a total and mean figure of 1773mm and 35.4mm, respectively for the dry season (Table 2).

The decade 1991-2000 recorded a higher decadal total rainfall of 14,861mm and a decadal mean of 1,486mm. The pattern of distribution was however more varied (Table 3).This decade exhibited a more fluctuating pattern similar to what was obtained elsewhere by Ikhile and Ikhile (2011). There were more uncertainties in the rainfall distribution in the drainage basin at this time as in other places (Ikhile and Ikhile, 2003). In the decade (1991-2000), there were double maxima of rainfall in July and September with a lower record in August (2,266mm, 2,455mm and 1,781mm respectively). The decadal totals and means of dry season against the wet season were 1510mm/302mm and 13,350mm/1,907mm respectively. In the dry season November was wet with no year experiencing zero rainfall. The total for November was 370mm. The December month was equally wet, but (1993, 1995 – 1997 and 1999) was dry, the total decadal value was 109mm. January in 1993-1994, 1996-1997 and 1999 had no rain; the total decadal rainfall was 70mm. The months of February and March were wet. The following years did not experience rainfall: 1993 - 1998 and 1991 respectively. The decadal totals were 366 mm and 594 mm respectively (Figure 3).

The decade 2001-2010, experienced the highest rainfall in all the decades with a total rainfall of 16324.2mm and a mean of 1632.4mm. The decade observed double maxima rainfall in July (6262.5mm) and September (7534.2). December was the driest month with mean rainfall of about 9mm. Both December and January had no rain for four years within the decade in 2001, 2006, 2008, and 2009; and 2001, 2005, 2007 and 2008, respectively.

Seasonal Rainfall Variability for Ado-Ekiti

Ado-Ekiti was observed to experience the lowest rainfall in the study area with a long-term mean rainfall of 1438.5mm a value that is lower than the threshold rainfall figure (1727mm) for the study area (see Table 1). However, the decades 1971-1980, 1981-1990 and 1991-2000 were found to have recorded mean annual rainfall values lower than the station minimum threshold rainfall value of 1438.5mm, thus are could be classified as failure decades vulnerable to drought conditions (Hashimoto, 1982a, Tsheko, 2003, Fowler et al., 2003).

A review of the rainfall pattern in Ado-Ekiti over the period reveals that the rainfall distribution was rather erratic. The 1991-2000 decade seemed to be the wettest and exhibited more even distribution pattern. The decadal rainfall totals however were lower compared with the other decades. The first decade (1961-1970) had a decadal total of 1,444 mm, while the decadal mean was 144 mm. The second decade (1971-1980) had more unevenly distribution pattern of rainfall. There was a sharp decline in rainfall between 1973 and 1974. The decadal total was 14,171 mm with a decadal total mean of 1,417mm. In the decade 1981-1990, the decadal total was 13,866 mm with a decadal total mean of 1,386mm. The decade (1991-2000) had a decadal total of 13,907 mm, and a decadal total mean of 1,390 mm, while the decade 2001-2010 was observed to be the wettest decade with a total rainfall of 17215mm and a mean decadal rainfall of 1722mm, a figure that about equals the threshold rainfall value.

The seasonal variation of rainfall over Ado-Ekiti showed a fluctuating trend. In the first two decades (1961-1970 and 1971-1980), there was one peak in the decade (1981-1990) (August/September) while the fourth decade (1991-2000) showed double maxima (June/July and September). In the decade (1961-1970), the dry season months were relatively wet. There was no year that did not experience rainfall in March (decadal total was 1,015mm). The month of December in 1961, 1965 and 1970 recorded zero rainfall. The wet season mean and decadal totals are as indicated in Table 3.

In the decade (1971 - 1980) the months of November and December were relatively drier. In 1972 – 1974, 1976, 1979, November was dry while there was rain in December only in the years 1971 – 1972, 1977 and 1980. The decadal total rainfall in November and December were 157mm and 106 mm, respectively. Four years also recorded zero rainfall in January (1971, 1975, 1976 and 1979). The following year (1979) recorded no rainfall in February and March. The decadal total rainfall was 1,125 mm. The wet season monthly totals/mean are as indicated in Table 5.6.7. In the (1981 - 1990) decade, the month of August recorded exceptionally high figure in contrast to other decades. The dry season was also wet with zero rainfall record in November 1982 and 1989. The decadal total was 199 mm. In the month of December, six years recorded zero rainfall (1981 – 1982, 1986 – 1987 and 1987); decadal total rainfall was 239.0mm. The following years had zero rainfall in January (1981, 1983 – 1984, and 1988 - 1989), decadal total was 326mm. The decade (1991 - 2000) witnessed the wettest dry season. About one to three years had no rainfall in all the dry season months; November (1991), December (1992), January (1992 - 1993), February (1992) and all the years had rainfall in the month of March. The decadal totals are (496mm, 184mm, 103mm, 505mm and 1,080mm) respectively. The wet seasons witnessed two peaks in June/July and September with a reduced decadal total rainfall in August. The decadal totals are as indicated on the table. The total decadal rainfall for the dry season was 1,648mm while the wet season was 11,538mm.

In this section of the drainage basin, a single rainfall peak was obtained in the study periods. In Akure this peak was recorded in September while in Ado-Ekiti it was recorded also in September (Table 3 and Figures 2). The pronounced August break syndrome previously recorded in the rainfall distribution seemed to be no more in existence (Ikhile, 2007a). This is in line with the general fluctuating trends observed in recent times in global climate change issues (Ikhile,2007a, Babatolu,2002, IPCC, 1996, 1991; Olaniran,1990; Ojo, 1987).

Table 2: Mean Seasonal Rainfall Variation (mm) at Akure (1981 – 2010)

Decade	Wet Season								Dry Season					
	Apr	May	June	July	Aug	Sept	Oct	Decadal Mean	Nov	Dec	Jan	Feb	Mar	Decadal Mean
1981- 1990	151	181	181	182	192	231	149	181	23	14	5	41	94	35
1991- 2000	152	170	181	227	178	246	182	191	37	11	7	37	59	30
2001-2010	148	202	208	227	219	257	146	228	59	9	27	27	103	45

Table 3: Mean Seasonal Rainfall Variation (mm) at Ado-Ekiti (1961-2010)

Decade	Wet Season								Dry Season					
	Apr	May	June	July	Aug	Sept	Oct	Decadal Mean	Nov	Dec	Jan	Feb	Mar	Decadal Mean
1961- 1970	127	149	307	174	161	237	170.3	1752	47	21	20	28	102	435
1971- 1980	110.8	132.5	148	185	164	209	115	1684	16	11	25	74	113	475
1981- 1990	133.9	133.9	190	184	203	208	146.1	1731	20	24	11	33	86	348
1991- 2000	124.4	152.3	163	165	156	223	156.2	1648	496	18	10	51	108	473
2001-2010	112.3	174.9	231	158	143	208	124.5	1704	35	10	19	41	87	384

Seasonal Rainfall Variability of Ondo

The rainfall distribution of Ondo during the period (1961-2010) showed a wide variability as shown in Figures 2 and 3. This finding is in line with the work of Babatolu (2002). Table 1 shows that the decades 1971-1980 and 1981-1990 had rainfall value lower than the threshold minimum rainfall of 1623.5mm. These decades could be said to be drought year since recorded rainfall was lower than the minimum station threshold rainfall (Hashimoto, 1982a, Fowler et al., 2003, Tsheko, 2003). The study reveals that the highest rainfall in the decades was recorded in 1963 (2,440mm), while the lowest was recorded in 1997 (1, 217mm). The rains decreased generally in the decade 1981-1990 with the lowest observed decadal mean rainfall of 1541mm, peaking in the decade 2001-2010 with recorded mean rainfall of 16838.5mm (Table 1). Table 4 presents the mean seasonal variation for wet and dry months in Ondo on decadal scale for a period of 50 years (1961-2010).

Seasonal Rainfall Variability of Benin City

The minimum threshold rainfall value for Benin was computed as 2300mm (Table 1). Only the decade 1971-1980 was found to experience rainfall lower than the minimum threshold value. This decade is seen as drought period with unsatisfactory rainfall. The decade 1971–1980, the total annual rainfall ranged from 1702 mm (1972) to 2585 mm (1980). In this decade, most January and December months were dry (Figure 3) with no rainfall for five years (1973, 1974, 1975, 1976, 1979). This decade was drier than the previous one. Despite the observed lower rainfall when compared against the minimum threshold for this decade, the rainfall value was however found to be higher than the area long-term mean annual rainfall of 1,727mm. Thus, the station experienced a higher rainfall value in all the decades than the area's minimum threshold rainfall figure. The long-term minimum threshold for Benin (2,300mm) was 33.2% higher than the basin minimum threshold rainfall value, thus the station is highly vulnerable to increasing flood peaks (Hashimoto, 1982a, Tsheko, 2003).

Generally, the first three decades showed double maxima of rainfall with an August break. In the fourth decade (1991–2000), the August break was absent with the August months recording generally higher rainfall values than all the other decades. This means that the normal pattern was reversed in this decade. Even the December months were wet. January was generally the driest month with a total of 682 mm of rain from 1960–2000. July was the wettest month with a total of 14 975 mm of rainfall from 1961–2000. Table 5 presents the mean seasonal variation for wet and dry months in Benin on decadal scale for a period of 50 years (1961-2010)

Table 4: Mean Seasonal Rainfall Variation (mm) at Ondo (1961-2010)

Decade	Wet Season								Dry Season					
	Apr	May	June	July	Aug	Sept	Oct	Decadal Mean	Nov	Dec	Jan	Feb	Mar	Decadal Mean
1961- 1970	148	141	219	259	209	240	217	2044	62	16	15	27	112	465
1971- 1980	161	177	202	261	164	234	182	1974	47	18	8	50	97	245
1981- 1990	175	201	217	211	164	254	154	1913	30	12	7	42	112	402
1991- 2000	165	173	276	234	158	295	198	2072	35	5	7	31	98	350
2001-2010	143	195	223	270	228	248	125	242	57	18	17	24	138	50.5

Table 5: Mean Seasonal Rainfall Variation (mm) at Benin-City (1961-2010)

Decade	Wet Season								Dry Season					
	Apr	May	June	July	Aug	Sept	Oct	Decadal Mean	Nov	Dec	Jan	Feb	Mar	Decadal Mean
1961- 1970	182	187	276	464	293	357	247	286	66	26	13	30	139	54
1971- 1980	188	188	281	357	289	372	237	273	71	32	7	75	83	53
1981- 1990	121	183	201	266	299	310	241	231	37	20	14	47	89	41
1991- 2000	199	239	261	377	370	338	286	295	74	35	24	48	113	58
2001-2010	219	281	291	235	292	398	244	327	105	18.4	16	60	127	65

CONCLUSION

Natural variability in the climate system is generally examined using the movement of the ITCZ or the squall lines cross the basin. Thus, a clear correlation can be observed between the movement of the ITCZ and the mean monthly rainfall depths. The time series data reveals that the wettest months of April to October with a break most often in August and the drier months of November to March for the 50-year period were consistent, revealing that there has been no change in the weather state frequencies and associated pressure difference across the basin over time.

The long-term mean annual rainfall threshold for the section of the Benin-Owena River Basin under study was found to be 1,727mm. The study shows that observed rainfall values for Benin was generally higher than the long-term threshold value, with only two years, 1972 (1,702 mm) and 1977 (1,716 mm) in the 50-year period under consideration had rainfall below the threshold mean value. This period was in the decade 1971-1980.

Rainfall in Akure was found to be the poorest in the area when compared against the minimum threshold rainfall value of 1,727 mm as only three (1991, 1995 and 2008) of the 30-year under investigation were observed to have recorded higher rainfall than the minimum threshold figure with mean annual rainfall of 1,853.4 mm (1990), 1,913.6 mm (1995) and 2,848.8 mm (2008). Ado-Ekiti and Ondo were slightly better in terms of reduced number of years vulnerable to drought conditions. Ado-Ekiti has 9 mean annual rainfall events with rainfall above the minimum threshold value, i.e. 1963, 1968, 1994, 1997, 2001, 2004, 2006, 2009 and 2010, while in Ondo there were 13 recorded rainfall events above the minimum threshold as observed in the following years – 1963, 1868, 1975, 1978, 1979, 1980, 1985, 1991, 1994, 1995, 2003, 2008 and 2010. It is imperative to note that Akure station experienced an exceptionally high rainfall in 2008 with ,2848.8 mm of rainfall, a figure that was the fourth highest observed rainfall in the study area in the 50-year period. In contrast, Ado-Ekiti was observed to experience the lowest rainfall with the driest years being 1964 and 1977 with mean rainfall values of 634.5 mm and 604.3 mm, respectively.

The implication here is that the basin is prone to drought hence too risky for rain-fed agriculture. Akure, Ado-Ekiti and Ondo are located in the northern part of the basin where rainfall reliability is low and the risk for failure or vulnerability to drought is high. The highest rainfall ever of 2,827.2 mm was recorded in Benin in 2010 season.

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