American Journal of Water Resources, 2014, Vol. 2, No. 1, 1-9
Available online at http://pubs.sciepub.com/ajwr/2/1/1

DOI:10.12691/ajwr-2-1-1

Spatial Distribution and Variability of Groundwater Quality in State Capital and Contiguous Local Government Areas under Urbanization Expansion

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Received September 19, 2013; Revised November 27, 2013; Accepted February 17, 2014

Abstract The objective was to investigate groundwater quality in boreholes located in Uyo urbanized state capital, and four contiguous Local Government Areas (LGAs) of Ibiono Ibom, Ikot Ekpene, Itu and Nsit Ubium, under Coastal Plain Sands(CPS) formation, for spatial and temporal variability of groundwater quality and compatibility with Nigerian Standards for Drinking Water Quality (NSDWQ)indicating prospects of pollution diffusion due to urbanization spread. Standard examination methods were employed as well as morphological and bacteriological counts. Data on waterquality properties were statistically analyzed using SPSS software version 17 for descriptive statistics, covariance (CV), ANOVA and for percentage compatibility computations. Data on Uyo samples showed the lowest values while Ibiono showed median values; heavy metals showed highest spatial variability at CV ≥ 35%. Significant difference ($P < 0.1$) was observed in temporal variability between 2013 and 1993 values (20 years interval). The suggested causes were: spread of pollution by construction ruts, stagnant polluted water, and vehicular traffic commuting urban-rural areas, open uncontrolled dumping of various solid/organic wastes, insanitary handling of water and wastewater and low standard of borehole drilling in rural-urban fringe adjusting to suburbanization. Compatibility with NSDWQ varied per parameter and location but were generally within acceptable standards; however, iron, lead and cadmium in the contiguous LGAs were higher in concentrations and should be periodically monitored. Bacterial counts, especially coliform count exceeded standard MPN and called for sanitation intensification.

Keywords: *groundwater quality, spatial variability, urban diffusedpollution, urban – rural fringe, percentage compatibility, drinking water standards*

Cite This Article: Obot Ekpo Essien, and Abasifreke E. Abasifreke, “Spatial Distribution and Variability of Groundwater Quality in State Capital and Contiguous Local Government Areas under Urbanization Expansion.” *American Journal of Water Resources*, vol. 2, no. 1 (2014): 1-9. doi: 10.12691/ajwr-2-1-1.

1. Introduction

Urbanization expansion has gone far in some State Capitals in Nigeria since the creation of their states. The development momentum has reached adjoining contiguous villages in the rural-urban fringe, many of them also being under different Local Government Areas (LGAs) but contiguous with the State Capital (which itself is a distinct LGA) or State Capital territory, which encompasses the State Capital and land areas within delineated distances from the State Capital as urban centre.

In Uyo metropolis, urban expansion has engulfed up to 90% of rural-urban fringe by sub urbanization land use within 20 years since its creation, especially in the last decade and two years (1998-2010) [1]. Suburbanization has penetrated rural-urban fringe to distances between 10 and 20km from the capital and many satellite villages along major transport routes in the States. The suburbanization expansion on land development involves many categories of land use like: Transportation (30.2%), Residences (21.4%), Commercial (17.6%), Institutional (universities, etc) (12.6%), Industrial (8.2%) leaving only 10% available land portion for rural farm holders' population [1]. The penetration into contiguous Local Government Areas by suburbanization development are extensive and varies within the recent decade for transportation at 4.79km^2 yr^{-1}, commercial (including borehole development for water vending) at 2.72km^2 yr^{-1}, residential at 2.54 km^2 yr^{-1}, institutional at 1.71 and industrial at 1.25km^2 yr^{-1}, causing undeveloped area to recede at -2.29km^2 yr^{-1} [1].

Therefore the effects of urbanization development are highly felt in contiguous areas to Uyo urban, hence the associated pollution diffusion by the cut and filled soil, by traffic flow of transportation vehicles and of earth moving and grading machines, wastewater flow, stagnant puddles of polluted waste water and solid waste movement. The coastal plain sands geology is generally a flat topography such that surface water are far and in between. This leaves the major source of drinking water as well as other water usages to groundwater, especially borehole supply, which is now upgraded to commercial vending commodity because of the exigency to meet the upsurge of water demand for residential and transiting population due to urbanization effect, which also has pulled in internal migrants from farm households to towns for residence and job-search and employment [2].

The expanding urban development involves the use of vehicular traffic (non-point source, commuter and private vehicles), land grading machine. This causes pollution re-distribution from polluted water passing through the soil profiles [3,4]. Under the flat terrain, this may move deep into soils' profile by percolation and eluviation [4,5]. In coastal plains sands, stream discharge is mainly by groundwater-driven dynamics [6], hence borehole is the main source of water supply than surface stream. The raison d'etre for this investigation, based on above scenario, is the consequential redistribution of diffuse pollutants in ruts and in infiltrating water from polluted puddles created in ditches, excavations or cuts made on uncompleted construction of urbanization development projects. This spread may enhance or move surface pollution to the groundwater if infiltrating polluted water falls into well interference which may exist due to the expanding borehole density under un-inhibited drilling [6]. For instance, heavy metals (HM) concentration in soils at pollution level are affected by anthropogenic cause such as road dust and gully pots which they may occupy. Such HM, attached to soil particles or in water puddles, may be spread the dust by mobility of rural-urban transport vehicle and construction equipment in the catchments [7]. By converting rural land into urban land, urbanization impacts produced more pollutants than farm lands especially heavy metals [8]. Thus, rapid suburbanization is spreading diffused pollution by adverse construction methods and equipment to contiguous LGAs which consequence on groundwater may be critical [9].

Human interference has pushed small scale or cottage industries to the rural-urban fringe areas and increased the use of metaliferous smelting industries. The spread of waste metal and organic waste into bushes, and spreading open waste water on the street have also taken place. Uncompleted roads with ditches and depressions are left to be filled with polluted run off which remain stagnant for days without drainage. In the past, rural dwellers did not allow waste water into the streets but now, waste water from eateries, baths, urinary and market places flow to the roads into the stagnant puddles unattended because of the expectation that those roads are left for government to complete. The delays in completion therefore create a sense of leaving with ponds of polluted stagnant waste water around human residences. These are the same localities which boreholes eventually may be sited.

Therefore, the spread or redistribution of the of HM and other water quality pollutants loads may be critical in the CPS under high infiltration of polluted waste water and eluviation process, since there is the possibility of surface pollutants infiltrating into the immediate radius of influence of boreholes which is between 150m and 500m (or 300m as mean) [10], should there be well interference. Since the water source in the CPS is groundwater-dependent, and a large population grows under urban expansion and depends on ground water, the quality and quantity of such groundwater relationship in redistribution and spreadof pollution in water quality are investigated for monitoring, control of water supply and policy framework on water treatment.

Therefore, the aim of this paper was to investigate the distribution and variability of groundwater quality between the urbanized state capital and the four contiguous local government areas with it. Specific objectives were: (1) to investigate the water physico-chemical properties in boreholes at Uyo and four contiguous LGAs all in the CPS, (2) to establish the pollution homogeneity and variability, (3) to establish their quality constituent compatibility with NSDWQ.

2. Materials and Methods

2.1. Study Area

The study covers the urban centre of Uyo Capital territory, capital of Akwa Ibom State of Nigeria and villages in four Local Government Areas (LGAs) contiguous with the State Capital, all of which are in the coastal plain sands formation. The contiguous LGAs are Uyo, Ibiono, Ikot Ekpene, Itu and Nsit Ubium. The Uyo Capital territory and contiguous LGAs are shown in Uyo map lying within latitudes 5° 00^{1}N and 5° 04^{1}N and longitudes 8° 47^{1}E and 7° 56^{1}E: Coastal plains sand geology is characterized as in Hydrotech [11].

2.2. Borehole Water Sampling and Laboratory Analysis

Water samples were collected from the representative boreholes in the four contiguous LGAs and the State Capital within the Coastal Plain Sands. One sample bottle was used for each LGA, and the bottle was properly labeled with the name of the particular LGA. Before using the sample bottles, they were thoroughly washed and rinsed clean with distilled water, before using them for the sample collection. Water samples in sample bottles were transported carefully to the laboratory at University of Uyo and Akwa Ibom Water Company Ltd. Uyo for chemical analysis while the sample heavy metals (HM) component was taken to Aluminum Smelter Company Laboratory, Ikot Abasi for acid digestion and flame atomic absorption spectrophometry.

2.3. Methods used in Water Analysis

The following methods were used for the various parameters in water analysis [12].

2.3.1. Physical Methods were:

1. Electrical conductivity using conductivity meterwith electrode, model DIST-3 by Hanna Ltd.
2. Total suspended soil by filtration and gravimetric methods.
3. pH value by electrometric method using pH meter, model H1/98/27 by Hanna Ltd.

2.3.2. Titrimetric Method for:

1. Calcium was by EDTA complexometric titration
2. Magnesium was by EDTA complexometric titration
3. Carbonate was by Acid titration
4. Bicarbonate was by Acid titration
5. Chloride was by Silver nitrate titration

6. Sulphide was by Titration of I_2 released with sodium thiosulphate on oxidation or sulphide with potassium iodate
7. Cadmium was by complexometric titration with EDTA

2.3.3. Colorimetric Methods for:

1. Nitrate was by Brucine method
2. Ammonium nitrogen by Nesslerization method
3. Phosphate was by molybdate blue colour method
4. Sulphate was by turbidimetric method
5. Iron was by the orthophenanthroline method

2.3.4. Flame Photometry was Used for:

Potassium and Sodium

2.3.5. Atomic Absorption Spectrophotometry was Used for:

Copper, Chromium, Cadmium, Lead, (using UNICAM model of Atomic absorption spectrophotometer.

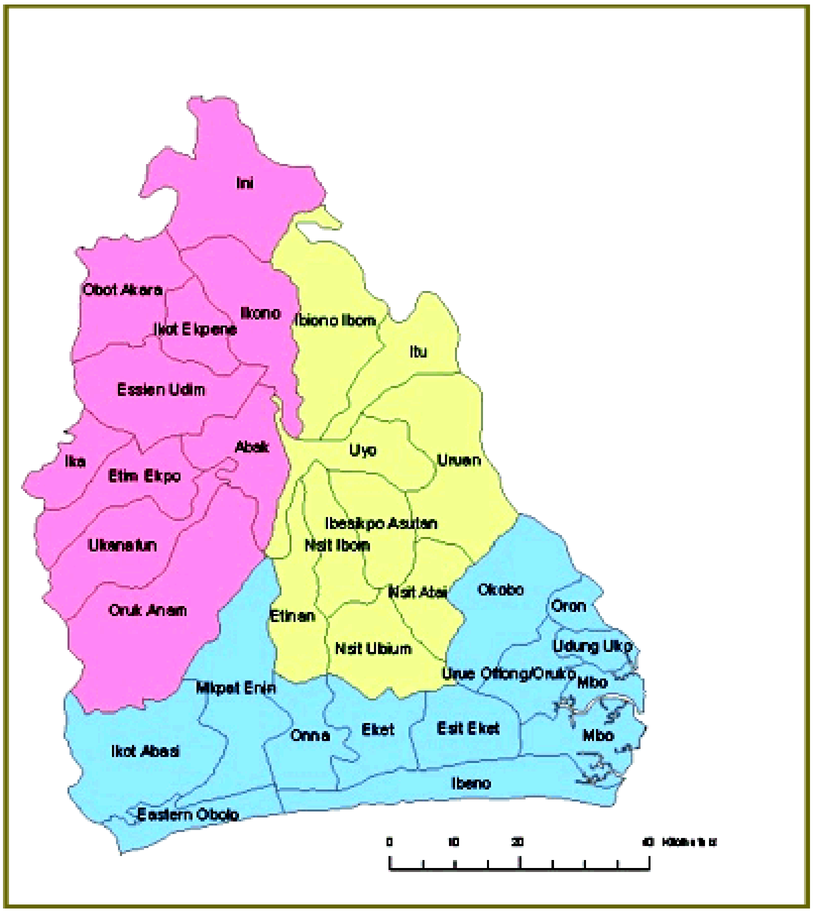

Figure 1. Showing map of Akwa Ibom State (Please note the locations of Uyo, Ibiono Ibom, Itu, Ikot Ekpene and Nsit Ubium LGAs)

Other quality properties analyzed were: total dissolved solids, total hardness, dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) [12].

2.3.6. Microbial Analysis

Nutrient agar was used for total bacterial count; MacConkey agar for total coliform bacterial count; Eosin for total faecal coliform and E. coli; Salmonella/Shigella agar for Salmonella count and dextrose agar for fungal counts.

2.4. Statistical Analysis

General descriptive and inferential statistics of borehole water quality data were analyzed using SPSS version 17 software (Words). Nonparametric test was used were geochemical data did not follow normal distribution in general. ANOVA was applied to test significant variance differences in borehole water quality properties from different LGAs in order to analyze any quality change in the rural-urban areas under the same underlying geological formation (parent material) that would implicate anthropogenic causes [13]. Covariance (CV) was computed for the range of spatial variability of quality distribution. The quality compatibility with the NSDWQ [14] as a public health guarantee, was checked using Eqn. 1 given as:

$$\text{Parameter compatibility with NSDWQ, \%} = \frac{NSDWQ - Water\ Parameter\ Mean\ Value\ x\,100}{NSDWQ} \quad (1)$$

Or

$$\text{Percentage compatibility} = \left[I - \frac{Sample\ Parameter\ Value}{NSDWQ\ Value} \right] \text{X } 100 \quad (2)$$

where NSDWQ = Nigerian Standard for Drinking Water Quality. Parameter value = 0 or ND means 100% compatible; and parameter value = NSDWQ value is 0% compatible.

3. Results

The mean concentrations of the borehole water quality properties in Uyo, the State Capital, and the four contiguous Local Government Areas, and the maximum permissible values of NSDWQ are shown in Table 1.

Compatibility of properties with NSDWQ is shown in Table 2 while their comparison and significant differences are given under discussion below.

Table 1. Physiochemical properties and basic statistics of groundwater samples in Uyo and contiguous LGAs

Sample	Uyo	Ibiono	Ikot Ekpene	Itu	Nsit Ubium	Mean	Sd	CV, %
pH	5.44	5.36	5.22	5.15	5.17	5.27	0.13	2.40
Elect conductivity uS/cm	0.09	0.039	0.075	0.045	0.055	0.06	0.02	35.0
TSS mg/l	Nil	Nil	Nil	Nil	Nil			
TDS mg/l	0.46	0.13	0.35	0.3	0.33	0.31	0.12	38.0
Acidity (CaCO3(mg/l)	16.2	12	15.55	14.15	14.33	14.45	1.61	11.2
Total alkalinity CaCO3 (mg/l)	20.1	22	24.05	34.25	24.2	24.92	5.48	22.0
Total hardness (mg/l)	4.1	3.2	2.9	3.15	3.1	3.29	0.47	14.2
Chlorine (mg/l)	23	21.2	17.39	20.05	19	20.13	2.13	10.6
Phosphate (mg/l)	0.05	0.048	0.029	0.04	0.035	0.04	0.01	21.8
Nitrate (mg/l)	0.02	0.021	0.045	0.03	0.039	0.03	0.01	35.4
Sulphate (mg/l)	0.16	0.2	0.55	0.35	0.4	0.33	0.16	47.5
Potassium (mg/l)	0.04	0.06	0.2	0.08	0.12	0.10	0.06	63.3
Sodium (mg/l)	0.01	0.03	0.15	0.08	0.09	0.07	0.05	76.3
Calcium (mg/l)	8.2	10.1	16.37	12.11	14.29	12.21	3.25	26.6
DO (mg/l)	5.3	6.5	11.22	7.89	9.23	8.03	2.31	28.8
BOD (mg/l)	2.1	2.4	2.77	2.45	2.56	2.46	0.24	10.0
COD (mg/l)	0.7	0.92	1.35	0.99	1.22	1.04	0.26	24.7
Lead Pb2+ (mg/l)	0.018	0.108	0.106	0.28	0.115	0.13	0.10	75.9
Iron Fe3+ (mg/l)	0.016	0.361	0.254	0.304	0.295	0.25	0.13	54.5
Copper Cu2+ (mg/l)	0.001	0.015	0.016	0.018	0.02	0.01	0.01	53.7
Cadmium Cd2+ (mg/l)	0.001	0.004	0.005	0.007	0.009	0.01	0.00	58.3
Chromium Cr6+ (mg/l)	0.001	0.001	0.002	0.003	0.006	0.00	0.00	79.8
GM	0.003	0.019	0.021	0.032	0.033	0.02	0.01	55.8

Table 2. Compatibility (%) of groundwater quality in Uyo and four contiguous local government areas with NSDWQ

Parameter	NSDWQ	Uyo, %	Ibiono, %	Ikot Ekpene, %	Itu, %	Nsit Ubium, %	Mean, %
pH	6.5-8.5	15	18	20	21	20	19
EC mS/m	1000	100	100	100	100	100	100
TSS	500	100	100	100	100	100	100
TDS	500	100	100	100	100	100	100
Acidity	4.5-8.2	-2.6	-1.7	-2.5	-214	-218	-2.2
Alkalinity	100-200	80	78	76	66	76	
Hardness	500	99	99	99	99	99	99
Cl^-	250	91	92	93	92	92	92
PQ_4^{3-}	3.50	99	99	99	99	99	99
NO_3^{3-}	50	100	100	100	100	100	100
SO_4^{2-}	100	100	91	100	100	100	100
Ca^{+2}	75	89	87	78	84	81	84
DO	1.0-5.0	.6	-30	-124	-58	-85	-61
Pb^{2+}	0.01	-80	-980	-960	-2700	-1050	-1200
Fe^{3+}	1	98	64	75	70	71	75
Cu^{2+}	1.00	100	99	9.8	98	98	99
Cd^{2+}	0.003	67	-33	-67	-133	-200	-233
Cr^{6+}	0.05	98	98	96	94	88	100

NSDWQ also conform to WHO guidelines.

4. Discussion

4.1. Water Quality Properties Variability

Up to 22 water quality properties were investigated in the physico-chemical categories. Statistical analyses show that significant differences existed in magnitudes of the quality properties across the contiguous LGAs and Uyo, the state capital. Quality changes as well as temporal changes occurred within a time interval of 20 years (1993-2013).

4.2. Spatial Variability

Non-homogeneity or spatial variability of water quality in the boreholes cut across all LGAs and the state capital. However, selected properties showed spatial variability in their locations on the same geological formation than others. For instance while the covariance (CV) varied between 2.4 and 79.76% in the whole area amongst the boreholes (which is a significant range), specific properties were relatively homogenous across the boreholes in the LGAs and in the geological formation while others showed marked variability (Table 1).

Properties which exhibited relative spatial homogeneity included cases with CV < 35%. These were pH, Acidity, Alkalinity, Hardness, Chlorine, Phosphate, Calcium, DO, BOD and COD (Table 1). Those with spatial variability included properties with CV ≥ 35%. These were: EC, TDS, nitrate, sulphate, potassium, and sodium, all HMs (Pb, Fe, Cu, Cd and Cr).

Properties with high CV show spatial changes in concentrations at different boreholes in separate LGAs. This effect is very significant to urban-rural and inter-rural communities' distribution of anthropogenic pollution of water quality properties in the areas under the same geological formation, confirming that urban diffuse pollution, and in this case urban-rural diffuse pollution, is an emerging challenge to suburbanization, in the aspect of rural water supply, in vulnerable local communities having groundwater as the main water supply source [9]. Invariably, rapid suburbanization in the rural-urban fringe areas has a potential pollution diffusion effect on the receiving groundwater or benefitting rural-urban communities.

4.3. Temporal Variability

In the present investigation, changes were observed in water quality from the distributed boreholes in four contiguous LGAs to state capital which were undergoing rapid urbanization expansion between them.

Comparatively, temporal variability compared the 1993 water quality to the present (2013). In 1991-1993 programme of government tube wells water supply through the Directorate for Food, Road and Rural Infrastructure (DFRRI) [16,17], average properties of tube well water showed low homogeneity inthe LGAs (CV = 6-33%) except for EC (56%), Chloride (37%) and iron (50%) (Table 3). However, the changes in spatial variability in nitrates, EC, pH, DO, TDS, alkalinity, nitrates, sulphate, phosphates, BOD, chloride, hardness became more distributed; the higher CVs in 1993 reversed to lower CVs in 2013 while lower CVs in 1993 became higher CVs in 2013, showing environmental quality change over time (20 years) caused by urbanization spread of pollutants, which is known to cause diffusion of pollution [9]. The more variable properties are of great concern to environmental health. The electrical conductivity serves the purpose of and Iron gauging the salinity of water. This comes about by dissolved organic salt moving through to the groundwater. Variability of total dissolved solid is about dissolved inorganic salts, small amount of organic matter and dissolution of gases [18]; and water with a total-solid content of less than 500 mg/l is desirable for domestic purposes, whereas higher concentration impart unpalatable taste and laxative effect on users, which situation would be detested by the community [9].Water with high dissolved-solids content has adverse impacts on irrigated crops, plants and grasses (such as used in landscaping and environmental beautification in urban centres [18]. Table 1 shows the TDS content and the total solid as being within the desirable range. Only a change in their temporal variability (Table 3) shows that there is a change in distribution of organic salts, organic waste; hence indicating an increase of their possible pollution sources between the LGAs in 20years of rural-urban spread.

4.4. Heavy Metals Variability

Heavy metals (HM) showed spatial variability of content (CV > 53%, Table 1), indicating that HM are being distributed differently in the environment. The geometric mean (GM) of HMs at each borehole varied significantly (P= 0.05) between 0.003 and 0.01 mg/l between borehole locations in the geological formation.

Groundwater contains soluble forms of iron, (ferrous iron, Fe(II)) only in anaerobic conditions [18]. That means anaerobic condition (or reduced level of DO or more CO2 gas in the groundwater ambience) is a prevailing condition for appreciable amount ofstable iron to dissolve and move to groundwater insoluble forms [18,20]. Consequently, low amount of soluble iron indicates ample dissolved oxygen in water, and, of course implicated the action of micro-organisms [18]. Within twenty (20) years interval, the amount of free corrosive CO_2 content within boreholes in the LG within the same geological formation ranged from low to very high (7-200 mg/l) (Table 3), hence the DO was low [5]. Iron, in ample amount, corrodes metal pumping pipes producing turbid appearance, distaste and interferes with laundry, which vocation is ubiquitous in the community, and relies on the conjunctive uses of groundwater. Such a case was observed in the past in the borehole water supply for the State College of Education, Afaha Nsit in the 1990's [17]. The iron content range was 3.4 mg/l but the astronomical content of corrosive CO2 (of 130 mg/l) imposed anaerobic condition that corroded pump fittings and ferrous pipes, and impaired water taste and colour (Table 4). Those fittings were changed at a great cost to DFRRI. Thus, this investigation either reassures quality water supply or exposes quality changes. Both cases were applicable in this case.

The trace metals lead and coppers amongst others affect users and materials. Lead corrodes copper parts and produces copper fast at higher concentration (Cu < 1.0 mg/l). The same is for Pb, which is carcinogenic, toxic, and can enter water through the gasoline expelled by automobiles, lead-based paints and lead-service pipes for interior decorations. It is known to affect children, nervous system, kidney damage [18,20].

Comparison between the covariance in the present (2013) water quality and the covariance of quality variation 20 years previously (in 1993) (Table 3), showed the paired sample correlation with very low coefficient (r = 0.156), while the paired sample tests of their mean (2013 and 1993 data) showed differences but not significant at P=0.05. Thus, the variability within the 20 years interval created less significant difference in the groundwater properties between the boreholes in the contiguous LGAs. However, the low correlation coefficient suggests that their means were actually different but the 2013 values were not dependent on or significantly related to the 1993 values. Thus, variability was caused by new factors other than parent material in 1993.Differencesin water quality properties recorded within the 20 years from 1993 (when governmental focus on rural water supply was implemented) to 2013 (within which years rural-urban development heightened) resulted in urbanization diffusing to the rural areas especially in contiguous communities and redistribution of water quality properties further changed significantly. Covariance in Table 3 shows that variability in water quality properties generally increased in the 20 years period. Those which increased included TDS, alkalinity, phosphate, nitrate, sulphate, DO, BOD. Iron showed slight reduction in temporal variability although its mean content actually increased from 0.17 to 0.25 mg/l within the 20 years period (Table 3), giving a time gradient of 0.004 mg/l per year. Covariance between 2013 and 1993 had only a fair correlation (r = 0.488) which gave significant difference at 10%.

The pH, and hardness reduced in mean concentration over the period. The higher concentration of ferrous iron content in 2013 against 1993 indicates increasing anaerobic conditions in the borehole, because under anaerobic condition iron is reduced to soluble ferric iron [18]. However, such anaerobic condition is environmentally harmful to ground water conjunctive uses in domesticuse, gardening, car washing and drinking. It also adversely affects biological purification.

Table 3. Comparison of changes in (2013) with DFRRI (1993) borehole water quality after 20 years interval

Quality parameter	Mean (2013)	DFRRI (1993)	Covariance (%)	
			2013	1993
pH	5.27	6.70	2.40	
EC	0.06	8.22	35	56
TDS	0.31	4.36	38	24
Alkalinity	24.92	14.57	22	16
Hardness	3.29	12.89	14.2	20
Chloride	20.13	7.64	10.6	37
Phosphate	0.04	15.99	21.8	17
Nitrate	0.03	17.41	35.4	13
Sulphate	0.33	9.96	47.5	19
DO	8.03	6.38	28.8	10
BOD	2.46	2.85	10.0	17
Iron	0.325	0.17	54.5	50

N/B.DFRRI (1993) is courtesy Essien and Sangodoyin, (2006); (2013) data are result of author's investigation (2010-2013).

Table 4. Compatibility of DFRRI (1993) selected water quality with NSDWQ and present (2013) quality properties

Quality parameter	Compatibility (%) with NSDWQ	
	Data (2013)	DFRRI (1993)
pH	19	-3
EC	99	98
TDS	100	100
Alkalinity	75	75
Hardness	99	99
Chloride	92	92
Phosphate	99	99
Nitrate	100	100
Sulphate	100	100
DO	61	61
Iron	75	75

N/B. pH used min. value (6.5), Alkalinity used min. value (100 mg/l), DO used lower base (1.0 mg/l)

When pH is below 6, as seen in 2013 properties (Table 1) against the 1993 pH (Table 3), the rates of oxidation is not rapid and this allows reduced forms to exist and colloids can as such be formed which will produce turbid and unacceptable quality water [18]. Under acidic rainfall preferential flow and eluviation process as may cause poor quality water to flow to the groundwater, and may result in production of colloidal precipitates which reduce water quality and increase sediments deposition; which means costly maintenance over time.

Wells, which usually produce good-quality water having low iron content, may change to produce poor-quality water when organic wastes have been discharged over years on the soil around or near them, which will create anaerobic condition in the soil [18,20]. This situation is of concern in this flat topographical area, where because of suburbanization participatory community sanitation activity has declined or stopped whereas the generation of construction ruts, organic wastes by construction machines, dusty air by vehicular traffic, acidic rainfall and NPS polluted puddles of runoff, and waste water from industries and commerce are still being generated. When suburbanization occurs, the community seems to be indifferent to rural sanitation activities leaving vegetal or organic and other waste heaps about and waiting for the Government to carry out everything; but the ruts and the wastes stay with them, sending infiltration pollution into the groundwater. The bacterial oxidation of organic wastes produced extensive CO_2content, anaerobic condition which reduced stable iron to soluble iron that move by eluviation and preferential flow to groundwater leading to more iron in ground water being produced and widely distributed (CV $\geq$ 54). Continued quality monitoring under urbanization expansion is required because of the prospect of diffused pollution from suburbanization. Thus, communities where iron in borehole water exceeds 0.3 mg/l fall into substandard water quality and that must be watched. Apart from Uyo, all other LGAs fell into this sub-standard condition with respect to other iron content. Other harmful HMs are lead and cadmium.

4.5. Uyo and LGAs in HM.

Data in Table 1 shows that HM concentrations in Uyo Metropolis, the State Capital are lower than those in contiguous communities. The reason for this change may not have specific answer but may be due to the imperviousness of urbanized state capital. Uyo is highly paved up in 90% of its surface area, so that all municipal waste water, sewage and NPS runoff drain directly into urban drainage channels rather than infiltrate the soil. These urban collectors take water to outlets in urban drainage streams, where HM have been found to have very high concentrations above normal standard for drinking water [21]. Hence, the concentrations of ground water quality properties in Uyo were found to be the lowest compared to those in contiguous LGAs (Table 1) and increased CV for HM to between 53.7% and 79.8%.Thus, channelization of urban drainage seems to have saved the groundwater in urban metropolis from intense HM pollution. Therefore, urbanization (such as increased impervious surface area) caused increased HM variability.

On the other hand, the contiguous rural-urban communities have less impervious but large pervious surface area, which allows muddied or polluted waste water, rainfall runoff and organic leachate from agricultural wastes and human wastes from unsealed toilets to infiltrate and flow through soil profile to the shallow water table in their terrain. There are no collector drains for the runoff.

Until recently these rural areas were not polluted with solid or liquid wastes because the households used the backyard burning for solid waste disposal; waste water was thrown into the farm or into dug pit. However, sub-urbanization has created interest in economic activities like various small-scale commercial enterprises, restaurants, mechanics workshops, hairdressing and barbing salons, etc. The solid wastes from these enterprises are littered in the fallows around their premises as open uncontrolled wastes dump while the waste water run off onto the road to be washed by rainfall to puddles and stagnant ponds or to infiltrate into the open pervious soil. Solid wastes included spent food and drink cans, juice packs, polythene bags, waste papers, used batteries, scrap metal pieces, damaged electrical /electronic devices, etc.

The dumping of these solid wastes in the open exposed them to the acid rains prevailing in the study area. Acid rains decreased the Ph which increased corrosivity of water enhancing mobilization of metal salts from soil. Heavy metals may move in the soil profile through micropores or cracks by preferential flows under acidic condition when high rainfall occurs [22,23], and soil pH influences bioavailability and transportation of HM. The open surface dumping of such wastes helped release HM into the soil in the area [23]. Metals like Pb, Cd, and Cu may be dissolved by the soft acidic water of high corrosivity and may increase metal concentration in drinking water. The food and vegetable wastes on soil surface can release HM metals into the soil by precipitation or absorption [25,26]. Thus, their concentrations over time were higher than they were 20 years previously and their distributions were spread out depending on intensity of urbanization. This resulted in wider variability (CV) than previously (Table 3).

4.6. Compatibility

Table 2 presents the compatibility of borehole quality properties with NSDWQ obtained by using Eqn. (1). Acidity, pH, alkalinity, Ca, DO, and all HMs varied significantly in their compatibility with NSDWQ. Others had 100% compatibility than many properties of boreholes in contiguous LGAs (Table 2).

The compatibility between the 2013 and the 1993 quality properties with NSDWQ were the same, or were not significantly different at P=0.01 (Table 4), however the variability of concentrations were significantly different. Paired sample correlation showed significant (P<0.01) correlation between their compatibilities, showing that, although changes were recorded in mean quantity of water quality properties, quality compatibility with NSDWA did not move significantly in the 20years interval.

Thus, property in borehole water showed significant spatial and temporal variability but property quality showed temporal compatibility within 20 years of urbanization expansion. The extent that quantity variability will continue to be within compatibility with quality standard under ongoing suburbanization, where environmental neglect subsists, is not certain. This calls for periodic monitoring and policy action.

4.7. Microbial Quality

The human activity constitutes a factor of change in groundwater quality through forms of contamination. Contamination also considers the introduction or discharge of pathogenic micro-organisms and or any substances which can make the water inadequate to public (especially human consumption). Agricultural activities abound in the contiguous rural-urban communities, and constitute one of the contaminants sources [27,28,29]. The contributor include the digestion of biodegrading agricultural waste in humid environment, and digestion of human and animal excrement, carcasses at markets waste heaps, as well as the puddles of water on incompletely constructed or eroded roads and market places receiving pollutants of different sorts drained to them, and eventually infiltrating into the soil largely because surface streams are not close by and the terrain is largely flat with numerous ditches and, depressions collecting waste water and runoff; also open toilet system or ones with unsealed pits, open urinary and open baths all drain their organic waste water with the bacterial population forming there directly into the soil of the flat landforms. The environmental waste, and insanitary condition and public distribution of excrement as well as no drainage for these waste waters created near-habitual deposits for microbial/organic pollutants path ways to ground water. Also contributing to microbial pollution of groundwater is the lack of sanitary protection of the drilled wells, mainly deficient isolation of the annular space with laitance (or loose grouting) at the non-saturated zone [30], and its location near sewage tanks or where the spills, drippings or splashes of water from fetchers at the public borehole locations have no drainage beyond the periphery of the well head. In some cases, car wash bays are located near the improperly sealed wells and the waste water ponds around the well vicinity having no drainage outlet in the locality, except to infiltrate into the soil.

Results of the morphological and biochemical characteristics (Table 5) for the five LGAs show colour differences, with samples from Ibiono and Itu being pinkish, from Nsit Ubium being methyl red, but from Uyo (State Capital) and Ikot Ekpene being colourless. The colourless characteristic may probably be due to better sanitary conditions in the boreholes tested or in that LGA generally. The gram reaction was negative for all samples. The bacteria shape was rod-like for all except Uyo and Ikot Ekpene. Glucose, lactose, and sucrose tests were also negative for Uyo and Ikot Ekpene while acid and gas were produced in the samples from the other 3 LGAs.

Also, the following tests were negative for all samples from the 5 LGAs: indole, methyl red, mobility, catalase, spore test and oxidose. Thus, the probable organism was identified asentero-bacter aerogenes for other 3 LGAs but none for Uyo and Ikot Ekpene.Bacterial counts (cfu/ml) were in increasing order of magnitude: 1100 (Itu) < 1200 (Ibiono) < 12000 (Nsit Ubium), but their coliform MPN were respectively $170^{+,}$ 180^{+} and 185^{+}. The coliform counts were above the quality standards of 0 per 100ml [12,14,26]. Therefore, treatment and precise sanitary measures, best practice in engineering in construction, and public enlightenment on sanitation and health are advised.

Table 5. Morphological and biochemical characteristics of bacteria isolated from water sample

Sample Test	Location				
	Ibiono	Uyo	Itu	Nsit Ubium	Ikot Ekpene
	Characteristics				
Colour	Pinkish	-ve	Pinkish	Methyl red	-ve
Gram reaction	-ve	-ve	-ve	-ve	-ve
Shape	Rod	-ve	Rod	Rod	-ve
Indole	+ve	-ve	+ve	+ve	-ve
MR	-ve	-ve	+ve	+ve	-ve
Mobility	+ve	-ve	+ve	+ve	-ve
Catalase	+ve	-ve	-ve	-ve	-ve
Spore test	-ve	-ve	-ve	-ve	-ve
Glocose	AG	-ve	AG	AG	-ve
Lactose	AG	-ve	AG	AG	-ve
Sucrose	AG	-ve	AG	AG	-ve
Oxidase	+ve	-ve	+ve	+ve	-ve
Probable organism	E. aerogenes	-ve	E. aerogenes	E. aerogenes	-ve
MPN/ 100ml total bacteria count (cfn/ml)	180+	Nil	170+	185+	Nil
	1200	Nil	1100	12000	Nil

Keys: AG – Acid/Gas production, MR – Methyle red, -ve – Negative, +ve – Positive, E.= Enterobacter

5. Conclusion

Groundwater quality in boreholes located in Uyo, Capital of Akwa Ibom State and four contiguous local government areas (LGAs) of Ibiono Ibom, Ikot Ekpene, Itu and Nsit Ubium were investigated for spatial and temporal variability, and compatibility with the Nigerian Standards for Drinking Water Quality (NSDWQ).

Standard methods of waste water examination for physico-chemical analysis were employed; acid digestion and analysis by Atomic Absorption Spectrophotometer were used for heavy metals analysis while MPN used for bacterial examination. Spatial variability was tested by ANOVA and covariance (CV), temporal variability changes were tested by ANOVA for significant differences between the present (2013) and 1993 water quality values (i.e. 20 years interval within which urbanization expansion in Uyo spilled into urban-rural fringe communities). Distribution of water properties in the LGAs showed variability: some exhibited mean homogeneity in the LGAs (CV< 35%) while others were highly varied in space and time ($CV \geq 35\%$). Heavy Metals (HM) were highly varied ($CV \geq 54\%$), and nitrate was < 50 mg/l. Uyo had the least magnitude while Ibiono Ibom had median magnitude and Nsit Ubium/Ikot Ekpene got the highest.

Uyo was observed with least values possibly because being at the south-easterly periphery of the coastal plain sands, it has drainage streams at that periphery which it could channel polluted water into but none at the other axis. Being paved up with 90% impervious area, infiltration of polluted water into surface soil was hindered, rather much of all polluted municipal waste water, rainfall runoff and sewage were channeled through constructed drainage channels to the urban drainage streams. The heavy metals were observed with high concentrations in the drainage stream water, which medium therefore saved the urban groundwater from HM pollution. The other LGAs are 90% pervious area opened to infiltration of all sorts of waste water and solubilized particles including HM, hence their HM concentrations were higher than the values in Uyo.

Variability in 2013 was far higher than in 1993 indicating increased diffusion of pollution; compatibility with NSDWQ varied, and Pb and Cd concentrations in the LGAs were above standard level and these should be addressed and monitored. However, compatibility with safety standards was generally acceptable, indicating that the borehole water was safe for drinking except in the cases of Pb, Cd and the effect of iron corrosion under anaerobic condition existing in the borehole medium.

Competing Interest

The authors declare that, to the best of their knowledge, the research herein reported is their sole effort and that no competing interests exist. The authors invest all copy right on the article in the journal.

Acknowledgement

The authors are grateful to Ministry of Rural Development (the former Directorate for Food, Rural Roads and Infrastructure (1991-1993)) for assistance to archives of data; and to Essien and Sangodoyin (2009) for the 1993 data on such boreholes.

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