Rainwater Quality Assessment in Uyo Metropolis using Water Quality Index

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ABSTRACT

Rainwater is source of water for drinking and for other purposes in Akwa Ibom State. Water quality index (WQI) was used to assess the quality of rainwater in Uyo metropolis, and pollution index to identify the individual parameter that was of risk. Twenty-two physiocochemical parameters and seven toxic metals were determined in rainwater from six locations, using standard methods. The results were compared with WHO Limits. With the exception of temperature, pH, Ni, Cd, Pb, and Fe, others were within the WHO limits. Pollution index of parameters revealed no pollution to 50% of the parameters, slightly polluted to 9%, strongly polluted to 9% and seriously polluted to 32% of parameters. The overall mean water quality index was 1202, with pattern in the order: Urua Akpan Andem < Champion breweries < Abak road < Aka road < Plaza <Udo Udoma road; and confirmed the water unfit for drinking, due to the presence of high levels toxic metals. Suitable and efficient purification method is required before rainwater could be used for drinking purpose in the urban city.

INTRODUCTION

Water is an indispensable natural resource; it is essential to life support systems. However, the impact of climate change and anthropogenic activities on water sources is threatening both the quantity and quality of the water resource[1]. Human activities especially in the urban areas release from various stationary and mobile sources large quantities of heavy metals, often exceeding the natural emissions rates into the atmosphere and soil[2, 3]. These metals are of concern because of their toxicity even at low concentrations[4]. They may exist in water in colloidal, particulate and dissolved phases[5].

Among the urban poor and rural dwellers in most parts of Africa, rain water is a seasonal source of water for drinking and domestic purposes. Yet not as much research attention appears to have been given to rainwater quality as water source compared with surface and underground water[6]. In Akwa Ibom State some people hold on to the traditional belief that coming from the sky, rainwater is a veritable source of fresh clean drinking water. It is not uncommon sight therefore, to see people putting out containers on raised platforms to collect the natural fresh 'clean' water. The aim of the study is: to determine the physicochemical properties and the toxic metal levels in rainwater; and to apply PI (pollution index) and WQI (water quality index as tools to identify individual parameters that are of risk and the overall quality status at each location, respectively.

MATERIALS AND METHODS

Study Area

Uyo metropolis is the capital of Akwa Ibom state of Nigeria. It has a land area of 7,249 km^{2} [7]. It lies between latitudes 4° 32′ and 5°33′ N and longitudes 7°35′ and 8°25′E. The rainy season starts from March/April and ends in mid-November, with July to September as the wettest month.

Sample collection and preservation and analysis

Rainwater samples were collected in clean plastic buckets placed on a raised platform in the open from six sites, with their general positioning system (GPS) coordinates and site description as in Table 1, in the months of September and October, 2014. The samples were then transferred into pre-cleaned sample containers (250 ml amber bottles for DO, and plastic bottles for physicochemical and metals analyses). DO samples were fixed on site with 1 ml each of manganous sulphate and alkali azide; samples for metal analysis were preserved in 1 ml HNO_3. All samples were transported to the laboratory in ice coolers for analysis. The pH and temperature were determined on site.

Table 1: General positioning system (GPS) coordinates and site description of the study area

Sites	Coordinates		Site description
	Longitude	Latitude	
Abak Road	37° 40′ 31″E	55° 33′ 17″N	Commercial activities, high/dense traffic area, urbanization.
Aka Road	37° 45′ 40″E	55° 48′12″N	High/dense traffic area, urbanization, Commercial activities
Champion Breweries	37° 45′ 40″E	55° 48′12″N	Industrial area
Udo-Udoma	37° 33′ 29″E	55° 21′ 17″N	Banking layout, vicinity of breweries, light traffic.
Urua Akpan Andem	37° 52′ 40″E	55° 31′ 28″N	Metropolitan market, commercial activities, urbanization, dense traffic.
Plaza	37° 52′ 40″E	55° 31′ 46″N	Recreational place, commercial activities, high traffic.

Calculation of Pollution index and water quality index

Pollution index of individual parameter (PI) was computed[8, 9] as:

$$PI = \sqrt{\frac{\left(C_i / S_i\right)^2_{max} + \left(C_i / S_i\right)^2_{min}}{2}} \quad \text{-Eqn 1}$$

Where: C_i is the mean value as determined in rainwater and S_i the WHO (2011) drinking water quality guideline.

Water quality was computed as described by[10]

First the unit weight was calculated using: $W_i = k / S_i$ - -Eqn 2a

Where: k is a constant of proportionality and computed using:

$$k = \left[\frac{1}{\left(\Sigma \, 1 / S_{i=1,2,....i} \right)} \right] \quad \text{--Eqn 2b}$$

Second, q_i is computed as:

$$q_i = \frac{C_i}{S_i} \times 100 \quad \text{-Eqn 3}$$

Where: q_i is the quality rating and C_i the value of each parameter in rainwater sample.

Finally, WQI is computed as:

$$WQI = \Sigma q_i \times W_i \quad \text{--Eqn 4}$$

Pollution index and WQI have been classified in five categories and are presented in Tables 2a and b, respectively.

Quality assurance and control included replicate analyses, reagent blanks and standard curves (for metals). Microsoft Excel was used for all computations.

Table 2a: Parameter classification based on Pollution index (PI)[9, 11]

Class	PI	Status
1	<1	No pollution
2	1-2	Slightly polluted
3	2-3	Moderately polluted
4	3-4	Strongly polluted
5	>5	Seriously polluted

Table 2b: Water quality for drinking water purpose classification[10]

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

RESULTS AND DISCUSSION

Physicochemical Properties of Rainwater

The results of the physicochemical properties are compared with WHO limits in Table 3. The total mean values of temperature, alkalinity, Cl^-, TH, COD, conductivity, TDS, SO_4^{2-}, PO_4^{3-}, K, Na, CO_3^{2-}, HCO_3^- are below their WHO (2011) recommended limit. Salinity, NO_3^-, and NO_2^- are not detected in all rainwater samples from Uyo metropolis. However, pH, BOD_5 exceed the WHO recommended limits. The pH of rainwater is slightly acidic and ranges from 6.00 to 6.5. The values are less acidic than is reported in Warri-Delta State (5.10 - 6.35)[6]. BOD_5 ranges from 3.5 (Abak road.) to 6.4 (Champion breweries) in October. The highest level of BOD_5 in the Champion breweries site may be caused by collection/dissolution of impurities, gases and bacteria, among others in rainwater. The mean levels of Ni, Cd, Pb, Cu, Fe, Mn and Zn are 0.06, 0.04, 0.24, 0.14, 2.90, 0.58 and 0.41, respectively (Table 4). Cu and Zn metals in rainwater are within the WHO permissible limits while Ni, Cd, Pb, Fe and Mn are above limits.

Pollution index

The total pollution index of each parameter (Tables 5, 2a) indicates that no pollution was observed for BOD_5, Cl^-, TH, Conductivity, TDS, SO_4^{2-}, PO_4^{3-}, K, Na, CO_3^{2-}, HCO_3^-, and Zn. For the toxic metals, the pollution index of Ni in rainwater ranges from slightly polluted (in Abak road, Aka road, Champion breweries and Udo Udoma road) to moderately polluted (in Urua Akpan Andem and Plaza). Cadmium reveals serious pollution at Udo Udoma, Urua Akpan Andem (market complex), and plaza, strong pollution at Aka road, and slight pollution at Abak road. For Pb, there is serious pollution at all the locations except Udo Udoma road (with slight pollution). Rainwater at Urua Akpan Andem shows strong pollution to Cu; no pollution is observed for other locations. Serious pollution is recorded for Fe, and no pollution to Mn and Zn, at all the locations. Pollution index is observed to be high in the high traffic and busy areas.

Water Quality Index (WQI)

Water Quality Index was computed for rainwater collected in Uyo metropolis in two ways: (i) based on 15 physicochemical parameters (the general water quality parameters) for the months of September and October; and (ii) a combination of physicochemical parameters and 7 toxic metals (to give the overall WQI) (Tables 6 and 7). The result indicates excellent water quality (fit for drinking purpose) in the two months (September and October) using only the physicochemical parameters. However, when the general physicochemical parameters were combined with toxic metals, the quality of rainwater dropped remarkably (Tables 7 and 2b) rendering the water unfit for drinking, and requiring application of purification techniques. Therefore, based on the overall results, the rainwater in Uyo is unfit for drinking without purification to remove toxic metals like Ni, Cd, Pb and Fe.

Table 3: Mean* seasonal variations of physicochemical characteristics of rainwater in Uyo metropolis

S/N	Parameter	Abak road		Aka road		Champion breweries		Udo Udoma road		Urua Akpan Andem		Plaza		Mean of means		WHO (2011)
		Sept	Oct.	Sept	Oct.	Sept	Oct.	Sept	Oct.	Sept	Oct.	Sept	Oct.	Sept	Oct	
1	Temp.	29.30	25.90	29.30	26.00	25.90	27.20	24.70	26.30	29.10	26.50	24.40	25.20	27.12	26.18	**27.5**
2	pH	5.84	6.14	5.72	6.56	6.56	6.53	5.50	6.58	6.02	6.57	6.09	6.57	5.95	6.49	**7.5**
3	BOD_5 (mg/l)	4.00	2.90	4.00	2.60	3.70	6.40	4.30	4.00	5.10	3.10	5.30	5.00	4.40	4.00	**6.0**
4	Acidity (mg/l)	28.00	37.30	41.30	26.70	26.70	26.70	34.70	32.00	50.70	32.00	32.00	32.00	35.57	31.12	**200**
5	Alkalinity (mg/l)	42.70	32.00	58.70	50.70	64.00	64.00	61.30	34.70	50.70	42.70	66.70	50.70	57.35	45.80	**200**
6	Chloride (mg/l)	16.00	21.80	22.70	26.50	37.90	20.80	33.10	24.60	30.30	27.50	30.30	39.80	28.38	26.83	**200**
7	Total hardness (mg/l)	0.90	1.00	0.90	1.10	1.10	0.90	1.00	1.00	1.00	0.90	1.00	0.90	0.98	0.97	**100**
8	COD (mg/l)	25.80	25.60	24.80	23.90	22.40	23.50	24.80	25.60	23.40	23.50	26.20	22.80	24.57	24.15	**1000**
9	Conductivity (μsCm^{-1})	4.17	5.46	9.96	6.94	3.77	10.03	4.25	6.17	10.12	5.70	5.33	4.50	6.27	6.47	**500**
10	TDS (mg/l)	2.06	2.72	4.99	3.48	1.88	5.02	2.36	3.21	4.99	2.87	2.71	2.28	3.17	3.26	**250**
11	SO_4^{2-} (mg/l)	0.60	0.50	0.50	0.40	0.60	2.10	0.30	0.20	1.20	0.80	0.80	0.40	0.67	0.73	**5.0**
12	PO_4^{3-}(mg/l)	0.03	0.03	0.06	0.06	0.06	0.1	0.06	0.03	0.13	0.03	0.03	0.03	0.06	0.05	**250**
13	K^+ (mg/l)	0.40	0.30	0.20	0.10	0.20	0.30	0.40	0.30	0.90	0.80	0.20	0.10	0.38	0.32	**200**
14	Na^+ (mg/l)	0.80	0.60	1.00	0.60	1.30	1.40	0.80	0.60	3.00	2.60	2.00	2.80	1.48	1.43	**500**
15	CO_3^{2-}(mg/l)	75.00	50.00	50.00	75.00	50.00	50.00	50.00	50.00	75.00	75.00	50.00	50.00	58.33	58.33	**500**
16	HCO_3^-(mg/l)	100.0	50.00	50.00	50.00	50.00	50.00	50.00	50.00	100.0	50.00	50.00	50.00	66.67	50.00	**-**

*n=3

Table 4: Mean levels of metals in rainwater from Uyo city

S/N	Parameter	Abak road	Aka road	Champion breweries	Udo Udoma road	Urua Akpan Andem	Plaza	Mean	WHO (2011)
1	Ni (mg/l)	0.05	0.05	0.05	0.05	0.07	0.07	0.06	0.02
2	Cd (mg/l)	0.01	0.02	BDL	0.12	0.04	0.03	0.04	0.003
3	Pb (mg/l)	0.20	0.38	0.14	0.11	0.38	0.21	0.24	0.01
4	Cu (mg/l)	0.16	0.13	0.12	0.15	0.13	0.14	0.14	2.00
5	Fe (mg/l)	2.74	2.49	2.66	2.20	2.85	4.46	2.90	0.30
6	Mn (mg/l)	0.50	0.36	0.42	0.32	0.44	1.43	0.58	0.40
7	Zn (mg/l)	0.40	0.33	0.38	0.34	0.45	0.53	0.41	3.00

Table 5: Pollution Index (PI) for each parameter

S/N	Parameter	Abak Road	Aka Road	Champion Breweries	Udo Udoma Road	Urua Akpan Andem	Plaza	Total PI	Status (Class)
1	**Temp.**	0.70	0.70	0.70	0.70	0.70	0.60	**4.10**	STP(4)
2	**pH**	0.60	0.60	0.60	0.60	0.60	0.60	**3.60**	STP (4)
3	**BOD5 (mg/l)**	0.30	0.30	0.60	0.50	0.50	0.60	2.88	SEP (5)
4	**Alkalinity (mg/l)**	0.10	0.20	0.20	0.20	0.20	0.20	**1.10**	SLP (2)
5	Chloride (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.60	NOP (1)
6	Total hardness (mg/l)	0.004	0.004	0.004	0.004	0.004	0.004	0.024	NOP (1)
7	**COD (mg/l)**	0.20	0.20	0.20	0.20	0.20	0.20	**1.20**	SLP (2)
8	Conductivity (μsCm^{-1})	0.003	0.006	0.005	0.004	0.006	0.004	0.028	NOP (1)
9	TDS (mg/l)	0.003	0.006	0.005	0.004	0.006	0.007	0.031	NOP (1)
10	SO_4^{2-} (mg/l)	0.002	0.001	0.004	0.0009	0.0003	0.002	0.0102	NOP (1)
11	PO_4^{3-}(mg/l)	BDL	0.014	0.014	0.014	0.014	BDL	0.056	NOP (1)
12	K^+ (mg/l)	0.0009	0.0003	0.0006	0.001	0.002	0.003	0.0078	NOP (1)
13	Na^+ (mg/l)	0.003	0.003	0.005	0.003	0.01	0.009	0.033	NOP (1)
14	CO_3^{2-} (mg/l)	0.1	0.1	0.10	0.10	0.10	0.10	0.60	NOP (1)
15	HCO_3^-(mg/l)	0.1	0.1	0.10	0.10	0.10	0.10	0.60	NOP (1)
16	**Ni (mg/l)**	**1.8**	**1.8**	**1.80**	**1.80**	**2.50**	**2.50**	**12.2**	SEP (5)
17	**Cd (mg/l)**	**2.40**	**4.70**	0.00	**28.3**	**9.40**	**7.10**	**51.9**	SEP (5)
18	**Pb (mg/l)**	**14.1**	**26.9**	**9.90**	**1.80**	**26.9**	**14.9**	**94.5**	SEP (5)

19	**Cu (mg/l)**	0.10	0.10	0.04	0.10	**4.60**	0.10	**5.04**	SEP (5)
20	**Fe (mg/l)**	**6.50**	**5.90**	**6.30**	**5.20**	**6.70**	**10.5**	**41.1**	SEP (5)
21	**Mn (mg/l)**	0.90	0.60	0.70	0.60	0.80	2.50	**6.10**	SEP (5)
22	Zn (mg/l)	0.10	0.10	0.10	0.10	0.10	0.10	0.60	NOP (1)

NOP –No pollution, **SLP** –Slightly polluted, **STP** –Strongly polluted, **SEP** –Seriously polluted

Table 6: Unit weight of parameters based on WHO drinking water standard

S/N	Parameter	WHO, 2011 (Si)	Unit weight (Wi)
1	Temp. (27.0 - 28.0)	27.5	7.41236E-05
2	pH (6.5 - 8.5)	7.5	0.000271786
3	BOD_5 (mg/l)	6	0.000339733
4	Alkalinity (mg/l)	200	1.0192E-05
5	Chloride (mg/l)	200	1.0192E-05
6	Total hardness (mg/l)	200	1.0192E-05
7	COD (mg/l)	100	2.0384E-05
8	Conductivity (μsCm^{-1})	1000	2.0384E-06
9	TDS (mg/l)	500	4.0768E-06
10	SO_4^{2-} (mg/l)	250	8.15359E-06
11	PO_4^{3-}(mg/l)	5	0.00040768
12	K^+ (mg/l)	250	8.15359E-06
13	Na^+ (mg/l)	200	1.0192E-05
14	CO_3^{2-}(mg/l)	500	4.0768E-06
15	HCO_3^-(mg/l)	500	4.0768E-06
16	Ni (mg/l)	0.02	0.101919893
17	Cd (mg/l)	0.003	0.679465952
18	Pb (mg/l)	0.01	0.203839786
19	Cu (mg/l)	2	0.001019199
20	Fe (mg/l)	0.3	0.00679466
21	Mn (mg/l)	0.4	0.005095995
22	Zn (mg/l)	3	0.000679466

Table 7: Quality rating and rainwater WQI at different sites

Site	#, *Season	Quality rating (Σqi)	WQI (Σqi x Wi)
Abak road	Sept.	343.9	0.05
	Oct.	299.6	0.05
	Overall	3965	667
Aka road	Sept.	339.4	0.05
	Oct.	316.5	0.05
	Overall	648.9	1259
Champion breweries	Sept.	958.2	0.10
	Oct.	384.7	0.07
	Overall	3024	318
Udo Udoma road	Sept.	330.1	0.05
	Oct.	328.1	0.06
	Overall	6511	2973
Urua Akpan Andem	Sept.	377.4	0.06
	Oct.	323.4	0.05
	Overall	6915	172
Plaza	Sept.	356.5	0.06
	Oct.	354.2	0.06
	Overall	5675	1822
Total WQI in Uyo metropolis	Sept.		0.38
	Oct.		0.33
	Overall		8762

Rainwater quality index computed using general water quality parameters (September and October) *Rainwater quality index computed using both the general water quality parameters and toxic metals (overall).

CONCLUSION

The study reveals that rainwater in Uyo metropolis is unsafe for drinking. The mean temperature (recorded in September), pH, Ni, Cd, Pb, and Fe, of the 22 parameters analysed, are above the WHO limit. The total pollution index (PI) indicates temperature, pH, BOD_5 COD, Ni, Cd, Pb, and Fe as contributing risk to rainwater quality. Overall, WQI dropped markedly in presence of Ni, Cd, Pb, and Fe, rendering the water unfit for drinking. Ways to minimise/or totally eliminate these metals is desirable for continued consumption of rainwater in the metropolis.

ACKNOWLEDGEMENT

The authors are grateful to the technical staff of Biochemistry Department for providing the work environment for laboratory analyses.

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Received *10th June 2015*

Revised *20th July 2015*

Accepted *27th August 2015*