Research Article

Spatio-temporal variation of the physico-chemical properties of rainwater in Benin City, Nigeria

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Abstract

Urbanized landscapes are known to have relatively high atmospheric pollutants due to high concentration of anthropogenic activities. This paper therefore examines the spatial and temporal variations of the physico-chemical properties of rainwater at the core, intermediate and urban fringe of Benin City. Rainwater samples were collected at 2 locations each at the core (Ring Road and Forestry), intermediate (Airport Road and Upper Mission) and urban fringe (Ikpoba Hill and Ogba) in the months of March and July, 2016. The physico-chemical properties of the rainwater differed significantly at the core, intermediate and urban fringe between the months of March and July with t-statistics of 3.029, 3.737 and 2.764 ($p < 0.05$) respectively. The difference in rainwater properties among the core, intermediate and urban fringe zones were insignificant in the months of March and July. With the exceptions of colour, turbidity, P and Fe in the month of March and P and Fe in the month of July, rainwater properties from the three locations, where WHO guidelines for drinking water is applicable, were within permissible limits. Water quality was excellent at the core, intermediate and urban in the month of July while it was excellent at the intermediate and urban fringe and good at the core in the month of March. Findings suggest that besides the role of rainfall amount in atmospheric cleansing, other factors such as wind profile and direction and atmospheric stagnation also play critical influence on rainwater quality.

Keywords: Rainwater, water quality index, physico-chemical properties, Benin City, Nigeria

Resumé

On sait que les paysages urbanisés présentent des polluants atmosphériques relativement élevés en raison de la concentration élevée d'activités anthropiques. Cet article examine donc les variations spatio-temporelles des propriétés physico-chimiques de l'eau de pluie à la périphérie centrale, intermédiaire et urbaine de Benin City. Des échantillons d'eau de pluie ont été collectés à deux endroits situés respectivement aux quartiers centraux (Route Périphérique et Forêt), intermédiaires (Route Aéroportuaire et Upper Mission) et urbains (Ikpoba Hill et Ogba) en mars et juillet 2016. Les propriétés physico-chimiques des eaux pluviales différaient significativement aux franges centrales, intermédiaires et urbaines entre les mois de mars et juillet avec des statistiques t de 3,029, 3,737 et 2,764 ($p <0,05$) respectivement. La différence de propriétés des eaux de pluie entre les zones centrales, intermédiaires et urbaines était insignifiante aux mois de mars et juillet. À l'exception de la couleur, de la turbidité, du P et du Fe au mois de mars et du P et du Fe au mois de juillet, les propriétés des eaux de pluie des trois sites, où les directives de l'OMS pour l'eau potable sont applicables, étaient dans les limites permises. La qualité de l'eau était excellente au centre, intermédiaire et urbaine au mois de juillet, tandis qu'elle était excellente à la périphérie intermédiaire et urbaine et bonne au centre au mois de mars. Les résultats suggèrent qu'outre le rôle de la quantité de pluie dans le nettoyage atmosphérique, d'autres facteurs tels que le profil et la direction du vent et la stagnation atmosphérique ont également une influence déterminante sur la qualité de l'eau de pluie.

Mots-clés: Eaux de pluie, indice de qualité de l'eau, propriétés physico-chimiques, Benin City, Nigéria

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Introduction

The rapidity of urbanization has its attendant challenges, especially in developing countries (Balogun and Balogun, 2014). Simultaneously, growths in population and human activities in urban landscapes enhance pollutant release and particulate loading in the atmosphere (Zhong *et al*., 2017). Densely settled areas discharge substantial quantities of effluence into the atmosphere (Baklanov *et al*., 2017). Thus, the transformation of rural domains into urban spaces, significantly influence the local air quality (George *et al*., 2007). The state of the atmosphere over an urbanized area may differ significantly due to relatively high and increasing load of atmospheric impurities.

On the bases of their properties, atmospheric impurities may be physical, chemical and biological. The physical constituents of the atmosphere essentially cover all forms of particulate matters or aerosols while it is chemically composed of gases that are constant in amount (e.g. nitrogen and oxygen) and those that are variable (e.g. CO_2, CH_4, CO, water vapour). Biologically, the atmosphere harbours microbial, some of which are causal factors of human diseases. Aerosols particles have been identified as critical factor in ecosystem biogeochemistry and nutrient cycling, as well as cloud development processes (Artaxo, *et al*., 2002).

Urbanization dramatically increases impervious surfaces which together with other urban fabrics aggravate thermal island phenomenon (Papafotiou and Katsifarakis, 2015; Babalola and Akinsanola, 2016). Thus, urbanization-related population increase will induce environmental alteration which has bearing with atmospheric composition of cities, in addition to the canopy layer urban heat island, thermal sensation and diverse forms of air pollution (Balogun and Balogun, 2014). Urban fabrics such as buildings, contrasting neighbourhood materials, relief and infrastructure control the degree of conversion and pathways of water during its conversion from atmosphere to the ground (McGrane, 2016). Human-related emission of aerosols can influence cloud and precipitation through aerosol-cloud interactions (Zhong *et al*., 2017).

The global increasing population trends in urban areas have implications on environmental quality and pressure on basic amenities. The atmosphere is dynamic both spatially and seasonally. Although water meant for domestic use is expected to be comparatively clean (Ayeni and Atedhor, 2017), the quality of rainwater which remains a major source of water in many climes due to poor access to potable water may vary over space and time in response to the dynamics of the atmosphere.

The scarcity of potable water is increasingly becoming a major challenge, especially in developing countries (Yususf and Oladipo, 2012; Inkani, 2016; Balogun *et al*., 2016). Studies have shown increasing contamination of ground and surface water resources in recent years (Balogun and Adegun, 2011 and 2012; Abua *et al*., 2014; Ayeni and Soneye, 2014; Oyatayo *et al*., 2015). This has led to increasing interest in rainwater harvesting (Mohammed *et al*., 2018). However, the seasonal variation of the quality of rainwater in a rapidly expanding urban landscape such as Benin deserves evaluation in the face of increasing urban pollution. This paper therefore examines the spatial and temporal variations of the physico-chemical properties of water in Benin City, Nigeria.

Methodology

Study Area

Benin City is a pre-colonial settlement and the capital of Edo State of Nigeria. The City which is situated in the humid rainforest belt of Nigeria lies within latitude 06^o 19'E to 06^o 21'E and longitude 5^{o}34'E to 5^o 44'E (Figure1). The wet season covers the months of March to October (Odekunle, 2004) with annual rainfall amount usually up to 2000 mm and mean temperature approximately 27 °C. The month of March is the warmest month in the forest belt of Nigeria due to increasing cloudiness during transition from the dry season to the wet season (Atedhor and John-Abebe, 2017) while the month of July is one of the months of peak rainfall since rainfall in the forest belt of Nigeria is bimodal with September being the second month of peak rainfall. From a total population of 762, 717 based on the 1991 census figures, the population of the city grew to 1,086,882 based on the 2006 census. Benin City has a radial network of roads which converge at the city centre. Economic activities are dominantly commercial and are largely concentrated at the city centre. These commercial activities generate huge waste that sometimes constitute nuisance due to poor refuse evacuation. The high vehicular traffic coupled with pockets of industrial activities remains sources of effluents.

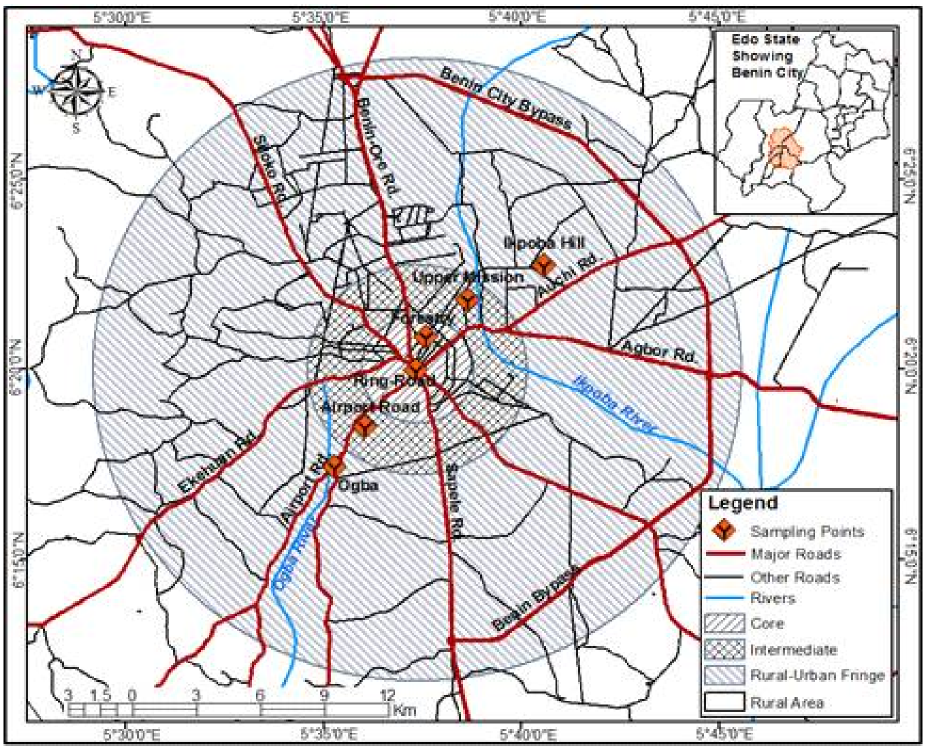

Figure 1: Benin City and Sampling Points (Inset: Edo State)

Sampling Locations and Collection of Water

Atmospheric chemistry varies seasonally (Idso *et al.,* 2002). Rainwater samples were collected in the core, intermediate and periphery of the Benin City (Figure 1) in the months of March (onset of the wet season) and July (peak of the rainy season) in 2016. The sampling locations were the core made up of Forestry (N06°20.243' and E005°37.559') and Ring-Road (N06° 19.973' and E005°37.325'), intermediate comprising Upper Mission (N06°22.437' and E005°39.544') and Airport Road (N06°19.713' and E005°39.986') and the periphery made up of Ikpoba Hill (N06°20.671' and E005°39.986') and Ogba (N06°17.656' and E005°35.426'). The physico-chemical properties of the water samples were analyzed in the laboratory of the Nigerian Institute of Oil Palm Research (NIFOR).

Data Analysis

Descriptive statistics (mean, maximum, minimum and range) were used to analyze the variation of the physico-chemical characteristics of rainwater among the sampling points. The data of physico-chemical properties were stated in three decimal places to account for slight variations. T-test was used to assess the significance of the difference of the physico-chemical properties of the rainwater between March and July. The variations of the physico-chemical properties of the rainwater samples among the core, intermediate and urban fringe in the month of March and July were analyzed using analysis of variance (ANOVA).

The water quality index (WQI) was calculated to evaluate the influence of the natural and anthropogenic activities on several key parameters of water chemistry (Ramakrishnaiah *et al.*, 2009; Ayeni and Atedhor, 2017). The processing involved three stages. The first stage involved assigning weight (wi) to each of the parameters according to their relative importance in the quality of water for drinking purposes. The assigned weights range from 1 (minimum) to 5 (maximum). The weight of 5 was assigned to nitrate and TDS, 4 to pH, EC, SO4, 3 to HCO, CL, 2 to Ca, Na, K while 1 was assigned to Mg (Vasanthavigar *et al.*, 2010). The second stage involved the computation of relative weight (Wi) using the equation "a".

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad \text{(a)}$$

Where, Wi is the relative weight, wi is the weight of each parameter, and n is the number of parameters. The third stage involved assigning quality rating scale (*qi*) for each parameter using $q_i = (C_i / S_i) \times 100$uidelines of WHO (2011) as shown in equation "b"

(b)

Where, qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l, and, Si is the WHO (2011) guidelines for drinking water quality for each parameter. In computing the WQI, the *SIi* was determined first for each parameter which was then used to determine the WQI as expressed in equations "ci" and "cii".

$$SI_i = W_i \cdot q_i \qquad \text{(ci)}$$

$$WQI = \sum SI_i \qquad \text{(cii)}$$

Where, SIi is the sub-index of ith parameter; qi is the rating based on concentration of ith parameter and n is the number of parameters. The computed WQI values were classified into five categories (Table 1) based on Sahu and Sikdar (2008).

Table 1: Water quality index classification

WQI range	Water quality
< 50	Excellent
50-100	Good
100-200	Poor
200-300	Very poor
>300	Unsuitable for drinking

Results and Discussion

The physico-chemical properties of the rainwater samples in the months of March and July are presented in Tables 2 and 3 respectively.

Table 2: Descriptive statistics of physico-chemical properties of rainwater for the core, intermediate and urban fringe in the month March

Parameter	Maximum permissible limit	Core	Intermediate	Urban fringe	Mean	Maximum	Minimum	Range
pH	8.5	6.835	6.880	6.955	6.890	6.955	6.835	0.120
Electrical Conductivity (EC) (µS/cm)	*	95.500	69.600	72.050	79.050	95.500	69.600	25.900
Salinity (g/l)	*	0.043	0.032	0.033	0.036	0.043	0.032	0.012
Colour (Pt.Co)	<5	8.000	11.800	6.750	8.850	11.800	6.750	5.050
Turbidity (NTU)	1	6.950	10.600	5.850	7.800	10.600	5.850	4.750
Total Suspended Solid (mg/l)	*	13.750	10.600	10.150	11.500	13.750	10.150	3.600
Total Dissolved Solid (mg/l)	500	47.750	35.150	36.050	39.650	47.750	35.150	12.600
Chemical Oxygen Demand (mg/l)	*	17.800	15.550	17.950	17.100	17.950	15.550	2.400
Hydrogen Carbonate (HCO_3) (mg/l)	*	27.450	24.400	27.450	26.433	27.450	24.400	3.050
Sodium (Na) (mg/l)	**	2.785	1.450	1.265	1.833	2.785	1.265	1.520
Potassium (K) (mg/l)	**	0.455	0.175	0.145	0.258	0.455	0.145	0.310
Calcium (Ca) (mg/l)	250	5.000	2.725	2.570	3.432	5.000	2.570	2.430
Magnesium (Mg) (mg/l)	150	1.920	0.645	0.815	1.127	1.920	0.645	1.275
Chloride (Cl^-) mg/l	250	27.550	26.650	28.900	27.700	28.900	26.650	2.250
Phosphorus (P) (mg/l)	0.03	2.445	1.590	1.685	1.907	2.445	1.590	0.855
Ammonium Nitrogen(NH_4-H) (mg/l)	*	0.115	0.085	0.115	0.105	0.115	0.085	0.030
Nitrate (NO_3^-) mg/l	10	4.140	3.015	2.670	3.275	4.140	2.670	1.470
Sulphate (SO_4^{2-}) (mg/l)	*	0.870	0.630	0.645	0.715	0.870	0.630	0.240
Iron (Fe) (mg/l)	0.03	1.275	0.800	1.005	1.027	1.275	0.800	0.475
Manganese (Mn) (mg/l)	1	0.048	0.035	0.029	0.037	0.048	0.029	0.019
Zn (Zn) (mg/l)	5	0.440	0.290	0.305	0.345	0.440	0.290	0.150
Copper (Cu) (mg/l)	1	0.018	0.013	0.022	0.017	0.022	0.013	0.010
Chromium (Cr) (mg/l)	0.05	0.009	0.008	0.006	0.008	0.009	0.006	0.003
Cadmium (Cd) (mg/l)	0	0.006	ND	0.003	0.005	0.006	0.003	0.003
Lead (Pb) (mg/l)	0.05	0.039	0.014	0.008	0.020	0.039	0.008	0.031

** Not covered by WHO, ** No health-based guideline value has been derived by WHO, ND Not Detected*

Table 3: Descriptive statistics of physico-chemical properties of rainwater for the sampling points in July

Parameter	Maximum permissible limit	Core	Intermediate	Urban fringe	Mean	Maximum	Minimum	Range
pH	8.5	5.760	5.285	5.720	5.588	5.760	5.285	0.475
Electrical Conductivity (EC) (µS/cm)	*	52.950	60.550	75.500	63.000	75.500	52.950	22.550
Salinity (g/l)	*	0.024	0.033	0.034	0.030	0.034	0.024	0.010
Colour (NTU)	<5	ND	ND	ND	-	-	-	-
Turbidity (NTU)	1	ND	ND	ND	-	-	-	-
Total Suspended Solid (mg/l)	*	2.050	1.550	2.900	2.167	2.900	1.550	1.350
Total Dissolved Solid (mg/l)	500	23.800	27.100	34.000	28.300	34.000	23.800	10.200
Chemical Oxygen Demand (mg/l)	*	3.350	1.700	1.850	2.300	3.350	1.700	1.650
Hydrogen Carbonate (HCO_3) (mg/l)	*	12.400	14.850	16.750	14.667	16.750	12.400	4.350
Sodium (Na) (mg/l)	**	0.490	0.695	0.795	0.660	0.795	0.490	0.305
Potassium (K) (mg/l)	**	0.085	0.110	0.130	0.108	0.130	0.085	0.045
Calcium (Ca) (mg/l)	250	1.545	1.805	2.215	1.855	2.215	1.545	0.670
Magnesium (mg) (mg/l)	150	0.400	0.505	0.660	0.522	0.660	0.400	0.260
Chloride (Cl^-) (mg/l)	250	19.150	21.900	23.650	21.567	23.650	19.150	4.500
Phosphorus (P)	0.03	0.120	0.149	0.189	0.152	0.189	0.120	0.069
Ammonium Nitrogen(NH_4-H) (mg/l)	*	ND	ND	ND	-	-	-	-
Nitrate (NO_3^-) (mg/l)	10	0.206	0.211	0.265	0.227	0.265	0.206	0.060
Sulphate (SO_4^{2-}) (mg/l)	*	0.130	0.150	0.175	0.152	0.175	0.130	0.045
Iron (Fe) (mg/l)	0.03	0.235	0.245	0.295	0.258	0.295	0.235	0.060
Manganese (Mn) (mg/l)	1	0.020	0.026	0.020	0.022	0.026	0.020	0.007
Zn (Zn) (mg/l)	5	0.126	0.079	0.116	0.107	0.126	0.079	0.047
Copper (Cu) (mg/l)	1	0.006	0.007	0.007	0.007	0.007	0.006	0.002
Chromium (Cr) (mg/l)	0.05	ND	ND	ND	-	-	-	-
Cadmium (Cd) (mg/l)	0	ND	ND	ND	-	-	-	-
Lead (Pb) (mg/l)	0.05	ND	ND	ND	-	-	-	-

** Not covered by WHO, ** No health-based guideline value has been derived by WHO, ND Not Detected*

Generally, with exception of pH (acidity), the physico-chemical properties of the water samples were higher in the month of March (onset of the wet season) compared to their July (peak of the rainy season) counterparts. The pH values ranged between 6.955 and 6.835 with a mean value of 6.890 in the month of March while its value ranged between 5.760 and 5.285 with a mean of 5.588 in the month of July. Thus, while rainwater samples from the core and intermediate were least acidic in the months of March and July respectively, rainwater samples from the urban fringe and core were most acidic in the month of March and July respectively. The pH values fall within the range reported in Wanzau metropolitan area in 2014 and 2015 (Zhang *et al.*, 2018). Rainwater sample from the core was most saline (0.043g/l) and least saline (0.032g/l) at the intermediate with a mean value of 0.036g/l in the month of March. Contrarily, rainwater sample from the urban fringe was most saline (0.034g/l) at the urban fringe while that of the core was least saline (0.024g/l) with a mean value of 0.030g/l in the month of July. The values indicate that rainwater is more saline during the onset of the wet season. Rainwater colour (Pt.Co) was highest at the intermediate (11.800) and lowest at urban fringe (6.750) with a mean value 8.850 in the month of March. Similarly, turbidity (nephelometric turbidity units) was highest at the intermediate (10.600) and lowest at the urban fringe (5.850) with a mean value of 7.800 in the month of March. Colour and turbidity were not detected in the month of July. The values of TSS (total suspended solid) were clearly higher in all the locations in the month of March. The highest

TSS was recorded at the core (13.750mg/l) while the lowest was recorded at the urban fringe (10.150mg/l) with a mean value of 11.500mg/l in the month of March. The urban fringe and intermediate had the highest (2.900mg/l) and lowest (1.550mg/l) TSS respectively with a mean value 2.167mg/l in the month of July. TDS were highest (47.750mg/l) and lowest (35.150mg/l) at the core and intermediate respectively with a mean value of 39.650mg/l in the month of March while its values were highest (34.000mg/l) and least (23.800mg/l) at the urban fringe and core respectively with a mean value of 28.300mg/l in the month of July. The relatively drier surfaces in the month of March may have accounted for the higher values for colour, TSS and TDS in the month compared to their counterparts in the month of July.

NO_3 and SO_4^{2-} were highest at the core with recorded values of 4.140mg/l and 0.870mg/l respectively and least at the intermediate urban fringe (2.670mg/l) and intermediate (0.630mg/l) respectively in the month of March. The values of NH_4^-H were highest with equal concentration values of 0.155mg/l in the month of March. NH_4^-H was not detected in the month of July. NO_3, NH_4^-H and SO_4^{2-} in precipitation are mainly from anthropogenic sources (Zhang *et al*., 1999; Cheng *et al*., 2011; Xiao *et al*., 2013; Zhao *et al*., 2013; Hoinaski *et al*., 2014; Zhang *et al*., 2018). However, while atmospheric pollution abatement strategies are being put in place in developed countries (Pénard-Morand and Annexi-Maesano, 2004; Fang *et al*., 2013), Nigeria is still grappling with environment-unfriendly developments, especially in energy consumption. Thus, the rate of anthropogenic-induced atmospheric pollution, especially in urbanized landscapes will continue with adverse effects on rainwater quality. The higher values of NO_3 and SO_4^{2-} at the core in the month of March affirm the influence of temperature on gaseous pollutants (Jayamurugan *et al*., 2013). Declining temperature gradient has been reported from the city centre to the urban fringe earlier (Odjugo and Iweka, 2006). The highest values of NO_3, and SO_4^{2-} were recorded at the urban fringe at 0.265mg/l and 0.175mg/l respectively while the lowest values were recorded at the core at 0.206mg/l and 0.130mg/l respectively in the month of July.

Out of the heavy metals analyzed from the rainwater samples, Fe had the highest concentration with a mean of 1.027mg/l with the core having the highest (1.275mg/l) while the intermediate had the lowest (0.800mg/l) in the month of March. The highest concentration of Fe was recorded at the urban fringe (0.295mg/l) while the least was recorded at the core (0.235mg/l) with a mean value of 0.258mg/l in the month of July. Mn concentration in the rainwater samples was highest (0.048mg/l) and lowest (0.029mg/l) at the core and urban fringe respectively with mean value of 0.037mg/l in the month of March while it was highest (0.026mg/l) at the intermediate and equally lowest (0.020mg/l) at the core and urban fringe in the month of July with a mean value of 0.022mg/l. Maximum (0.440mg/l) and minimum (0.290mg/l) concentrations of Zn were detected at the core and urban fringe respectively with a mean value of 0.305mg/l in the month of March while maximum (0.126mg/l) and minimum (0.079mg/l) were recorded at the core and intermediate respectively with a mean of 0.107mg/l in the month of July. The concentration of Cu appeared to be low at all the locations irrespective of seasons. Maximum (0.022mg/l) and minimum (0.013mg/l) Cu were recorded at the urban fringe and intermediate respectively with a mean value of 0.017mg/l in the month of March. Maximum (0.007 mg/l) Cu were equally recorded at the intermediate and urban fringe while minimum (0.006mg/l) was detected at the core with a mean value of 0.007mg/l. Cr, Cd and Pb were not detected in the rainwater samples from all the sampling units in the month of July. The highest (0.009mg/l) and lowest (0.006mg/l) concentrations of Cr were detected at the core and urban fringe respectively with the mean of 0.008mg/l in the month of March. Cd concentrations were highest (0.006mg/l) and lowest (0.003mg/l) at the core and urban fringe with a mean value of 0.005mg/l in the month of March while the highest (0.039mg/l) and lowest (0.008mg/l) concentrations of Pb were detected at the core and urban fringe with a mean value of 0.020mg/l in the month of March. Balogun and Orimoogunje (2015) have reported correlation between land use and air pollution in Benin City. The spatial variation of the physico-chemical properties of the rainwater samples could therefore be attributed to the disparity in land use. With the exceptions of colour, turbidity, P and Fe in the month of (March) and P and Fe in the month of July, where WHO guidelines for drinking water are applicable, the physico-chemical properties of the rainwater samples were within permissible limits.

The statistical analysis of the difference in the physico-chemical properties of rainwater between March and July for the core, intermediate and urban fringe is presented in Table 4. The difference in the physico-chemical properties of rainwater at the core, intermediate and urban fringe showed statistical significance between March and July with t-statistics of 3.029, 3.737 and 2.764 respectively ($P < 0.05$). This clearly shows that rainwater quality can vary temporarily in an urbanized area owing to meteorological-induced variations in the loading of atmospheric pollutants.

Table 4: T-statistics of the variation of physico-chemical properties of rainwater between March and July, 2016

Pairs	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	*t*	df	Sig. (2-tailed)
Core1- Core2	5.934	9.794	1.959	1.891	9.977	3.029	24	.006
Intermediate1- Intermediate2	3.431	4.591	.9183	1.536	5.327	3.737	24	.001
Urban fringe1- Urban fringe2	2.326	4.209	.842	.589	4.064	2.764	24	.011

Where 1 and 2 represent dry season and wet season respectively

The statistical variations of the physico-chemical properties of rainwater among the core, intermediate and urban fringe in the months of March and July are presented in Tables 5. From the analysis, rainwater appeared not to show significant spatial variation from the core to the urban fringe in Benin City during the months of March and July. As Christopherson and Byrne (2006) noted, asymmetrical geometric profiles in a city affect radiation patterns and winds. The lack of clear variation of the physico-chemical properties of rainwater from the core to the suburban could be attributed to the mixed land uses and their associated irregular shape which influence the concentration of atmospheric particulates Benin City.

Table 5: ANOVA of rainwater quality among the core, intermediate and urban fringe

March (onset of the wet season)						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	319.21	2	159.60	0.123	0.88	3.12
Within Groups	93749.74	72	1302.08			
Total	94068.95	74				
July (peak of the wet season)						
Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	141.68	2	70.84	0.23	0.10	3.12
Within Groups	22467.58	72	312.05			
Total	22609.25	74				

The parameters with their assigned weight and relative weight based on WHO guidelines (2011) are presented in Table 6 while the computed rainwater quality index for the different sampling points are presented in Table 7.

Table 6: Parameters with their assigned weight and relative weight of water parameters

S/N	Parameter	WHO guideline(2011)	Weight(wi)	Relative weight (Wi)
1	pH	6.5-8.5	4	0.077
2	TDS	500 mg/L	5	0.096
3	EC µS/cm	500 mg/L	4	0.077
4	Ca^{2+}	75 mg/L	2	0.038
5	Mg^{2+}	30 mg/L	2	0.038
6	Na^{+}	200 mg/L	4	0.077
7	K^{+}	200 mg/L	2	0.038
8	Cl^{-}	250 mg/L	3	0.058
9	NO_3	45 m/L	5	0.096
10	SO_4^{2-}	250 mg/L	4	0.077
11	HCO_3	500 mg/L	1	0.019
12	Fe	0.3 m/L	4	0.077
13	Mn	0.1 m/L	3	0.058
14	Zn	3.0 m/L	2	0.038
15	Pb	0.01 m/L	4	0.077
16	(NH4-N)	0.5 m/L	3	0.058
			$\sum$wi =52	$\sum$Wi =1.00

Table 7: Computed WQI for the sampling points

Site	Water Quality Index March	Water quality interpretation	Water Quality Index July	Water quality interpretation
Core	80.91	Good	15.10	Poor
Intermediate	46.04	Excellent	15.51	Excellent
Urban fringe	46.39	Excellent	17.40	Excellent

The computed sub-index of parameters and the overall WQI for March and July are presented in Appendices 1 and 2. While TDS and NO_3^- had the highest relative weight (0.096), HCO_3 had the lowest relative weight (0.019). Rainwater quality was excellent at the core, intermediate and urban fringe in the month of July while it was excellent at the intermediate and urban fringe and good at the core in the month of March. The excellent quality of rainwater buttresses its recommendation for drinking and other domestic uses (Issaka *et al*., 2015), especially in the month of March. It is important to note that water quality index values are better in the month of July. This shows that the atmosphere is cleaner in the month of July which is one of the peaks of the rainy season in the rainforest belt of Nigeria where Benin City is located. Besides, the month of March marks the onset of the wet season in the rainforest belt of Nigeria (Odekunle, 2004; Atedhor and John-Abebe, 2017). Rainfall plays a vital role in the removal of pollutants from the atmosphere. However, the distinction in WQI at the Core between the March and July confirms that the efficiency and rate of washout scavenging are only partly a function of rainfall rate (Oke, 2002). Thus, although rainwater is relatively free from impurities (Mohammed *et al*., 2018), this depends on season and location. Furthermore, the direction of transportation of atmospheric pollutants is influenced by wind profile and direction. Atmospheric stagnation can also influence the concentration of atmospheric concentration of pollutants.

Air pollutants concentrations in urban areas have been blamed on anthropogenic sources such as road traffic and industries in France, China, Brazil, Malaysia, e.t.c. (Xiao *et al*., 2013; Pénard-Morand and Annexi-Maesano, 2004; Hoinaski *et al*., 2014; Zhang *et al*., 2018). Rainwater quality is influenced by air pollutants (Hoinaski *et al*., 2014). The higher concentration of the physico-chemical properties of rainwater in the core of Benin City, especially during the onset of the wet season could be attributed to higher vehicular traffic. As revealed in Figure 1, the major streets in Benin City converge at the core which is a central business district (CBD). The CBD coupled with administrative functions attract high vehicular influx to the core of the city. Apart from the type and intensity of emission, the concentration of air pollutants is also influenced by meteorological parameters and topography (Oke, 2002; Pénard-Morand and Annexi-Maesano, 2004; Jayamurugan *et al*., 2013; Zhang *et al*., 2018). Rainwater quality is expected to vary with environmental circumstances (Despins *et al*., 2009). Meteorological parameters such as rainfall and humidity, temperature, wind speed and direction vary on a seasonal basis. Meteorological conditions affect dilution and diffusion of pollutants in the atmosphere (Zu *et al*., 2018). These seasonal meteorological changes may have largely accounted for the variation of the physico-chemical properties of rainwater at the different locations between the months of March and July.

Conclusion

The paper examined the spatial and temporal variations of the physico-chemical properties of rainwater at the core, intermediate and urban fringe of Benin City between the months of March and July (2016). With the exceptions of colour, turbidity, P, Fe in the month of March and P and Fe in the month of July, physico-chemical properties of rainwater from all the locations, where WHO guidelines for drinking water are applicable, were within permissible limits. Spatially, rainwater showed insignificant variations in March and July. Temporarily, rainwater differed significantly at the core, intermediate and urban fringe between the months of March and July. The WQI values were excellent at the core, intermediate and urban fringe in the month of July while its values were excellent at the intermediate and urban fringe and good at the core in the month of March. The better WQI values in the month of July indicate that the efficiency and rate of washout scavenging of atmospheric pollutants increase with rainfall amount considering the fact that the month of July coincides with one of the rainfall peaks in the rainforest belt where Benin City is located. The distinction in rainwater quality between the core and the intermediate and urban fringe in the month of March suggests that besides the role of rainfall in atmospheric cleansing, other factors such as wind profile and direction and atmospheric stagnation also play critical control on the concentration of atmospheric pollutants and by extension rainwater quality.

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Appendix: Computed sub-index of parameters and the overall WQI for March and July

	MARCH WQI																
Parameters	pH(S)li	TDS(Sli)	EC(Sli)	Ca(Sli)	Mg(Sli)	Na(Sli)	K(Sli)	Cl(Sli)	(NO3(Sli)	SO4(Sli)	HCO3(Sli)	Fe(Sli)	Mn(Sli)	Zn(Sli)	Pb(Sli)	NH4-N(Sli)	WQI
Core [redacted]	6.433	0.955	1.528	0.267	0.256	0.111	0.009	0.661	0.920	0.028	0.110	34.000	2.850	0.587	30.800	1.392	80.91
Intermediate	6.475	0.703	1.114	0.145	0.086	0.058	0.004	0.640	0.670	0.020	0.098	21.333	2.100	0.387	11.200	1.008	46.04
Rural-urban fringe	6.546	0.721	1.153	0.137	0.109	0.051	0.003	0.694	0.593	0.021	0.110	26.800	1.710	0.407	6.000	1.338	46.39
	JULY WQI																
Parameters	pH(S)li	TDS(Sli)	EC(Sli)	Ca(Sli)	Mg(Sli)	Na(Sli)	K(Sli)	Cl(Sli)	(NO3(Sli)	SO4(Sli)	HCO3(Sli)	Fe(Sli)	Mn(Sli)	Zn(Sli)	Pb(Sli)	NH4-N(Sli)	WQI
Core [redacted]	5.421	0.476	0.847	0.082	0.053	0.020	0.002	0.460	0.046	0.004	0.050	6.267	1.200	0.17	0.000	0.000	15.10
Intermediate	4.974	0.542	0.969	0.096	0.067	0.028	0.002	0.526	0.047	0.005	0.059	6.533	1.560	0.11	0.000	0.000	15.51
Rural-urban fringe	5.384	0.680	1.208	0.118	0.088	0.032	0.003	0.568	0.059	0.006	0.067	7.867	1.170	0.15	0.000	0.000	17.40