

Spatial and Temporal Variation in Water Quality of River Benue, Nigeria

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ABSTRACT

The study investigates the spatial and temporal variation in water quality parameters at ten different locations along River Benue for twelve consecutive months. In order to explore the spatial variation among different stations and seasonal changes, multivariate analysis of variance (MANOVA) was used to group these on the basis of spatial similarities. MANOVA on season and station shows that there is no significant difference between the stations investigated while there is for the seasons. This could be viewed as a resulting from the narrow spatial sampling interval (12 km at 0.7% total length of River Benue). However, discriminate analysis identified all the parameters to discriminate between the three seasons with 99.2% correct assignments. Two discriminate functions were found and the total variance cumulative was 100% between seasons. The first function explained 64.8% of the total variance between the seasons while the second function explained 35.2%. Total solids (TS) were the highest contributor in discriminate functions 1 and 2. Therefore, discriminate function analysis would enable us to predict the likely season a water sample from metropolitan Makurdi was collected given the values of the water quality parameters. It also enables us to conclude that all the parameters were responsible for significant seasonal variations in River Benue water quality.

Keywords: River Benue; Water; Quality and Variation

1. Introduction

The quality and quantity of river water is influenced by both natural processes and anthropogenic interferences; the latter constitutes one of the major causes of environmental problems that alter the hydrochemistry in our river systems. Rivers are highly heterogeneous at spatial as well as temporal scales. Variation in the quality and quantity of River water is widely studied across the globe. Riedel *et al.* [1] examined the spatio-temporal variation in trace elements in Patuxent River, Maryland, while Gupta and Chakrapani [2] studied temporal and spatial variations in water flow and sediment load in Narmada River Basin, India. Temporal and spatial variation of nutrient levels in the Nemunas River (Lithuania and Belarus) has been reported [3]. Multivariate statistical techniques for the evaluation of spatial and temporal water quality of the Mahanadi River—estuarine system, was reported in India [4]. Schaefers and Alber [5] studied temporal and spatial trends in nitrogen and phosphorus inputs to the watershed of the Altamaha River, Georgia, while Quadir *et al.* [6] studied spatio-temporal variation

in water quality of Nullah Aik, a tributary of the River Chenab, Pakistan. In a case study of the River Bagmati; Kannel *et al.* [7] examined spatial-temporal variation and comparative assessment of water qualities of urban river system. Najafpour *et al.* [8] reported evaluation of spatial and temporal variation in river water quality of Shiroud River that discharges to southern part of Caspian Sea, Iran. In their work, they used multivariate statistical techniques to evaluate spatial and temporal variations in water quality and found that discriminate analysis gave the best results for both spatial and temporal analysis. Nikhil and Azeez [9] in India examined the spatio-temporal variation in water quality and quantity of Bharathapuzha River basin using multivariate statistical analysis tools. They found that in basins that are more disturbed, monsoonal discharge was much higher than discharges in other seasons, while the slightly disturbed basin had consistent level of discharge throughout the season. They concluded that change in land use and the impact of dams are major reasons for the spatiotemporal variation in the surface water chemistry of the River.

The use of various statistical analysis techniques such as multivariate analysis of variance (MANOVA), factor

*Part 4 in the series of chemicals in River Benue.

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analysis (FA), and discriminant analysis (DA) has been employed widely in recent years for analyzing environmental data and drawing meaningful information [10-13]. In this work, a large data matrix was obtained for twelve consecutive months for River Benue in Central Nigeria to examine the influence of possible sources on the water quality, in order to explain the pollution status of the River. The relationship between the sampling sites, identification of water quality variable(s) responsible for the spatial and temporal variations in water quality was investigated.

2. Materials and Methods

River Benue arises from Adamawa Plateau in the Western Cameroons and flows west across Central Nigeria and joins River Niger 483 km from the Atlantic coast. Its width varies from about 488 to 976 m and its navigable length is more than 965 km during the wet (Raining) season and it is about 1370 km long. The annual total rainfall and diurnal temperature in Makurdi (latitude $7^{\circ}44'$ and longitude $8^{\circ}31'E$) range from 1200 - 2000 mm (from April to October) and an average of $28^{\circ}C - 35^{\circ}C$, respectively. The river within Makurdi metropolis receives discharges from the Mu and Ageba streams and effluents from Wurukum Abattoir, Wadata open market and the Coca-Cola Plc and Benue Breweries Plc plants. There were ten identified sampling stations: the River Mu and Ageba streams discharge points, University of Agricul-

ture Makurdi Water Intake, Coca-Cola plant, Benue Breweries, River Ageba, Wildlife Park, Wurukum Abattoir, Saint Joseph's, Nigerian Army School of Military Engineers (NASME) Water Intake, Wadata Open Market and Rice Mill with a total of twelve (12) kilometers distance covered along Makurdi axis of the River (**Figure 1**). The choice of these stations was informed by the various anthropogenic activities that have been going on, close to or along the river course.

At each station, three (3) sample points were collected along a North-South transect across the River. Samples were taken 30 cm below the water surface five (5) times with 500 mL white glass bottles that had been washed thoroughly with distilled deionized water and rinsed with acetone and dried at $105^{\circ}C$ for thirty minutes (30 min) before use, and transferred into 2.5 litre brown borosilicate glass bottles. Sampling was conducted every two weeks for 12 months (July 2008 and June 2009). Samples collected were stored in an improvised Ice Box (A 50—litre plastic bucket with cover packed with ice blocks), and transported to the laboratory for analysis.

Methods

The odour and taste were analyzed with sensory organs. A portable digital JENWAY model pH meter 3505 with glass electrode was used to determine the pH of the water samples in the laboratory. A general purpose JENWAY

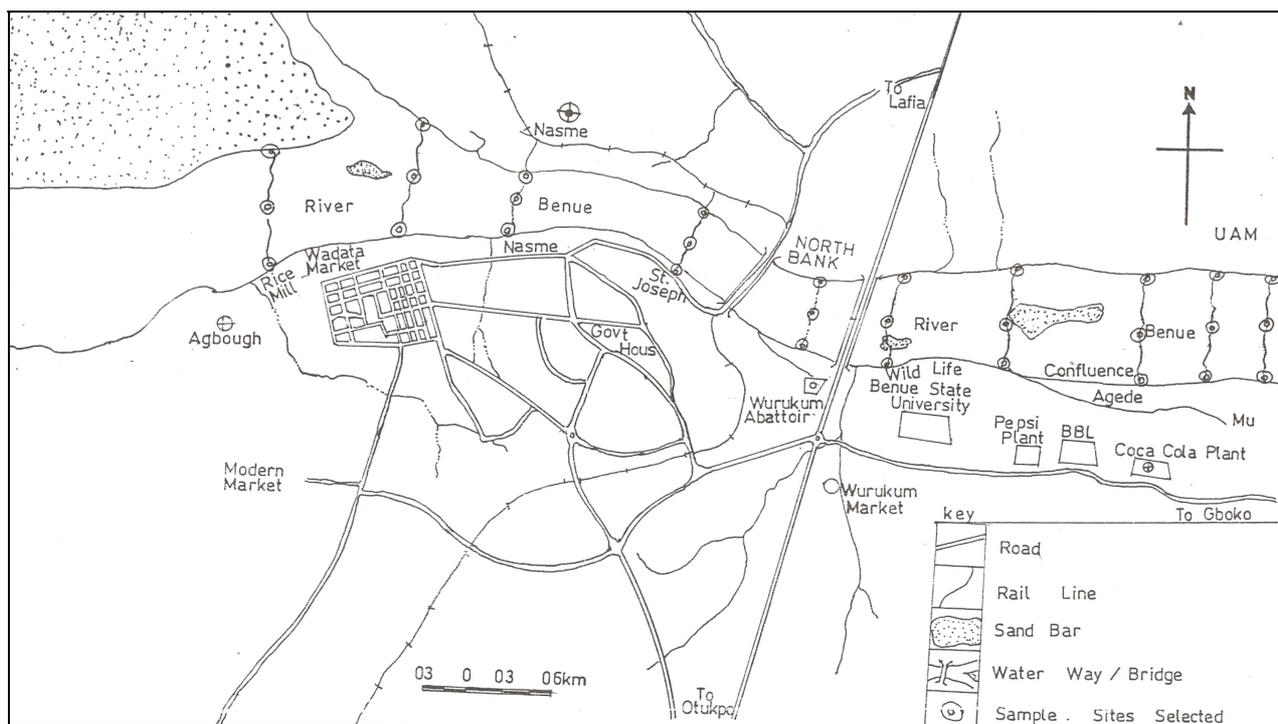


Figure 1. Map showing River Benue in the Makurdi Metropolitan Area (Sampling stations are indicated by transects marked \emptyset across the River).

digital portable model conductivity meter/TDS 470 was used to determine the water surface temperature, total dissolved solids (TDS) and electrical conductivity (EC) on the field. Analysis of dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total solutes (TS), total suspended solids (TSS), alkalinity, chloride ion and phosphate ion were analyzed according to standard methods [14]. Total hardness was determined by using EDTA titrimetric method. Statistical analyses were performed using SYSTAT 16.0 (SPSS, USA). Results from the water analysis are expressed as mean values of replicate determinations with their standard errors. Multivariate statistical techniques were applied to examine the effect on spatial and temporal variations of parameters from each sampling stations and across the three seasons.

3. Results and Discussion

The summary of descriptive statistics of the results of the analysis is presented in **Table 1**, indicating the maximum, minimum, mean values of the parameters and standard error. TS recorded the highest value of 947 mg/L while the chloride ion concentration exhibited the least value of 2.41 mg/L. The standard error around the means is substantially high and random. This could be as result of spatial seasonal changes and also the different anthropogenic activities surrounding the study area [8].

The data obtained were grouped into three seasons as first rainy (S_1), dry (S_2) and second rainy (S_3) as shown in **Table 2**. The COD exhibited the highest values across

the seasons 159 mg/L, 181 mg/L and 193 mg/L for S_1 , S_2 and S_3 , respectively. Similarly, chloride ion recorded the least values of 1.55 mg/L, 1.06 mg/L and 1.19 mg/L for S_1 , S_2 and S_3 , respectively. The high TS value of 393 mg/L for the S_3 could be due to sampling period (the beginning of the second rainy season).

In order to explore the spatial variation among different stations and seasonal changes, MANOVA was used to group these on the basis of spatial similarities (**Table 3**). Analyses between and within data stations showed that there were no significant differences at a significance level of $\alpha = 0.05$. This result could be viewed that the spatial sampling interval (12 km at 0.7% total length of River Benue) is rather small even as the focus was only in the Makurdi metropolitan area (a 30 km stretch of the River). Obviously the River is impacted by the same or similar influences over the spatial sampling interval which could explain the lack of significant variation in the properties in the area. This could be useful in a monitoring protocol: within a year, not much change in properties is expected of the River, so any observed significant change could suggest a point source polluting event.

However, analysis shows that there were significant differences for the seasons (**Table 3**). The tests of equality of group means (**Table 4**) measure each parameter's potential before the discriminate model is created. Each test displays the results of a one-way ANOVA for the parameters using season as the grouping variables. As shown by the p-values (sig.), all the parameters signifi-

Table 1. Descriptive statistics of selected water quality parameters in River Benue.

Parameter	Min.	Max.	Mean	Std. Error.
Turbidity (NTU)	3.50	6.00	4.88	0.06
Temperature (°C)	26.3	30.9	28.2	0.06
Conductivity ($\mu\text{S}/\text{cm}$)	26.4	127	86.9	2.43
pH	6.40	7.79	7.01	0.03
TS (mg/L)	47.0	947	227	14.7
TSS (mg/L)	20.0	892	183	14
TDS (mg/L)	17.1	70.0	45.1	1.13
Hardness (mg/L)	6.00	56.0	26.1	1.1
Alkalinity (mg/L)	0.40	4.00	2.03	0.08
Chloride (mg/L)	0.4	2.41	1.26	0.05
Phosphate (mg/L)	1.20	19.0	5.34	0.32
BOD (mg/L)	1.50	20.0	8.23	0.40
COD (mg/L)	120	286	178	2.85
DO (mg/L)	0.63	3.63	1.80	0.06

Table 2. Seasonal variation in physio-chemical parameters of the River Benue.

Parameters	Rainy Season (S ₁)	Dry Season (S ₂)	Rainy Season (S ₃)
Turbidity (NTU)	5.10 ± 0.05	4.58 ± 0.12	4.96 ± 0.10
Temperature (°C)	27.7 ± 0.1	28.4 ± 0.1	28.6 ± 0.4
TSS (mg/L)	113 ± 13	98.1 ± 7.5	337 ± 25
TDS (mg/L)	36.0 ± 2.0	42.4 ± 1.4	56.8 ± 0.3
TS (mg/L)	148 ± 15	140 ± 8	393 ± 25
pH	7.01 ± 0.03	7.22 ± 0.02	7.13 ± 0.02
Conductivity	58.2 ± 1.3	85.3 ± 2.7	117 ± 1
DO (mg/L)	1.91 ± 0.06	1.93 ± 0.16	1.55 ± 0.05
BOD (mg/L)	11.3 ± 0.83	6.18 ± 0.47	7.28 ± 0.45
COD (mg/L)	159 ± 2	181 ± 6	193 ± 5
Total Hardness (mg/L)	15.8 ± 1.4	36.4 ± 1.4	26.1 ± 0.92
Alkalinity (mg/L)	2.61 ± 0.13	1.83 ± 0.17	1.66 ± 0.07
Chloride (mg/L)	1.55 ± 0.10	1.06 ± 0.05	1.19 ± 0.04
Phosphate (mg/L)	5.65 ± 0.67	3.73 ± 0.2	6.63 ± 0.57

Note: S₁ (July, 2008-October, 2008); S₂ (November, 2008-February, 2009); S₃ (March, 2009-June, 2009).

Table 3. Model for Multivariate tests for all sample stations and seasons of River Benue.

Effect	Model	Value	F	p-value (Sig.)
Station	Pillai's Trace	1.25	0.976	0.557
	Wilk's Lambda	0.239	0.986	0.525
	Hotelling's Trace	1.67	0.994	0.504
	Roy's Largest Root	0.549	3.34	0.00
Season	Pillai's Trace	1.68	29.5	0.00
	Wilk's Lambda	0.024	29.7	0.00
	Hotelling's Trace	11.0	29.9	0.00
	Roy's Largest Root	6.69	37.3	0.00

cantly contributed to the model. Wilk's lambda is another measure of a parameter's potential before the model is created; smaller values indicate the parameter is better at discriminating between groups. **Table 4** suggests that the parameter's discriminating ability be ranked from the highest to the lowest as listed: hardness, TS, TSS, TDS, temperature, BOD, pH, alkalinity, COD, Cl⁻, turbidity, PO₄³⁻, EC and DO.

Tables 5 and **6** shows Fisher's linear discriminate functions coefficient and Eigen-values for discriminate functions for the three seasons, respectively. Two discriminate functions were obtained and the total variance cumulative was 100% between seasons. The first function explained 64.8% of the total variance between sea-

sons while the second function explained 35.2% (**Table 6**).

Wilk's lambda is a measure of how well each function separates cases into groups. It is equal to the proportion of the total variance in the discriminate scores not explained by differences among the groups. Smaller values of Wilk's lambda tests indicate greater discriminatory ability of the function. The small values of Wilk's lambda of 0.043 and 0.264 for discriminate functions 1 and 2 respectively (**Table 7**), shows that very small portions of the discriminate scores were not explained by the differences among the seasons.

The associated chi-square statistic in **Table 7**, test the hypothesis that all the means of the functions listed (that

Table 4. Tests of equality of group means.

Parameter	Wilk's Lambda	F	p-value (Sig.)
TS	0.466	67.0	0.00
pH	0.774	17.1	0.00
EC	0.882	7.86	0.01
DO	0.930	4.43	0.14
PO ₄ ³⁻	0.879	8.04	0.01
COD	0.795	15.0	0.00
BOD	0.753	19.2	0.00
Alkalinity	0.791	15.5	0.00
Turbidity	0.878	8.15	0.00
Cl ⁻	0.818	13.0	0.00
Hardness	0.462	68.1	0.00
TSS	0.487	61.6	0.00
Temp.	0.655	30.8	0.00
TDS	0.507	56.9	0.00

Table 5. Fisher's linear discriminate function coefficients for the seasons.

Parameter	Season		
	1.00	2.00	3.00
TS	0.256	0.477	0.809
pH	642	668	657
EC	0.193	0.233	0.154
DO	-19.3	-16.4	-18.3
PO ₄ ³⁻	-5.77	-6.28	-5.33
COD	0.762	0.803	0.790
BOD	-2.28	-2.58	-3.00
Alkalinity	-50.3	-54.3	-51.9
Turbidity	39.2	38.6	40.5
Cl ⁻	-43.8	-51.0	-51.8
Hardness	-4.12	-3.93	-4.01
TSS	-0.618	-0.852	-1.16
Temp.	176	180	180
Constant	-4663	-4939	-4905

is functions 1 and 2) are equal across groups (seasons 1 to 3). The small p-value (sig) of 0.00 for each function indicates that the discriminate functions do better than chance at separating the seasons. **Table 5** shows the

Table 6. Eigen-values for discriminate functions for three seasons.

Function	Eigen-value	% of variance	Cumulative %
1	5.15 ^a	64.8	64.8
2	2.79 ^a	35.2	100

First 2 canonical discriminate functions were used in the analysis.

Table 7. Wilk's Lambda test of discriminate function for temporal variation of the River.

Test of functions	Wilk's Lambda	Chi-square	p-value (Sig.)
1 through 2	0.043	350	0.00
2	0.264	148	0.00

Table 8. Discriminate function coefficient of temporal variation of the River.

Parameter	Function	
	1	2
TS	10.1	6.82
pH	0.621	-0.568
EC	-0.083	-0.644
DO	0.221	-0.360
PO ₄ ³⁻	0.078	0.765
COD	0.189	-0.139
BOD	-0.456	-0.296
Alkalinity	-0.331	0.567
Turbidity	0.086	0.277
Cl ⁻	-0.721	0.081
Hardness	0.231	-0.223
TSS	-9.66	-5.88
Temp.	0.432	-0.017

Table 9. Classification results for discriminate analysis of the seasons.

Season	Predicted Group Membership			Percent correct ^a
	1.00	2.00	3.00	
1	40	0	0	100
2	1	39	0	97.5
3	0	0	40	100

^a99.2% of original group cases correctly classified.

Fisher's linear discriminate function coefficient which can be used for predicting the likely season a particular water sample was collected in the Makurdi metropolitan area given the concentration of the parameters. Temporal variation of the river Benue was also analysed using discriminate functions (**Table 8**).

The validity of using the discriminate functions for this prediction is certain, as 99.2% of original group cases were correctly classified or predicted (**Table 9**). The structure matrix (**Table 10**) shows the correlation of each parameter with the discriminate functions. The ordering of the discriminating ability of the parameters as indicated by the correlations is close to that indicated by using the Wilk's lambda criteria in **Table 4**. This is because the structure matrix is unaffected by the co-linearity among the parameters (see **Table 11**). The discrepancies observed when using the table of standardized discriminate functions coefficient (**Table 8**) in ranking the discriminating ability of the parameters in the model when compared with those indicated by the Wilk's lambda criteria in **Table 4**, is obviously due to the existing co-linearity among parameters which would have inflated the discriminating ability of some of these parameters. We therefore, recommend the use of the structure matrix of the two discriminate functions in ranking the discriminating ability of the River Benue water quality measuring parameters in the Makurdi metropolitan area. The ranking according the structure matrix from the highest to the lowest discriminating ability of the parameters is TS, TSS, hardness, TDS, temperature, BOD,

alkalinity, PO_4^{3-} , COD, pH, Cl^- , turbidity, EC and DO using both discriminant functions.

Table 10. Structure Matrix of each parameter with the discriminate functions.

Parameter	Function	
	1	2
TDS ^a	0.454*	0.282
Temperature	0.318*	0.041
BOD	-0.234*	0.128
Alkalinity	-0.227*	0.001
COD	0.220*	0.053
pH	0.197*	-0.183
Cl^-	-0.189*	0.117
EC	0.156*	-0.059
TS	0.293	0.501*
TSS	0.272	0.491*
Hardness	0.364	-0.415*
PO_4^{3-}	-0.001	0.222*
Turbidity	-0.093	0.184*
DO	-0.075	-0.130*

^aThis variable not used in the analysis; *Largest absolute correlation between each variable and any discriminate function.

Table 11. Correlation coefficient matrix for water quality parameters.

Parameters	TS	pH	EC	DO	PO_4^{3-}	COD	BOD	Alkalinity	Turbidity	Cl^-	Hardness	TSS	Temp	TDS
TS	1.00													
pH	0.249	1.00												
EC	0.253	0.173	1.000											
DO	-0.160	0.040	-0.027	1.000										
PO_4^{3-}	-0.214	0.044	0.422	0.216	1.0000									
COD	0.105	-0.043	0.346	-0.078	0.308	1.000								
BOD	0.214	0.249	0.002	-0.279	0.077	-0.001	1.000							
Alkalinity	-0.128	0.483	0.101	0.463	0.251	-0.054	0.061	1.000						
Turbidity	0.120	-0.019	0.346	0.395	0.330	0.203	-0.214	0.017	1.000					
Cl^-	0.190	0.185	0.067	0.223	-0.213	-0.014	-0.030	0.094	0.194	1.000				
Hardness	-0.237	-0.061	0.069	0.280	0.048	0.055	-0.430	0.064	-0.033	0.083	1.000			
TSS	0.997	0.248	0.250	-0.127	-0.196	0.103	0.191	-0.108	0.149	0.164	-0.230	1.000		
Temp	-0.068	-0.261	-0.136	0.350	0.033	-0.105	-0.168	0.064	-0.004	0.100	0.371	-0.062	1.000	
TDS	0.380	0.084	0.112	-0.461	-0.299	0.076	0.349	-0.310	-0.326	0.361	-0.175	0.309	-0.094	1.000

4. Conclusion

Multivariate statistical techniques were used to examine spatial and temporal variations in water quality of River Benue in the Makurdi metropolitan area in Central Nigeria. Discriminate analysis on station shows that there is no significant difference between the stations investigated but there is on seasons. Fourteen parameters discriminate between the three seasons with 99.2% correct assignments. This suggests that the anthropogenic activities, mainly the discharge of effluents from industries, run-off from agricultural farm land and wastewater from residential areas into the river account for the observed variability in the water quality (especially with respect to TS, pH, PO_4^{3-} , and alkalinity).

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