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A study of the physico-chemical water quality, hydrology and zooplankton fauna of Opa Reservoir catchment area, Ile-Ife, Nigeria

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This study was aimed at relating the zooplankton fauna of Opa reservoir catchment area (Rivers Obudu, Opa and Esinmirin) to their physico-chemical water parameters and some aspects of their hydrology. Basin perimeter, basin width, total length, number of streams, river order and discharge showed significant positive correlation with species occurrence, while compactness ratio showed significant positive correlation with abundance. Conductivity, total dissolved solids, biological oxygen demand (BOD_5) and major ions were generally higher in the dry season than in the rainy season. On the other hand, flow velocity, discharge, total suspended solids, apparent colour, true colour, turbidity, dissolved oxygen (DO), DO saturation, phosphate and organic matter were higher in the rainy season than in the dry season. Cluster analysis indicated a strong relationship among some physico-chemical water parameters. pH, Na^+, Mg^{2+}, SO_4^{2-}, DO, DO saturation, BOD_5, Cu, Mn, Cr, Co, Pb, As and PO_4^{3-} all showed significant correlation ($p < 0.05$) with zooplankton occurrence and/or abundance.

Key words: Abundance, basin, hydrology, rivers, water parameters, species occurrence.

INTRODUCTION

Most limnological studies have concentrated on the biology and the physico-chemistry of lakes and rivers with little or no attention on their hydrology. A complete assessment of a water body is however based on appropriate monitoring of its hydrology, physico-chemistry and biology (Meybeck and Helmer, 1992). In river systems, nutrients, sediments and organisms move according to the water speed. This flow if permanent is a controlling factor in the distribution and abundance of organisms (Neiff, 1996). Variation in hydrologic regime are undoubtedly of great importance, and responsible for main changes in a great number of environmental factors related to each other and to the zooplankton, such as current velocity, turbidity and suspended solids (Casanova and Henry, 2004).

Zooplankton are an important component of the aquatic biota and play a pivotal role in the food web by forming a link between the lower trophic level organisms (phytoplankton) and the higher trophic level organisms such as macroinvertebrates and fish. They are susceptible to variation in a wide number of environmental factors including water temperature, light, chemistry (particularly pH, oxygen, salinity, toxic contaminants) and food availability (Paterson, 2001). Zooplankton, like all organisms have a range of environmental conditions to which they are adapted. The optimum environment for one species may be barely tolerable to another (Parker and Corbilt, 1993). Animals also live within a certain range of environmental condition called the tolerance range for any environmental factor, and at either limit of

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Table 1. Site description of the sampling stations.

Station Ref. code	River system	Longitude (E)	Latitude (N)	Altitude (m)	Depth range (m)
OB1	Obudu	004°37.142^1	07°33.281^1	335	0.10-0.45
OB2	Obudu	004°37.394^1	07°34.256^1	333	0.12-0.40
OB3	Obudu	004°36.140^1	07°33.757^1	314	0.15-.0.65
OB4	Obudu	004°34.680^1	07°32.783^1	287	0.35-1.12
OB5	Obudu	004°32.760^1	07°31.432^1	269	0.50-1.50
OB6	Obudu	004°36.215^1	07°33.421^1	313	0.25-0.90
E2	Esinmirin	004°36.154^1	07°28.670^1	313	0.15-0.50
E3	Esinmirin	004°35.476^1	07°28.672^1	271	0.20-0.65
E6	Esinmirin	004°34.205^1	07°29.866^1	265	0.35-0.95
E8	Esinmirin	004°33.033^1	07°30.799^1	256	0.45-1.25
MK1	Esinmirin	004°36.675^1	07°30.353^1	ND	0.15-0.45
MK2	Esinmirin	004°36.190^1	07°29.150^1	ND	0.17-0.52
OP2	Opa	004°34.568^1	07°31.231^1	267	0.70-1.05
OP4	Opa	004°33.345^1	07°31.112^1	263	0.70-1.15
OP5	Opa	004°35.433^1	07°31.684^1	274	0.65-0.95
OP6	Opa	004°32.862^1	07°31.056^1	262	0.84-1.75

the tolerance range, one or more essential functions cease (Miller and Harley, 1999).Previous limnological surveys of Opa Reservoir (Akinbuwa ,1992; Akinbuwa and Adeniyi, 1991; 1996) accounted for the taxonomic composition of zooplankton fauna as well as their relationship with the physico-chemical water quality of the reservoir. Ogunfowokan et al. (2011) also gave an account of the trophic status and physico-chemical water parameters of Opa Reservoir and two other reservoirs (Asejire Reservoir and Ede Reservoir) in south west Nigeria. Zooplankton studies in other Nigerian fresh-waters include the works of Iloba (2002) on Ikpoba Reservoir, Ayodele and Adeniyi (2006) on River Oshun impoundments, Ibrahim (2009) on Challawa River, Bwala et al. (2010) on NIFFR reservoirs, as well as Achionye-Nzeh and Ismaikaiye (2010) on the University of Ilorin reservoir. This study was aimed at making a complete assessment of the three river systems that flow into Opa Reservoir based on their hydrology, water physico-chemistry and an aspect of their biology (zooplankton), and relating the findings to previous limnological accounts on the reservoir.

MATERIALS AND METHODS

Study area

The study was based on the catchment area of Opa reservoir, covering parts of Atakumosa West, Ife Central and Ife East Local Government Areas of Osun State, Nigeria. The area lies between Latitudes 07°28^1-07°35^{1}N and Longitudes 004°32^1-004°38^{1}E. Coordinates and site descriptions of the sampling stations are provided in Table 1. Sixteen (16) sampling stations were established in the study area covering the upper reach, middle reach and the lower reach of each river system (Figure 1). The dry season is shorter and usually lasts for about five months (November-March) while the rainy season prevails for the remaining seven months of the year (April-October). The annual regime of rainfall shows two peaks (one in June/July and the other in September) separated by a short dry spell in August.

Sample collection and analyses

Sampling was carried out every other month between September 2004 and July 2005 on the sixteen established stations. Ambient air and water temperature were determined by a mercury-in-glass thermometer. Flow velocity was determined by placing a float in the water and measuring the time taken to travel a predetermined distance (Jones and Reynolds, 1996). Discharge was estimated from the product of the flow velocity and the cross-sectional area of the river (that is basin width and water depth) (Chapman and Kimstach, 1996). pH was determined by using a standardized pH meter while conductivity was determined by using a standardized Jenway conductivity meter. Samples for physico-chemical and zooplankton analyses were collected from the surface layers in all the sampling stations. Dissolved oxygen (DO) and biological oxygen demand (BOD_5) samples were collected in oxygen bottles (250 ml reagent bottles). DO samples were fixed *in situ* with Winkler's reagents A (Manganous sulphate) and B (Alkali iodide). BOD_5 samples were incubated in a dark cupboard at room temperature for five days and afterwards fixed with Winkler's reagents.

Zooplankton samples were filtered through 45 µm plankton net and preserved in 5% formalin solution. Further analysis of zooplankton was done in the laboratory by viewing under a compound light microscope and identification was done based on standard identification guides (Egborge and Chigbu, 1988; Egborge, 1994; Alekseev, 2002; Fernando, 2002; Kutikova, 2002). Species diversity was determined using the Margalef index. Water samples for physico-chemical analyses were collected in new and uncontaminated 2 liters plastic bottles. Colour, turbidity, total solids (TS), total dissolved solids (TDS) and total suspended solids (TSS) were all determined using the appropriate laboratory methods described by APHA et al. (1995). DO and BOD_5 were determined by

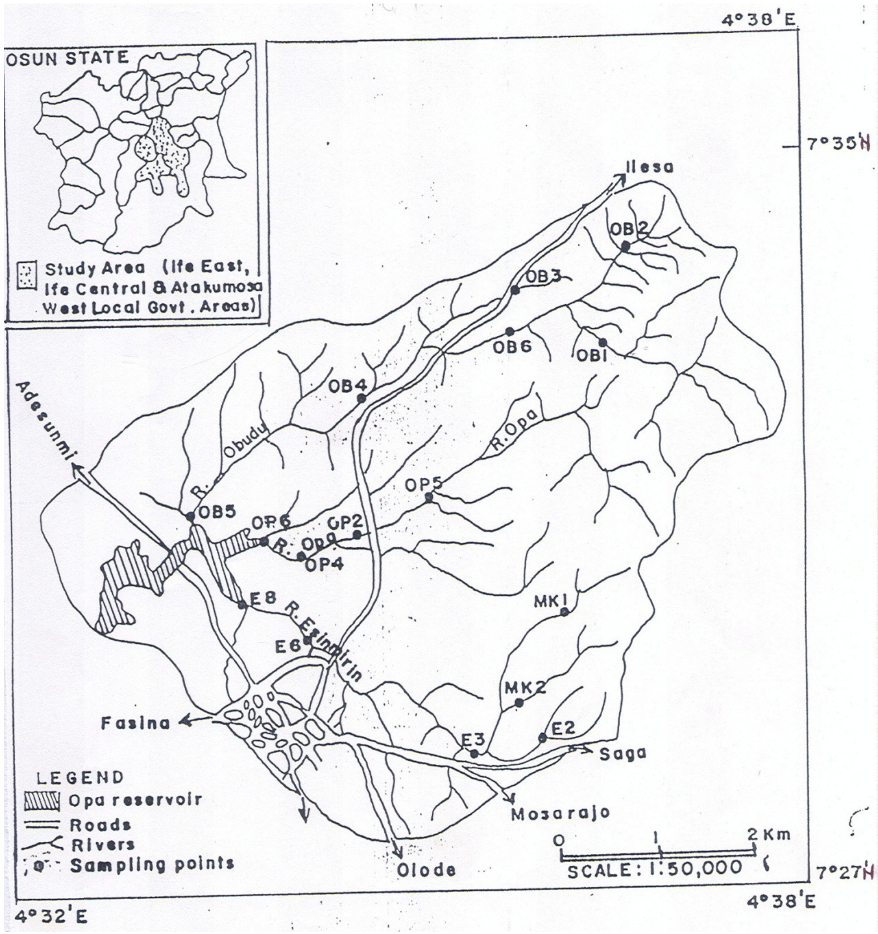

Figure 1. The Catchment basin of Opa Reservoir showing the water sampling stations (Inset: Map of Osun State showing the study area).

Winkler's titration method while alkalinity and acidity were determined by acid-base titration method (APHA et al., 1995). Mohr titration method was used to analyze chloride ion (Cl^-) while complexiometric titration method was used for calcium and magnesium (APHA et al., 1995). Sulphate (SO_4^{2-}) was determined by turbidimetric/spectrophotometric method while Organic matter was analysed by chromic acid digestion (APHA et al., 1995). Spectrophotometric method was used for both nitrate and phosphate (APHA et al., 1995) while atomic absorption spectrophotometry (AAS) was used for sodium (Na^+), potassium (K^+) and all the investigated trace metals (Pb, Zn, Fe, Cu, Mn, Ni, Co, Cr, Cd, and As) at their respective wavelengths (APHA et al., 1995). The data obtained were subjected to statistical analyses using descriptive statistics, cluster analysis and regression analysis.

The various definitions and determination methods used to determine the hydrological parameters are given in Table 2.

RESULTS

Physico-chemical parameters

The general descriptive statistics of physico-chemical water parameters in Opa Reservoir catchment basin are given in Table 3. For hydro-physical parameters; air temperature ranged from 25.0 to 36.0°C, while water temperature ranged from 22.0 to 33.2°C. Apparent colour and true colour ranged from 52.0 to 874.3 Pt.Co and 8.8 to 355.0 Pt.Co respectively. Turbidity ranged from 4.6 to 69.7 NTU. Total solids and total suspended solids ranged from 90 to 300 mgL^{-1} and 10 to 60 mgL^{-1} respectively. Flow velocity ranged from 0.05 to 0.44 ms^{-1}, while discharge ranged from 0.002 to 3.53 $m^3s^{-1.}$

For the general chemical characteristics of water quality; pH ranged from 6.70 to 8.11, while conductivity ranged from 64.3 to 421.4 μScm^{-1}. Alkalinity and acidity ranged from 7 to 210 $mgCaCO_3L^{-1}$ and 12 to 102 $mgCaCO_3L^{-1}$ respectively, while total dissolved solids ranged from 40 to 300 mgL^{-1}.

For major ions; Calcium and magnesium ranged from 2.4 to 34.8 mgL^{-1} and 0.5 to 27.5 mgL^{-1} respectively. Sodium ranged from 5.62 to 11.45 mgL^{-1}, potassium ranged from 1.03 to 9.23 mgL^{-1}. Cl^- ranged from 3.6 to 47.8 mgL^{-1}, while HCO_3^- and SO_4^{2-} ranged from 8.4 to 252 mgL^{-1} and 0.2 to 7.2 mgL^{-1}, respectively.

For nutrient compounds and oxygen parameters; nitrate and phosphate ranged from 0.61 to 2.48 mgL^{-1}

Table 2. Determination of hydrological aarameters.

Parameter	Definition/method of determination
Basin length (L_B)	Straight line distance from outlet to the point on the basin divide used to determine the main channel length line
Basin width (W_B)	Average width of the basin determined by dividing the area, A, by the basin length
Basin perimeter(P_B)	The length of the line that defines the surface divide of the basin
Basin shape (SH_B)	A measure of the shape of the basin computed as the ratio of the length of the basin to its average width
Compactness ratio (CR_B)	The ratio of the perimeter of the basin to the circumference of a circle of equal area. Computed from A and P_B
Main channel length ((L_C)	The length of the main channel from the mouth to the basin divide
Sinuosity ratio	The ratio of the channel length to the basin length
Total length	The length of the basin from the point of outlet to discharge
Drainage density	The ratio of the total length of the basin to the basin area
Stream frequency	The ratio of basin area to number of stream segments
Drainage index	The ratio of the stream frequency to the basin drainage density
Drainage type	The pattern of flow of the rivers and streams in the basin

Wetzel and Likens (2000).

Table 3. General descriptive statistics of physico-chemical water parameters in Opa Reservoir catchment basin.

Parameter	Minimum	Maximum	Mean	Standard deviation	Median	Mode
Air Temp. (°C)	25.0	36.0	29.7	2.7	29.5	32.0
Water Temp. (°C)	22.0	33.2	26.3	1.7	26.0	27.0
Apparent Colour (Pt.Co)	52.0	874.3	278.2	202.9	210.7	153.0
True Colour (Pt.Co)	8.8	355.0	64.1	80.6	37.6	8.8
Turbidity (NTU)	4.6	69.7	22.0	16.2	16.7	13.7
TS (mgL^{-1})	90	300	142	54	120	100
TSS (mgL^{-1})	10	60	28	13	25	20
Flow Velocity (cms^{-1})	5.0	44.4	20.2	11.3	20.0	33.3
Discharge (m^3s^{-1})	0.002	3.53	0.43	0.61	0.16	0.02
pH	6.70	8.11	7.38	0.36	7.37	7.25
Conductivity (μScm^{-1})	64.3	421.4	161.9	76.5	136.9	120.2
Alkalinity ($mgCaCO_3L^-$)	7	210	58	40	44	22
Acidity ($mgCaCO_3L^-$)	12	102	29	18	22	16
TDS (mgL^-)	40	300	111	53	95	80
Ca^{2+} (mgL^{-1})	2.4	34.8	14.6	8.2	12.9	7.7
Mg^{2+} (mgL^{-1})	0.5	27.5	3.9	4.8	2.4	0.5
Na^+ (mgL^{-1})	5.62	11.45	8.94	1.90	9.1	8.82
K^+ (mgL^{-1})	1.03	9.23	4.36	2.52	3.19	3.12
Cl^- (mgL^{-1})	3.6	47.8	18.4	11.8	15.1	8.2
HCO_3^- (mgL^{-1})	8.4	252	72	47.9	55.2	26.4
SO_4^{2-} (mgL^{-1})	0.2	7.2	1.5	1.4	1.0	0.2
NO_3^- (mgL^{-1})	0.61	2.48	1.24	0.47	1.17	1.28
PO_4^{3-} (mgL^{-1})	0.08	3.17	0.49	0.51	0.31	0.23
SiO_2 (mgL^{-1})	1.2	47.0	16.1	10.8	12.1	25.0
Organic Matter (mgL^{-1})	0.46	9.2	4.20	2.52	3.93	3.72
DO (mgL^{-1})	1.2	7.6	5.1	1.3	5.2	6.0
DO Saturation (%)	15.0	94.4	64.0	15.7	64.7	85
BOD_5 (mgL^{-1})	0.4	4.4	1.8	0.9	1.6	1.2
Cu (mgL^{-1})	0.01	1.58	0.69	0.45	0.68	0.01
Fe (mgL^{-1})	0.05	41.2	1.7	6.04	0.9	0.3

Table 3. Contd.

As (mgL^{-1})	0.05	0.7	0.26	0.18	0.20	0.20
Mn (mgL^{-1})	0.01	2.36	0.12	0.33	0.07	0.01
Co (mgL^{-1})	0.01	0.03	0.02	0.01	0.01	0.01
Pb (mgL^{-1})	0.03	16.74	6.17	4.39	5.73	0.06
Ni (mgL^{-1})	0.01	0.05	0.2	0.1	0.1	0.1
Cr (mgL^{-1})	0.01	0.14	0.04	0.03	0.04	0.06
Zn (mgL^{-1})	0.01	0.05	0.02	0.01	0.02	0.01
Cd (mgL^{-1})	0.004	0.872	0.306	0.280	0.030	0.208

and 0.08 to 3.17 mgL^{-1}, respectively. Organic matter ranged from 0.46 to 9.2 mgL^{-1}. DO and DO saturation ranged from 1.2 to 7.6 mgL^{-1} and 15.0 to 94.4% respectively, while BOD_5 ranged from 0.4 to 4.4mgL^{-1}.

For heavy metals; Cu ranged from 0.01 to 1.58 mgL^{-1}, Fe ranged from 0.05 to 41.2 mgL^{-1}, As ranged from 0.05 to 0.7 mgL^{-1}, Mn and Co ranged from 0.01 to 2.36 mgL^{-1} and 0.01 to 0.03 mgL^{-1} respectively. Pb ranged from 0.03 to 16.74 mgL^{-1}, Ni and Cr ranged from 0.01 to 0.05 mgL^{-1} and 0.01 to 0.14 mgL^{-1}, respectively. Zn ranged from 0.01 to 0.05 mgL^{-1}, while Cd ranged from 0.004 to 0.872 mgL^{-1}.

Seasonal and intra-basin variations of hydro-physical parameters

Apparent colour, true colour, turbidity, total suspended solids (TSS), flow velocity and discharge were all generally higher in the rainy season (304.6±30.6 Pt.Co, 83.5±14.1 Pt.Co, 23.3±2.4 NTU, 29±2 mgL^{-1}, 0.23±0.02 ms^{-1}, and 0.57±0.10 m^3s^{-1} respectively) than in the dry season (238.2±32.6 Pt.Co, 35.8±4.1 Pt.Co, 20.1±3.0 NTU, 27±2 mgL^{-1}, 0.12±0.02 ms^{-1}, and 0.10±0.03 m^3s^{-1}). Apparent colour decreased from the upper reach to the lower reach in River Opa (383.9±201.8, 156.7±85.5 and 122.8±64.8 Pt.Co), while there were no definite patterns in the other two rivers. Like in apparent colour, turbidity decreased downstream of River Opa (30.3±15.3 NTU, 11.0±2.8 NTU, 9.6±3.7 NTU) but showed no patterns in the other two rivers. Flow velocity showed a definite pattern in River Obudu only, with an upward trend downstream of the river (0.15±0.09 ms^{-1}, 0.23±0.09 ms^{-1}, 0.27±0.11 ms^{-1}). Discharge on the other hand showed a distinct pattern in River Esinmirin only (0.05±0.03, 0.07±0.05 and 0.80±0.62 m^3s^{-1}), although highest value in River Obudu was also recorded in the lower reach. TSS was lowest in the upper reaches of River Obudu and River Esinmirin and this showed a significant difference ($p < 0.05$) from the middle and the lower reaches.

Seasonal and intra-basin variations of general chemical characteristics of water quality

Conductivity, alkalinity, acidity and total dissolved solids (TDS) were generally higher in the dry season (195.1 μScm^{-1}, 70 $mgCaCO_3L^{-1}$, 34 $mgCaCO_3L^{-1}$, 131 mgL^{-1}, respectively) than in the rainy season (140.0 μScm^{-1}, 49 $mgCaCO_3L^{-1}$, 25 $mgCaCO_3L^{-1}$, 99 mgL^{-1}). There was a slight increase in pH downstream of River Opa (7.22, 7.24, and 7.41). Conductivity increased downstream of Rivers Obudu (116.5, 124.8 and 126.6 μScm^{-1}) and Opa (127.9, 140.4 and 196.0 μScm^{-1}). Total dissolved solids and conductivity were highest at the lower reach of each river.

Seasonal and intra-basin variations of major ions

All the major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^- and SO_4^{2-}) except Na^+ were higher in the dry season than in the rainy season. Sulphate showed a significant difference ($p < 0.05$) between the two seasons. Na^+ increased downstream in River Esinmirin (5.81, 8.62 and 10.02 mgL^{-1}). K^+ increased downstream in the Obudu River (3.23, 4.28 and 4.38 mgL^{-1}) and likewise was Cl^- (13.7 mgL^{-1}, 15.0 mgL^{-1}, 17.2 mgL^{-1}). In River Opa, HCO_3^- increased downstream (40.7, 54.9 and 83.3 mgL^{-1}) and likewise was SO_4^{2-} (0.9 mgL^{-1}, 1.7 and 1.9 mgL^{-1}). K^+, Cl^-, HCO_3^- and SO_4^{2-} were all highest at the lower reaches of the three rivers, although only HCO_3^- showed a significant difference ($p < 0.05$).

Seasonal and intra-basin variations of nutrient compounds and oxygen parameters

The investigated nutrient compounds and oxygen parameters were nitrate (NO_3^-), phosphate (PO_4^{3}), organic matter, dissolved oxygen (DO), DO saturation and biological oxygen demand (BOD_5). Phosphate, organic matter, DO and DO saturation were generally higher in the rainy season (0.50, 4.10 and 5.4 mgL^{-1} and 67%) than in the dry season (0.48 mgL^{-1}, 3.71 mgL^{-1}, 4.7 mgL^{-1} and 59.7%, respectively), while nitrate and BOD_5 were generally higher in the dry season (1.32 mgL^{-1} and 2.0 mgL^{-1}) than in the rainy season (1.19 mgL^{-1}, 1.7 mgL^{-1}%, respectively).

DO showed a significant difference ($p < 0.05$) between the two seasons. There was a decrease in organic matter

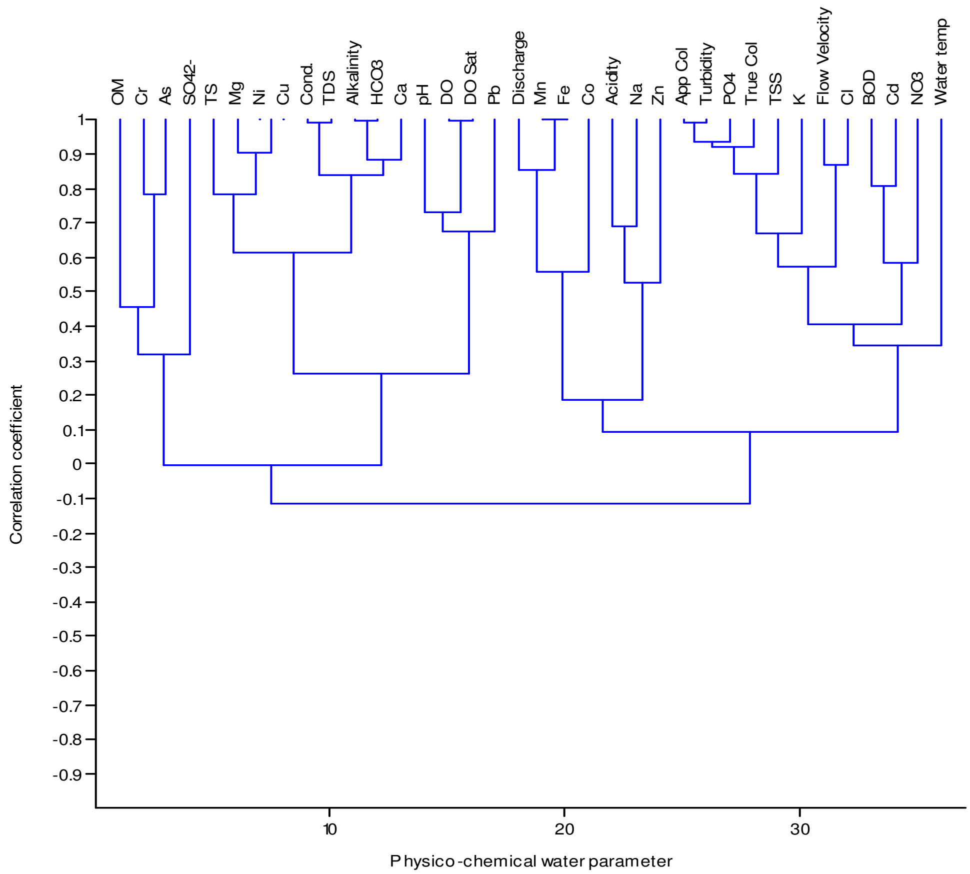

Figure 2. Cluster analysis showing the relationship among physico-chemical water parameters in River Obudu ($p < 0.05$; $r = 0.7067$; $n = 6$).

concentration from the upper reach to the lower reach of River Esinmirin (4.92, 3.83, and 3.20 mgL^{-1}). DO decreased down-stream of River Obudu (5.5, 5.4 and 5.1 mgL^{-1}) and River Esinmirin (5.8, 5.5 and 4.0 mgL^{-1}). DO saturation also decreased downstream of Rivers Obudu (68.4, 68.0 and 63.2%) and Esinmirin (70.6, 69.9 and 50.8%).

Seasonal and intra-basin variations of trace/heavy metals

Cu, As, Co and Ni were higher in the rainy season (0.76 mgL^{-1}, 0.30 mgL^{-1}, 0.02 mgL^{-1}, 0.20 mgL^{-1}) than in the dry season (0.54 mgL^{-1}, 0.24 mgL^{-1}, 0.01 mgL^{-1}, 0.13 mgL^{-1}), while Cd, Fe, Mn, Pb, and Cr were higher in the dry season (0.33, 2.30, 0.20, 6.28 and 0.05 mgL^{-1}) than in the rainy season (0.29, 0.80, 0.07, 6.07 and 0.04 mgL^{-1}). Only nickel however showed a significant difference ($p < 0.05$) between the two seasons. Cu increased down-stream of the Obudu River (0.55 mgL^{-1}, 0.89 mgL^{-1}, 1.08 mgL^{-1}) and so also were Fe (0.70 mgL^{-1}, 0.90 mgL^{-1}, 11.0 mgL^{-1}) and Mn (0.07 mgL^{-1}, 0.08 mgL^{-1}, 0.47 mgL^{-1}). In River Esinmirin, Mn increased downstream (0.02, 0.08 and 0.09 mgL^{-1}) and likewise was Pb (0.05, 5.00 and 8.29 mgL^{-1}). Cr decreased downstream of River Opa (0.05, 0.04 and 0.03 mgL^{-1}).

Relationship among the physico-chemical parameters

In River Obudu, a number of clusters were observed among the physico-chemical water parameters at $p < 0.05$. A major cluster was formed among conductivity, TDS, alkalinity, HCO_3^- and Ca while another one was formed among apparent colour, turbidity, PO_4^{3-}, true colour and TSS (Figure 2). pH, conductivity, TDS, HCO_3^-, alkalinity, Ca^{2+}, TS, Cl^-, K^+, acidity and SO_4^{2-} formed a big cluster at $p < 0.05$ in River Opa. There was another major cluster among TSS, DO, DO saturation, true colour, Cd, apparent colour, turbidity, flow velocity and phosphate (Figure 3). The clustering pattern of physico-chemical water parameters in River Esinmirin was similar to that of River Opa (Figure 4), with TS, TDS, conductivity, Ca^{2+}, discharge, Cl^-, HCO_3^-, SO_4^{2-}, K^+, acidity and flow velocity forming a big cluster at $p < 0.05$. TSS, Zn, Mn, apparent colour, turbidity, NO_3^- and PO_4^{3-} formed another big cluster in R. Esinmirin.

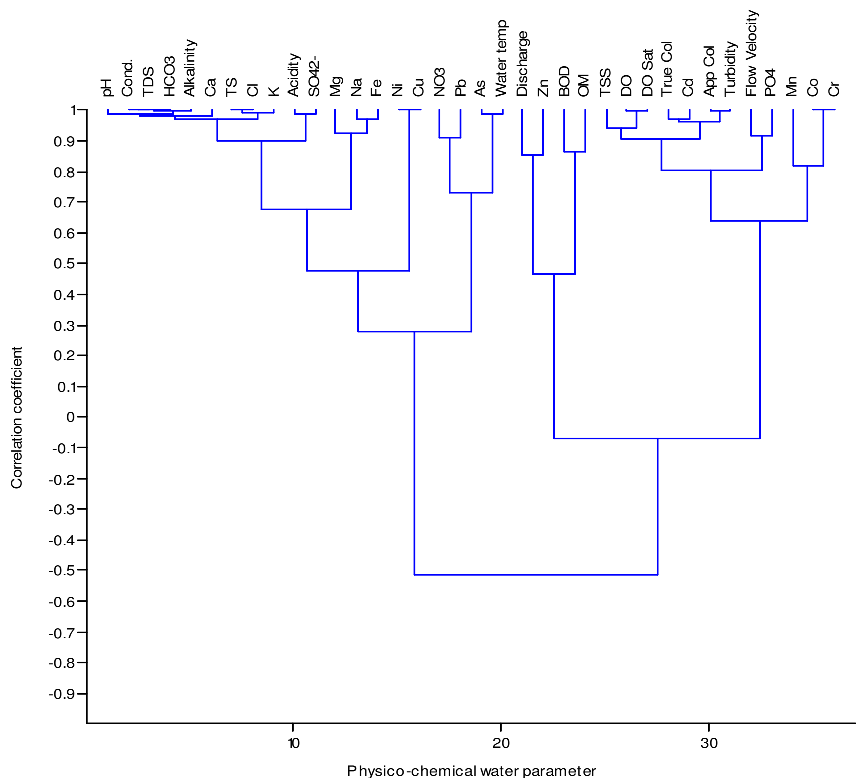

Figure 3. Cluster analysis showing the relationship among physico-chemical water parameters in River Opa ($p < 0.05$; $r = 0.8114$; $n = 4$).

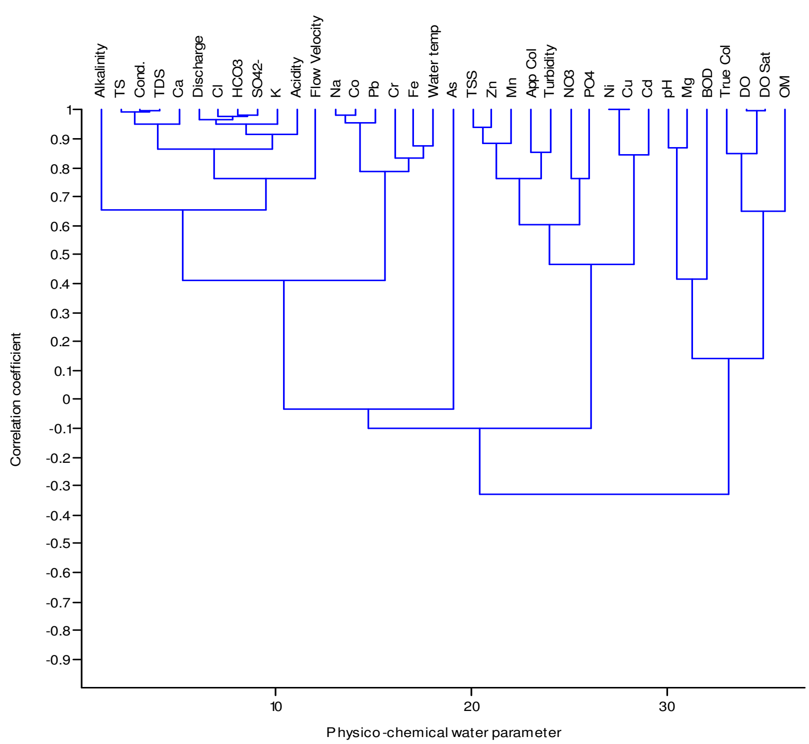

Figure 4. Cluster analysis showing the relationship among physico-chemical water parameters in River Esinmirin ($p < 0.05$; $r = 0.7067$; $n = 6$).

Hydrology characteristics

Discharge was highest at the lower reach in R. Obudu and increased towards the downstream in R. Esinmirin ($0.05 \pm 0.03\ m^3s^{-1}$, $0.07 \pm 0.05\ m^3s^{-1}$, $0.80 \pm 0.62\ m^3s^{-1}$). It was also generally higher in the rainy season ($0.57 \pm 0.10\ m^3s^{-1}$) than in the dry season ($0.10 \pm 0.03\ m^3s^{-1}$) and this showed a significant difference ($p < 0.05$). The drainage pattern in the three rivers was generally dendritic. Area, perimeter, basin width, main channel length and basin length were all highest at the lower reaches of the three rivers (OB5, OP6 and E8). Drainage density decreased downstream in the three rivers.

Zooplankton fauna

The zooplankton fauna of the rivers comprised two phyla, three classes, four orders, fourteen families and forty-six species. A checklist of the species is given in Table 4. Rotifers were the most dominant with nine families and thirty-five species, while the crustacean zooplankton were represented by only five families and eleven species. The relative occurrence and abundance of zooplankton in the sampling stations are also given in Table 5.

Relationship between zooplankton and physico-chemical parameters

The relationships between zooplankton and investigated physico-chemical parameters were established using the regression and correlation analysis. pH, Na^+, SO_4^{2-}, biological oxygen demand (BOD_5), Cu, Mn and Cr all showed significant correlation ($p < 0.05$) with zooplankton occurrence. pH and BOD_5 showed significant inverse correlation ($p < 0.05$) with occurrence, while Na^+, SO_4^{2-}, Cu, Mn and Cr all showed significant positive correlation ($p < 0.05$) with the occurrence of zooplankton.

Phosphate (PO_4^{3-}), DO, DO saturation and Co showed significant correlations ($p < 0.05$) with the abundance of zooplankton. PO_4^{3-} showed a significant positive correlation ($p < 0.05$) with abundance, DO and DO saturation showed highly significant inverse correlation ($p < 0.01$) with abundance, while Co showed a highly significant positive correlation ($p < 0.01$).

Mg^{2+}, Na^+, SO_4^{2-} and Cu showed highly significant positive correlation ($p < 0.01$) with species diversity of zooplankton. As, Co and Pb also showed significant positive correlation ($p < 0.05$) with species diversity.

Relationship between hydrological parameters and zooplankton

Discharge, river order, area, perimeter, basin width, number of streams, total length and discharge all showed significant positive correlation ($p<0.05$) with the occurrence of zooplankton. Total length showed a highly significant positive correlation with occurrence ($p<0.01$). All other hydrological parameters showed insignificant positive correlation ($p>0.05$) with occurrence.

There was a significant positive correlation ($p<0.05$) between compactness ratio and abundance. River order, sinuosity ratio, stream frequency and drainage density showed insignificant inverse correlation ($p>0.05$) with the abundance of zooplankton. A highly significant positive correlation ($p<0.01$) occurred between river order and species diversity, while a significant positive correlation ($p<0.05$) occurred between number of streams and species diversity.

DISCUSSION

Apparent colour, true colour, turbidity, total suspended solids, flow velocity and discharge were all higher in the rainy season than in the dry season. This seasonal variation pattern is common for most tropical inland ecosystems as a result of allochthonous run-off into river basins during the rainy season. Turbidity is a measure of suspended solids in water, and the amount of these solids is largely determined by the velocity of the water (Moore, 1989; Michaud, 1991). This is obvious in the clustering of turbidity with apparent colour, true colour and flow velocity in River Opa, and in the clustering of turbidity with apparent colour and total suspended solids in River Obudu. The increase in flow velocity and discharge in the rainy season can be attributed to rainfall which further increased their values. Discharge, volume of water per unit time (Allaby, 1999) was highest at the lower reaches of River Obudu and River Esinmirin since the volume of water passing down increases as water winds its way along a stream or river from its source (Chapman and Reiss, 1995).

Conductivity, total dissolved solids and virtually all the major ions were higher in the dry season than in the rainy season. Conductivity is a measure of dissolved ions or solids in water, and tends to increase with evaporation of water from the basin, and consequent concentration of the dissolved ions. The direct relationship between conductivity and dissolved solids or ions is evidenced in the clustering of conductivity with the major ions and total dissolved solids. Conductivity and total dissolved solids were also observed to be highest at the lower reach of each river. This may be associated with anthropogenic activities like farming and dumping of wastes in the downstream stations. The connection of the downstream stations with the reservoir was another probable factor for relatively high conductivity and total dissolved solids.

Phosphate and organic matter were also higher in the rainy season than in the dry season. This seasonal pattern can easily be linked to allochthonous inputs from the nearby terrestrial surfaces in the rainy season, thereby increasing their concentrations. The water bodies

Table 4. Taxonomic checklist of zooplankton in Opa Reservoir catchment area.

Taxon				
Phylum	**Class**	**Order**	**Family**	**Species**
Rotifera	Eurotatoria	Ploima	Brachionidae	*Brachionus calyciflorus*
				Brachionus quadridentatus
				Brachionus budapestinensis
				Brachionus falcatus
				Brachionus bennini
				Brachionus angularis
				Brachionus plicatilis
				Branchionus sp.
				Anuraeopsis racenensis
				Keratella tropica
				Keratella lenzi
				K. cochlearis cochlearis
				K. cochlearis macracantha
				Macrochaetus longipes
				Squatinella mutica
				Notholca sp.
				Platyias leloupi
			Colurellidae	*Lepadella patella*
				Lepadella uncinata
			Lecanidae	*Lecane quadridentata*
				Lecane luna
				L.luna presumpta
				L. leontina
				L.lunaris
				Lecane sp.
				Monostyla bulla styrax
				Monostyla lunaris
			Trichocercidae	*Trichocerca cylindrica*
				Trichocerca sp.
			Notommatidae	*Cephalodella mucromata*
				Enteroplea lacustris
			Gastropodidae	*Ascomorpha ovalis*
			Asplanchnidae	*Asplanchna priodonta*
			Euchlanidae	*Beauchampiella eudactylota*
		Flosculariacea	Filinidae	*Filinia terminalis*
Arthropoda	Brachiopoda	Cladocera	Chydoridae	*Camptocercus rectrirostris*
			Moinidae	*Moina micrura*
				Moinodaphnia macleayi
			Sididae	*Diaphanosoma excisum*
			Daphnidae	*Scapholeberis kingi*
				Simocephalus vetulus
	Copepoda	Cyclopoida	Cyclopidae	*Thermocyclops neglectus*
				Halicyclops troglodytes
				Microcyclops varicans
				Eucyclops macrurus
				Halicyclops korodiensis

Table 5. Species occurrence, mean abundance (org/m^3) and species diversity of zooplankton in the stations.

River system	Station	Species occurrence	Mean Abundance (org/m^3)	Species diversity
River Opa	OP2	8	240	0.16
	OP4	25	910	0.17
	OP5	21	430	0.25
	OP6	27	1240	0.27
River Obudu	OB1	16	200	0.27
	OB2	15	340	0.25
	OB3	18	2170	0.19
	OB4	18	320	0.25
	OB5	27	1200	0.27
	OB6	16	370	0.24
River Esinmirin	E2	4	200	0.10
	E3	5	100	0.14
	E6	10	890	0.18
	E8	13	370	0.20
	MK1	8	300	0.08
	MK2	1	80	0.10

might be considered meso-eutrophic as a result of the relatively high concentrations of phosphorous and nitrogenous nutrients. The overall mean concentration of NO_3^- (1.24 mgL^{-1}) fairly exceeded the typical concentration of freshwaters (<1.0 mgL^{-1}) though far less than the recommended maximum level of 5 mgL^{-1} (Chapman and Kimstach, 1996). PO_4^{3-} (0.49 mgL^{-1}) also exceeded the recommended maximum level (0.1 mgL^{-1}) of phosphates in lakes and streams (Moore, 1989; Michaud, 1991). Fertilizer run-off into the basins could have contributed to the elevated levels of these nutrients (Chapman and Kimstach, 1996) since most of the sampled stations were close to farmlands. Dissolved oxygen (DO) and DO saturation were higher in the rainy season owing to the fact that the solubility of oxygen in water increases with decrease in temperature (Lowe-Connel, 1987), which is characteristic of the rainy season. Biological oxygen demand was generally higher in the dry season than in the rainy season, most likely as a result of increase in ambient and water temperature and the consequent rise in the metabolic rate of the aquatic organisms in the dry season. Increased BOD_5 in the dry season could also be associated with increased biological activities (respiration and decomposition of organic matter) which in turn must have been catalyzed by the rise in temperature. Generally, the seasonal pattern in the physico-chemical water parameters of these three rivers indicated that the onset of rains signals a radical change in physico-chemical characteristics of tropical rivers (Lowe-McConnel, 1987; Chapman and Kramer, 1991).

The significant correlation shown between some selected hydrological parameters and the community structure of zooplankton further confirms the relevance of hydrology in limnological studies. River order, area, perimeter, basin width, total length and discharge had a direct relationship with occurrence. A direct relationship was observed between compactness ratio and abundance, and also between river order and species diversity. All these parameters are indices of carrying capacity in a lotic freshwater environment, which in turn determines the community structure of organisms.

Discharge, area, perimeter, basin width, main channel length and basin length were all highest at the lower reaches of the three rivers. High occurrence and abundance of zooplankton were also recorded at the downstream stations. It could therefore be inferred from this study that these hydrological parameters play a vital role in the occurrence and population density of zooplankton. This also indicates that the parameters were good indices of the carrying capacity of the rivers.

Water discharge is one of the parameters affecting zooplankton seasonal variation in rivers (Saunders and Lewis, 1988a, b; Brown et al., 1989, Pace et al., 1991; Van Dijk and Van Zanten, 1995; Vranovsky, 1995), as confirmed from this study with high discharge and high occurrence of zooplankton species in the rainy season. This observation is further supported by the beliefs of Canfield and Jones (1996) that high water discharge provides a larger water volume where animals can develop, and Pace et al. (1991) that small rivers with low discharge have correspondingly lower zooplankton abundance. High discharge was also observed to have coincided with high nutrient loading in the rainy season, which could have in turn stimulated plankton growth as evident in the positive correlation between PO_4^{3-} and zooplankton abundance. The relationship between phosphate and zooplankton abundance is a strong indication that the abundance and biovolume of both phytoplankton and zooplankton are largely regulated by the resource base and tend to increase with the trophic state of freshwaters (Canfield and Jones, 1996). The richness of the water bodies in nitrates and phosphates as well as the moderate presence of *Brachionus spp.*, *Keratella* spp., *Asplanchna priodonta* and *Filinia terminalis* suggests that the rivers were meso-eutrophic (Attayde and Bozelli, 1998).

DO and DO saturation showed highly significant inverse correlation with zooplankton abundance in contrast to previous surveys of the reservoir (Akinbuwa and Adeniyi, 1991; Akinbuwa, 1992). This is probably because dissolved oxygen is a more sensitive environmental factor in a reservoir (lentic environment) than in a lotic river, where the water is constantly being oxygenated by turbulent actions. It is also expected that oxygen consumption through respiration should increase with increase in abundance of organisms, thereby lowering the concentration of dissolved oxygen in a water body. Many of the investigated parameters did not however show significant correlation with the community structure of zooplankton. This is probably because many environmental factors affect zooplankton only at extreme levels (example toxic contaminants, oxygen) and will not be important in all freshwaters (Paterson, 2001).

Conclusion

This study reveals that the physico-chemical and biological nature of inland water bodies is closely linked to their hydrology, the surrounding terrestrial surfaces, as well as the anthropogenic activities in and around the basin. Oxygen and hydrological parameters as well as nutrient compounds played a major role in the occurrence and distribution of zooplankton fauna in the reservoir catchment basin. High concentrations of nu-trients brought into the basin through anthropogenic acti-vities and run-off, as well as the presence of zooplankton indicator species of eutrophication were an indication of a eutrophic freshwater system.

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