THE PHYSICO-CHEMICAL HYDROLOGY OF A TROPICAL SEASONAL RIVER – UPPER OGUN RIVER

A. A. ADEBISI

Hydrobiology and Fisheries Unit, Department of Zoology, University of Ibadan, Ibadan

Received February 19, 1980

Keywords: hydrological regimes, lotic, lentic, residual pools, diel thermal stratification, transparency, pH, dissolved oxygen, dissolved oxygen, dissolved carbon dioxide, conductivity

Abstract

The physico-chemical properties of the Ogun River were recorded between January 1974 and December 1975. A wet season with mean monthly rainfall of 9.72 cm. (s.d. = 5.07 cm) occurred from April through October, while a dry season with mean monthly rainfall of 0.56 cm. (s.d. = 0.99 cm) occurred between November and March. The seasonal changes in the rainfall of the drainage area resulted in an alternation of the hydrological regimes of the river. The high water level of the river that arose as a result of the rains made the water flowed unidirectionally from July through December. After the rains, the water level receded gradually to a point where by January the river broke up into a chain of pools. In a lotic state, the water's tansparency, pH, total alkalinity and conductivity were lower, while its dissolved oxygen, free carbon dioxide concentrations were higher than the corresponding conditions in the residual pools formed when the water was lentic. In this latter form, the observed diurnal surface water temperature fluctuations were more and diel thermal stratification occurred. It was evident that the water in both phases was well aerated. The diurnal fluctuations in the water temperatures and the relationships between the determined environmental factors were assayed.

Introduction

A knowledge of the hydrological conditions of a body of water is most vital when assessing its productivity and other characteristics. The literature available on the hydrology of lakes, large rivers and streams is vast. Despite the fact that seasonal rivers constitute important sources of fish (Holden & Green, 1960; Reed *et al.*, 1967) and are of common occurrence, especially in the tropics (Lowe-McConnell, 1975), not much attention is being paid to their limnology.

This paper constitutes the first record of an investigation into the hydrological regimes of the upper course of the Ogun River, which flows only seasonally, and the effect of the seasonality of the river on the physico-chemical properties of the water.

Materials and methods

The physico-chemical properties of the water, water depth, rainfall and air temperatures were monitored regularly between January 1974 and December 1975. It was not possible to maintain a continuous bimonthly sampling program owing to the irregularity of transport between the sampling site and the laboratory. Intervals between readings were seldom of more than four weeks. Monthly means of all readings were calculated and used.

Water depth and rainfall readings were read off improvised floating depth gauge and rain-gauge, respectively. Water depth readings were to the nearest 0.01 m, while the rainfall readings were recorded to the nearest 0.1 cm.

A maximum/minimum mercury thermometer to determine the air shade temperature was hung under a tree about 2 m above the water surface. The daily minimum and maximum water temperatures occur between 05.00 and 07.00 hours and between 13.00 and 15.00 hours, respectively in the tropics (Talling, 1955) and during summer time in the temperate parts of the world (Hopkins, 1971). The water temperatures regarded as the minimum and maximum values were, therefore, taken at 07.00 hours and 15.00 hours, respectively using a 0-50°C mercury-in-glass thermometer.

Vertical changes in the water temperatures were taken on three different dates with a 2 l Hydro-Bios water sampler fitted with a thermometer according to Ruttner (1965) at 09.00 hours. Hourly changes in the air and surface water temperatures were recorded during the dry season (12-13 January 1974) and the wet season (6-7 April 1974), over 36-hour periods.

All temperature readings were recorded to the nearest 0.1°C.

A white 15 cm-radius Secchi disc was used to measure the transparency of the water to the nearest 0.1 m as described by Ruttner (1965).

Hydrobiologia 79, 157-165 (1981). 0018-8158/81/0157-0165$01.80.

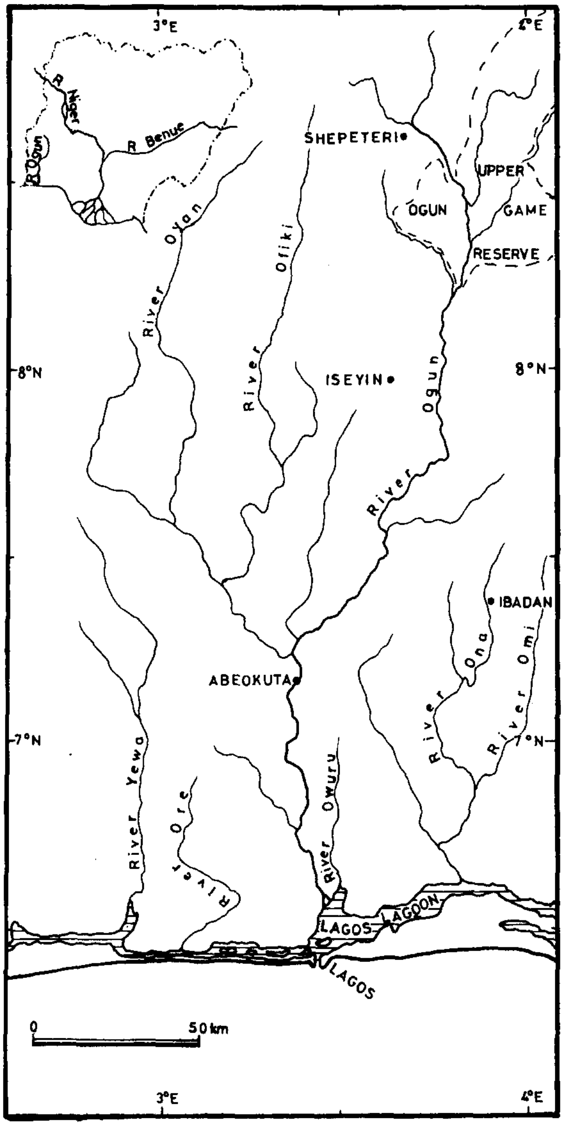

Fig. 1. Map of South-West Nigeria showing the study area-the Upper Ogun River in the Upper Ogun Game Reserve. Inset shows the location of the Ogun River in Nigeria.

Samples of the surface water were collected for chemical analyses between 07.00 and 09.00 hours. The pH and conductivity of the samples were determined in the field soon after collection using battery operated WTW.D812.Weilheim pH 56 and Electronic Switchgear MC-1 conductivity meter, respectively. The conductivity readings were recorded in μmhos/cm at 25°C. The total alkalinity (TA) and dissolved oxygen concentration (DO_2) determinations were by the titrimetric methods described by Mackereth (1963). The units for TA and DO_2 determinations were mg $CaCO_3$/l and mg O_2/l, respectively. The free carbon dioxide content (CO_2) and percentage oxygen saturation (% O_2) were computed from the pH-TA and the expected-observed DO_2 concentrations relationships, respectively as given by Mackereth (1963).

All samples for analyses were taken at three different points along the river within the Upper Ogun Game Reserve. All data were, however, pooled together for treatment since very little difference was observed in the results obtained for the different sampling stations.

Geography and the environmental conditions of the experimental site

Ogun River is one of the major rivers of Nigeria. It runs from its source (3°28″ E, 8°41″ N) in the Oyo State of Nigeria and enters the Lagos lagoon at a point on longitude 3°25″ E and latitude 6°35″ N (Fig. 1). The experimental site, Upper Ogun River, is located in the Upper Ogun Game Reserve at an altitude of 300-500 m above sea level and lies in the Savanna belt. The width and depth of the river at this point varied from 24 to 36 m (mean = 31.3 ± 3.3 m) and 1.8 to 3.2 m (mean = 2.5 ± 04 m), respectively, during the month of April. The water bed comprised mainly of fine and coarse sand particles. The river is banked by either exposed rocks or muddy banks with a few occasional gaps of sand banks. It is fringed by savanna and forest trees and aquatic grasses and shrubs. Floating and rooted hydrophytes were quite sparce. There were several pieces of fallen dead trees lying on the bottom of the water, sometimes projecting out of the water.

Between November and March, the monthly precipitation ranged from 0.0 to 2.8 cm (mean = 0.6, s.d. = 1.0), while between April and October the monthly rainfall reading was between 1.6 and 16.3 cm (mean = 9.7, s.d. = 5.1) (Fig. 2). The periods of heaviest rainfall recorded were the months of July and September. The mean total annual rainfall for the 1974/1975 observations was 70.8 cm.

The pattern of the monthly changes in the water level as plotted in Fig. 2 shows that the water level continued to recede up till May despite the fact that the rains commenced in April. The river began to swell slowly in June. As the rains increased, the rise in the water level became more rapid. At a certain point, the water in the different residual pools on the river channel began to flow into one another. This transitional period occurred in July in 1974, but in June in 1975. The water level attained its peak in

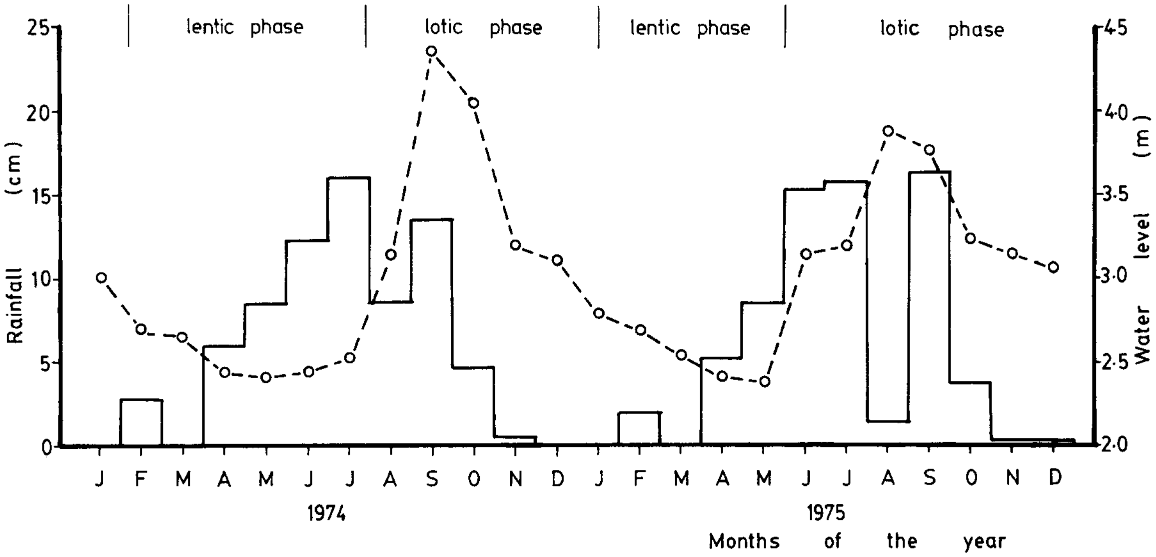

Fig. 2. Monthly variations in the rainfall (histogram) and the river level (o---) between January 1974 and December 1975.

September in 1974, but in August in 1975. In 1974, the recorded peak of the water level was 4.36 m, while in 1975 it was 3.50 m. With the cessation of the rains, the water level began to recede. By January during the two years of observation, the river broke up into a chain of pools again.

From November through April, the maximum air shade temperature ranged from 30.8 to 35.6°C (mean = 32.88°C, s.d. = 1.70°C). The highest air shade temperatures (34.3-35.6°C) were recorded between March and April. The maximum air shade temperature was lower between May and October (range = 28.1-33.1°C, mean = 29.90°C, s.d. = 1.34°C). Between April and October, the minimum air temperature varied between 18.8 and 21.7°C (mean = 20.30°C, s.d. = 0.86°C). The lowest minimum air temperatures were recorded between November and March (range = 9.0-17.8°C, mean = 13.24°C, s.d. = 3.01°C). January was the coldest month of the year with the minimum air temperature ranging between 9.0°C and 10.5°C (Fig. 3). Ob-

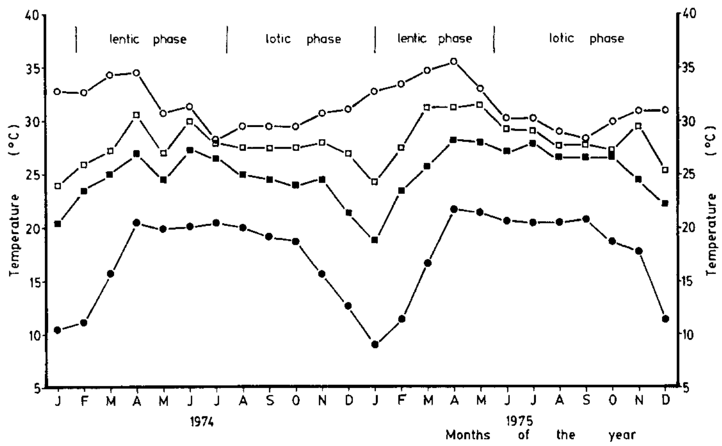

Fig. 3. Monthly variations in the maximum (o———o) and minimum (o———o) air shade temperatures and the water temperatures taken at 15.00 hrs (□———□) and 07.00 hrs (■———■) between January 1974 and December 1975.

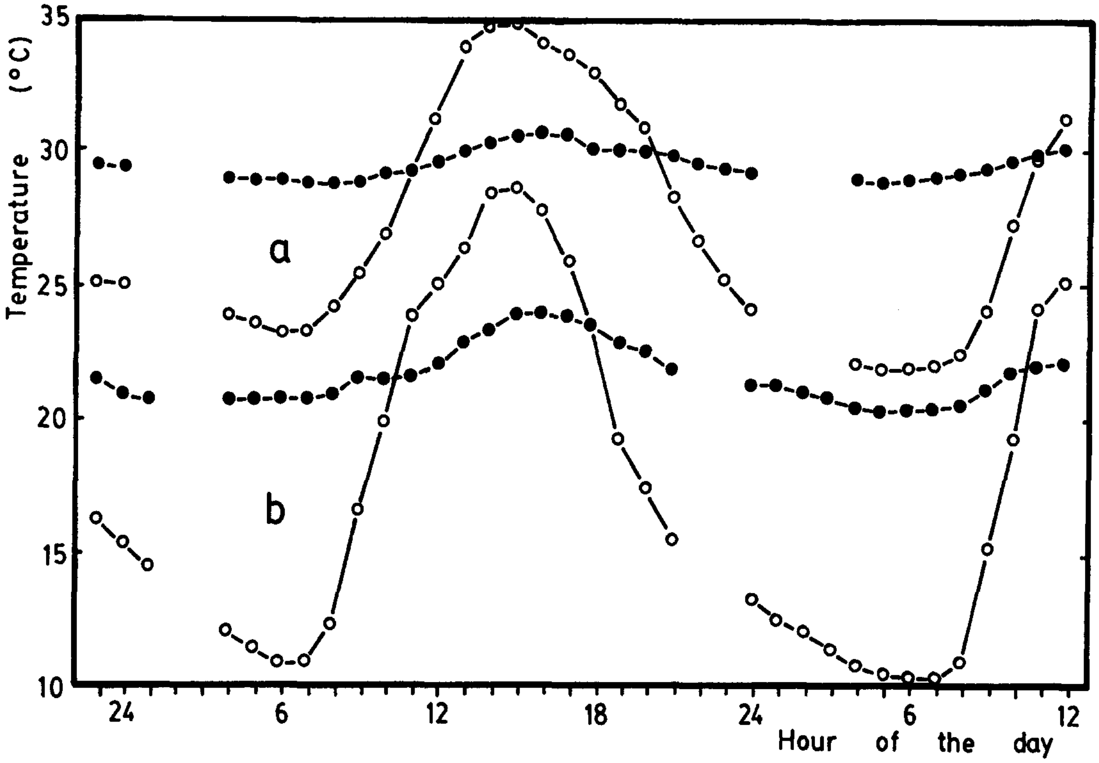

Fig. 4. Diurnal fluctuation in the air shade temperature (o) and surface water temperature (•) taken on (a) 6-7th April 1974 and (b) 12-13th January 1974.

tained data on the hourly changes in the air temperatures showed that the minimum air temperatures were recorded between 05.00 and 07.00 hours, while the maximum air temperatures were attained at 15.00 hours (Fig. 4).

Between April and October, the mean water temperatures taken at 07.00 and 15.00 hours were 26.4 ± 1.4°C and 28.7 ± 1.6°C respectively, while the water temperatures at 07.00 and 15.00 hours were 23.0 ± 2.2°C and 27.0 ± 2.2°C, respectively from November to March (Fig. 3). Fig. 4 shows that the water temperature was minimal between 04.00 and 08.00 hours, sometimes up till 09.00 hours and was maximal between 15.00 and 16.00 hours, both during the dry and wet seasons.

The results obtained from taking the water temperature at different depths in the morning (09.00 hours) and afternoon (15.00 hours) are presented in Fig. 5. These figures reveal that the water column was virtually isothermal from the surface to the bottom in the mornings but thermally stratified in the afternoons. These figures also show that the temperature of the bottom water increased diurnally, although not as much as the surface water temperature.

The minimum of the Secchi disc transparency occurred between August and October. As from November, a gradual increase in the transparency was recorded (Fig. 6). The water was most transparent in February. During this month, the Secchi disc could be seen through the water at a depth of about 1.13 m. A steady decrease in its transparency began in March, attaining its minimal value in August, when the Secchi disc could not be seen beyond the depth of 0.26 m from the water surface.

The pH of the water ranged between 6.9 and 7.9. The water was more alkaline (pH 7.6-7.9) between May and July than at any other time during the year. As from August, the pH gradually dropped down to about 7.0. This minimal value was attained during the height of the flood in September (Fig. 6).

The seasonal variations in the alkalinity of the water are included in Fig. 6. The total alkalinity was 65.6 to 77.9 mg $CaCO_3$/l when the water was lentic. It reached its peak values of 75.4 to 77.9 mg $CaCO_3$/l when the water level was lowest. As the water level increased during the rains, the alkalinity of the water decreased.

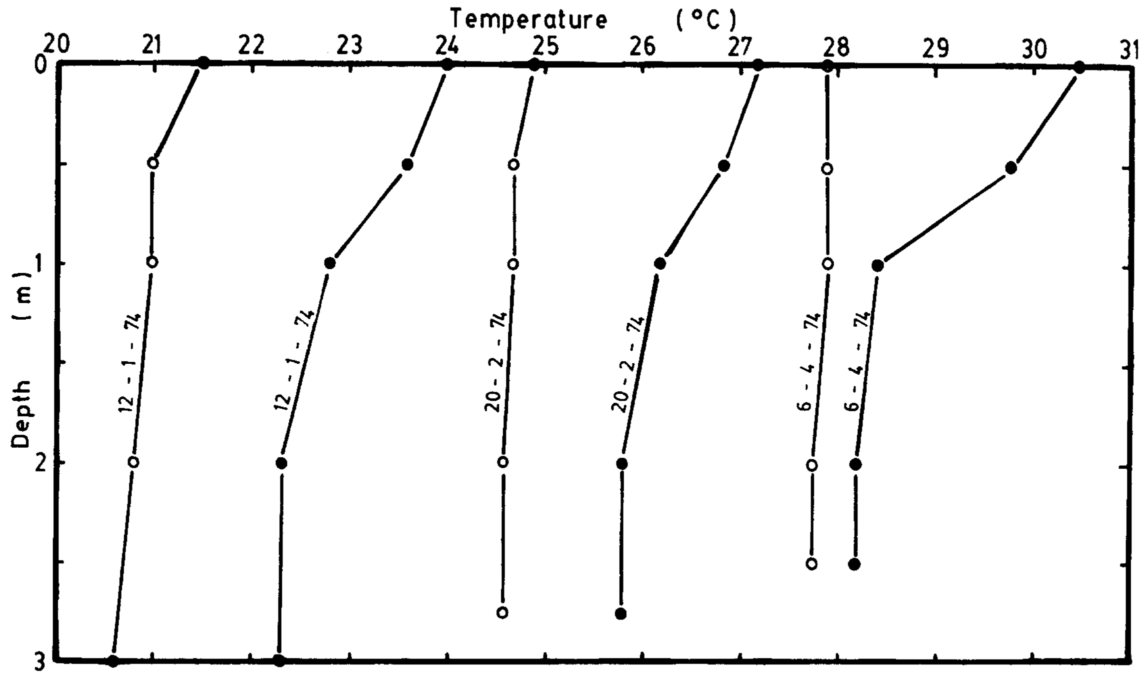

Fig. 5. Phases of the thermal stratification of the water of the Upper Ogun River.

The dissolved free carbon dioxide in the water ranged from 1.9 to 3.7 mg CO_2/l between May and July but was greater than 5 mg CO_2/l between August and April (Fig. 6).

The dissolved oxygen content of the water attained its first annual minimal value in April 1974 (5.10 mg/l) and March 1975 (4.94 mg/l) (N.B. No readings were taken in March 1974). Thereafter, the concentration of the dissolved oxygen gradually increased, reaching its first and major peak value in May (Fig. 6). In May 1974, it was 7.62 mg/l while in May 1975, it was 6.30 mg/l. As the water level began to rise, a gradual decline in the values of the dissolved oxygen, which culminated in another period of minimal value of dissolved oxygen concentration, was observed. This period was July in 1974, but August in 1975. In September, 1974 and October 1975, the second annual peak periods of dissolved oxygen concentration of 6.36 mg/l and 5.81 mg/l respectively were recorded. From August to October, the concentration of the dissolved oxygen recorded for both 1974 and 1975 remained relatively high and steady. Between November and March, it was observed that the dissolved oxygen gradually dropped. At no time was the percentage saturation of oxygen below 50% (Fig. 6).

The total ionic content of the water, measured as the conductivity at 25°C, ranged from 31 to 131 μmhos/cm. The lowest conductivities of 31 to 41 μmhos/cm were recorded between the months of August and October (Fig. 6). Beginning from November, the conductivity of the water rose steadily until it attained its maximum value of 120 to 131 μmhos/cm in May. Between June and July, a gradual fall in the conductivity of the water was observed. As the water became lotic in July, the conductivity of the water dropped more rapidly and it remained low during this period when the water in the pools was in a lotic state.

Table 1 shows the correlation coefficients (r) for all pairs of determined environmental factors computed from the two years' data. All estimated values of (r) which exceeded the 5% probability level are considered to indicate significant correlation.

Discussion

The very low correlation between the rainfall and water level ($r = 0.1410, p > 0.1$) is due to the observed lag between the onset of the rains and the rise in the water level. This has been attributed to the fact that the ground surrounding

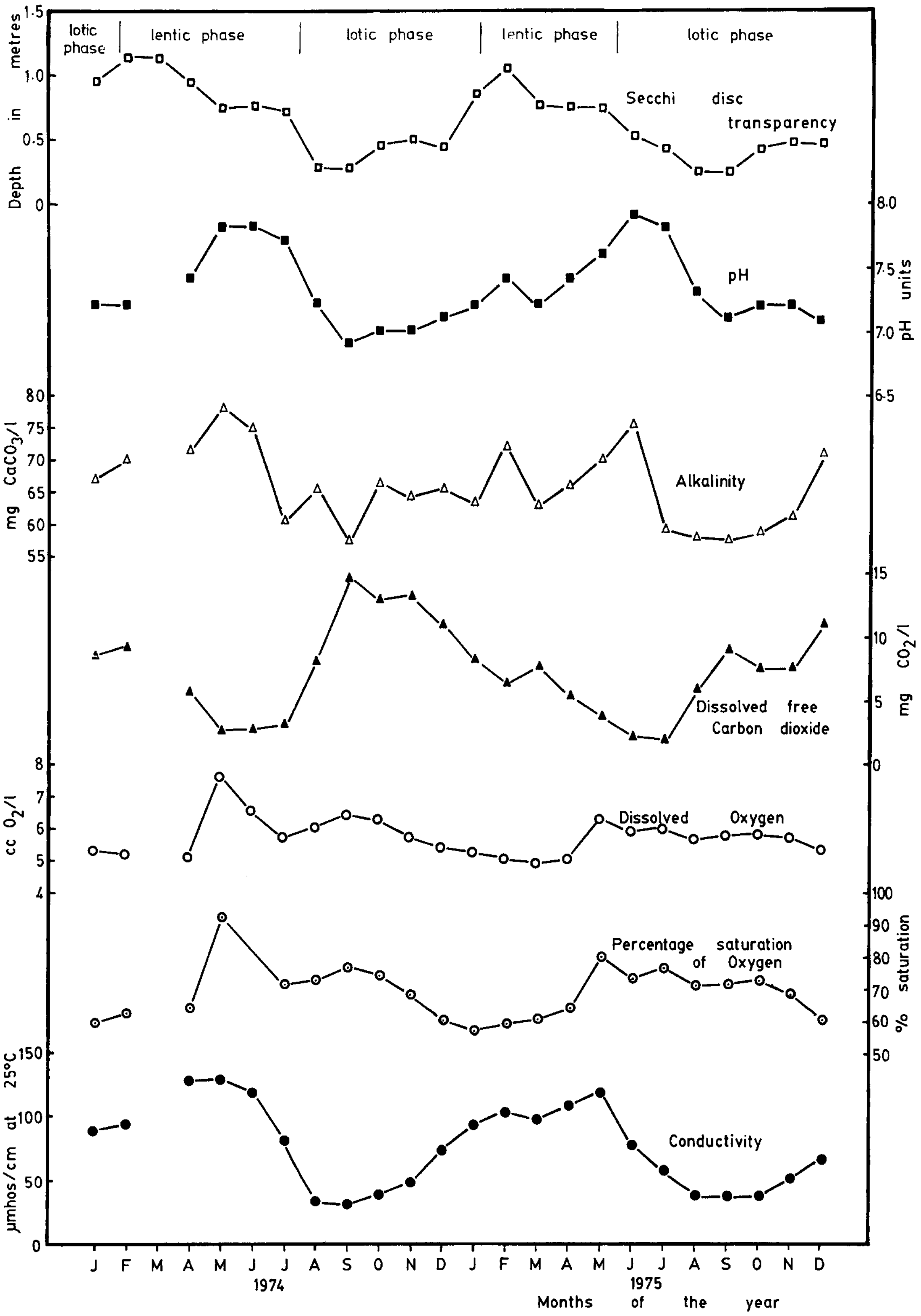

Fig. 6. Monthly variations in the transparency, pH, alkalinity, dissolved free carbon dioxide, dissolved oxygen, percentage saturation of oxygen and conductivity in the Upper Ogun River (January 1974 to December 1975).

Table 1. Correlation coefficient (r) values for the physico-chemical properties of the Ogun river

	Rain-fall	Water level	Air temp. (Max)	Air temp. (Min)	Water temp. (Max)	Water temp. (Min)	Trans-parency	pH	Alka-linity	CO_2	DO_2	$\%O_2$ satn.	Conduc-tivity
Rainfall													
Water level	0.1410												
Air temp. (Max)	−0.5023*	−0.0999											
Air temp. (Min)	0.6771*	0.0971	−0.3091										
Water temp. (Max)	0.3117	−0.2288	0.2579	0.7105*									
Water temp. (Min)	0.5908*	−0.0999	−0.0791	0.8927*	0.8150*								
Transparency	−0.3428	−0.7350*	0.7584*	−0.4429*	0.1241	−0.2095							
pH	0.5414	−0.6298*	0.0395	0.4289*	0.3816*	0.5031*	0.2851						
Alkalinity	−0.0421	−0.5016*	0.3859*	−0.1090	0.0714	−0.0539	0.5071*	0.3689					
CO_2	−0.4375*	0.6067*	−0.1301	−0.4309*	−0.4170*	−0.5305*	−0.2891	−0.9499*	−0.3504				
DO_2	0.4973*	0.1646	−0.5178*	0.4995*	0.1043	0.2404	−0.3429	0.2744	0.2597	−0.2219			
$\%O_2$ satn.	0.6316*	0.0990	−0.4756*	0.7204*	0.2980	0.5436*	−0.3447	0.4911*	0.0398	−0.3726	0.9435*		
Conductivity	−0.0684	−0.8804*	0.7085*	−0.0922	0.2567	0.0488	0.7849*	0.4647*	0.6657*	−0.5589*	0.3436	−0.0257	

*Significant correlation coefficient values.

a body of water has a tendency to absorb the early rains until it is saturated (Hill & Webb, 1958; Holden & Green, 1960; Egborge, 1970). Rainfall also showed low correlations with the measured physical hydrology of the river; Secchi disc transparency ($r = -0.3428$, $0.1 > p > 0.05$) and the afternoon surface water temperature ($r = 0.3117$, $p > 0.1$), except the morning surface water temperature ($r = 0.5908$, $0.01 > p > 0.001$). These results seem to support the view that the physical hydrology of freshwater bodies is not determined solely by the rainfall (Holden & Green, 1960; Egborge, 1970). Egborge (op. cit.), however, singled out rainfall as the most important climatic factor influencing the physical hydrology of the Oshun River, Nigeria.

Between November and March, a wide difference is observed between the daily maximum air temperature and the maximum surface water temperature. Macan (1958) attributed such a phenomenon to the cooling effect resulting from a very high rate of water evaporation taking place during this period of drought. Conversely, when the atmosphere is more humid and the rate of evaporation is lower due to the frequent rains between April and October, the maximum air and surface water temperatures are quite close. This observation and the recorded correlation coefficients between the maximum air temperature and the surface temperature of the water in the afternoon ($r = 0.2579$, $p > 0.1$) seem to emphasize the importance of the relative humidity of the ambient air in the determination of the maximum water temperature. However, the minimum air temperature is more closely related to the afternoon ($r = 0.7105$, $p < 0.001$) and morning ($r = 0.8927$, $p < 0.001$) surface water temperatures.

Fine silt held in suspension when the water was lotic was probably responsible for the extremely low transparency observed between August and December. As soon as the water turns lentic in January, it becomes relatively clearer. The gradual decrease in the transparency after this transitional period of maximal transparency may be due to increasing plankton abundance. In River Sokoto, Holden & Green (1960) observed that a gradual decrease in the water transparency between January and August coincided with the plankton build up in the river. The water level is significantly correlated to the transparency ($r = -0.7350$, $p < 0.001$). The negative value of r is an indication that, generally, the transparency is low when the water level is high and vice versa.

The seasonal fluctuation of the water level is also significantly correlated to its conductivity ($r = -0.8804$, $p < 0.001$), pH ($r = 0.6298$, $p < 0.001$) and the alkalinity ($r = -0.5016$, $0.01 > p > 0.001$). The negative values of r indicate that the conductivity, pH and alkalinity of the water decrease with the increasing water level. Similar observations have been made by Holden & Green (1960) and Talling & Rzoska (1967) on rivers Sokoto and Nile, respectively. In River Oshun, significant negative correlation coefficients for the water level–conductivity and water level–pH relationships, but a positive although low relationship between the water level and the alkalinity, were reported by Egborge (1970).

The conductivity of the water increases with the increasing values of its total alkalinity. It can be inferred from this observation that the CO_3 and HCO_3^- ions are the major ions of the Ogun River. This is an indication that the lime content of its catchment area is high (Strøm, 1939). Similar observations have been reported by Holden & Green (1960), Talling & Rzoska (1967) and White (1966) for Rivers Sokoto, Nile and Niger, respectively. The dominant ions in River Oshun were $SiO_3^=$ and Ca^{++} (Egborge, 1970).

In River Ogun, it was observed that the peak periods of the pH, alkalinity and conductivity coincided and that the pH and conductivity readings were significantly correlated ($r = 0.4647$, $0.02 > p > 0.01$). The Secchi disc transparency was also closely correlated to the conductivity ($r = 0.7849$, $p < 0.001$) and alkalinity ($r = 0.5071$, $0.01 > p > 0.001$). White (1966) and Egborge (1970) opined that a significant positive correlation between transparency and conductivity is an indication of increasing adsorptions of ions on the suspended matter with increasing concentration of the latter and vice versa. This means that the ions in River Ogun existed to a large extent in loosely adsorbed forms on the surfaces of the suspended materials.

The seasonal variation of the chemical hydrology of the Ogun River is broadly similar to those of River Sokoto in the northern part of Nigeria (Holden & Green, 1960) and River Oshun before its impoundment in the southern part of Nigeria (Egborge, 1970). Differences in the annual ranges and the number of peaks in the annual variations of their chemical hydrology exist. These can be accounted for by the differences in their geographical locations and physical hydrological conditions.

A case in point is the seasonal fluctuations of their dissolved oxygen concentrations (DO_2). Peak DO_2 occur in these rivers between May and June and in September. The May-June peak was attributed to phytoplankton bloom while the September peak was attributed to the rigorous aeration of the water due to the rapidity of the water flow concomitant with the high flood (Holden & Green, 1960; Egborge, 1970). A third peak caused by the strong harmattan wind was recorded in the Sokoto River in January (Holden & Green, op. cit.). The harmattan wind in the southern Nigeria was probably not strong enough to effect a January peak in DO_2 in Rivers Ogun and Oshun.

Another example is the similarity in their ionic contents. Holden & Green (op. cit.) observed that the total ionic content of River Sokoto was generally low. The conductivity of River Oshun (44-96 μmhos) was also considered low by Egborge (1970). The latter is comparable to that of the Ogun River (31-131 μmhos). The wider conductivity range recorded for Ogun River might be due to the fact that its water flows only seasonally.

The lentic phase of the Ogun River's transparency, conductivity, pH and alkalinity were higher while its dissolved free carbon dioxide was lower than the lotic phase's. All these indicate that the primary production in the lentic phase is higher than in the lotic phase of the river (Northcote & Larkin, 1956; Khan & Siddiqui, 1971).

Whitney (1942) asserted that fluctuations of the water temperature influence pH, DO_2 and CO_2 pulses of the water. The lentic phase of the Ogun River showed a more marked thermal instability with respect to the lotic phase. This goes to suggest that the water during the lentic phase is probably less stable chemically when compared with the conditions obtained during the lotic phase. The possible impact of the exigencies of the instability of the environmental conditions of this river on its resident fauna and flora needs to be investigated.

References

Egborge, A. B. M. 1970. The hydrology and plankton of the River Oshun, Western State, Nigeria. M.Sc. thesis, University of Ibadan. 126 pp.

Hill, M. B. & Webb, J. E. 1958. The topography and physical features of Lagos harbour and Lagos lagoon. Phil. Trans.; R. Soc. Ser. B. 683: 319-333.

Holden, J. M. & Green, J. 1960. The hydrology and plankton of the River Sokoto. J. Anim. Ecol., 29: 65-84.

Hopkins, C. L. 1971. The annual temperature regime of a small stream in New Zealand. Hydrobiologia, 37 (3-4): 397-408.

Khan, A. A. & Siddiqui, A. Q. 1971. Primary production in a tropical fish pond at Aligarh, India. Hydrobiologia, 37 (3-4): 447-456.

Lowe-McConnell, R. H. 1975. Fish communities in tropical freshwaters Longman. London and New York. 337 pp.

Macan, T. T. 1958. The temperature of a small stony stream. Hydrobiologia, 12: 89-105.

Mackereth, F. J. H. 1963. Some methods of water analysis for limnologists. Freshwat. Biol. Ass. Sciet. Publs. 21: 72 pp.

Northcote, T. G. & Larkin, P. A. 1956. The indices of productivity in British Columbia lakes. J. Fish. Res. Ed., Canada 13 (4): 515-540.

Reed, W., Burchard, J., Hopson, A. J., Jenness, J. & Yaro, I. 1967. Fish and fisheries of Northern Nigeria. Ministry of Agriculture, Northern Nigeria.

Ruttner, F. 1963. Fundamental of Limnology. 3rd Edition. University of Toronto Press. 242 pp.

Strøm, K. M. 1939. Conductivity and reaction in Norwegian lake waters. Int. Revue ges. Hydrobiol. Hydrogr. 38., 250-258.

Talling, J. F. 1955. Some observations on seasonal and diurnal changes of stratification in Lake Victoria. East African Fisheries Research Organization Annual Report, 1955/1956.

Talling, J. F. & Rzoska, J. 1967. The development of plankton in relation to hydrobiological regime in the Blue Nile. J. Ecol., 55: 636-662.

White, E. (Edit). 1966. The first scientific report of the Kainji Biological Research team-Liverpool.

Whitney, R. J. 1942. Diurnal fluctuations of oxygen and pH in two small ponds and a stream. J. Expt. Biol. 19: 92-99.