

Seasonal and Spatial Patterns in Water Quality and *in Situ* Responses of *Daphnia Magna* along River Kaduna, Nigeria

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ABSTRACT

Variations in biochemical oxygen demand and dissolve oxygen affect aquatic organisms and have the potential to disrupt the ecological equilibrium of aquatic ecosystems. This study examined the effects of these environmental factors on the growth, reproduction and survival response of *Daphnia magna* at various sampling sites with differing levels of pollution in the River Kaduna, Nigeria, during both the dry and wet seasons. The physicochemical changes and the structure and dynamics of the *D. magna* community were monitored bi-monthly. *In situ* bioassays involving *D. magna* were conducted twice at five sampling locations in River Kaduna, Nigeria. Exposure was followed by reported measurements of growth, survival, and reproduction at 7 and 14 days. Mean station dissolved oxygen ranged from 2.75 to 4.15 mg/L, while biochemical oxygen demand ranged from 1.47 to 2.13 mg/L. Growth values were higher in wet season than dry season values at Stations 1 – 4; reproductive values were higher in dry season values at Stations 1 and 3, higher in the wet season values at Station 2, and equal at Station 4. This study assessed field bioassay screen of organism responses associated with ambient water conditions. The findings show that in stations with low pollution levels in the River Kaduna, Nigeria, higher DO levels promote improved *D. Magna* growth and reproductive function.

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INTRODUCTION

River water quality changes along urban and industrial reaches as wastewater inputs, runoff, flow, and seasonal conditions vary. Studies of River Kaduna have reported spatial and seasonal differences in physicochemical measures and water quality classifications, including poorer conditions at some urban downstream locations (Ogbozige et al., 2018; Sadiq et al., 2022). Chemical measurements help to describe water conditions but do not, on their own, show how an organism responds to the combined exposure. Water flea which is a freshwater crustacean (*Daphnia magna*) is sensitive to toxic environmental contaminants or stress, which makes it a model organism for aquatic risk assessment (Ahmed 2023; Carlos et al. 2005).

Daphnids are geographically distributed worldwide; their ease of culture under laboratory conditions, short life cycle, sensitivity to anthropogenic substances and easiness of handling in laboratory make them excellent research tools to assess the impacts of toxicants on non-target aquatic organisms (Ahmed 2023; Vale et al. 2016). Field deployed organisms experience multiple, changing influences. Temperature, oxygen, water hardness, food quality, suspended material, flow, and chemical mixtures can all affect performance. Thus, observed differences among stations or seasons should not be attributed to a specific pollutant without appropriate chemical measurements (Moulinec et al., 2025). Studies using *Daphnia* in river water increasingly pair biological endpoints with chemical profiling, and still treat chemical attribution cautiously when only part of a mixture is measured (Moro et al., 2024;

Romero-Alfano et al., 2025; Romero-Alfano et al., 2026). The present study assessed the seasonal and spatial patterns in water quality and *in situ* responses of *Daphnia magna* along River Kaduna, Nigeria. Its objective described water quality conditions at five stations, summarizing the reported growth, survival, and reproductive responses of deployed *D. magna* across dry and wet seasons.

MATERIALS AND METHODS

Study Area and Sampling Stations

Kaduna state (Lat. 10.52 °N, Long 7.44 °E) is one of the most developed industrial cities of Northern Nigeria (Fig. 1). Among the industries in Kaduna state are textile, flour mill, fertilizer, brewery and bottling companies. Kaduna State like most parts of Nigeria has two distinct seasons, a dry (November to mid-April) and wet (April to October) seasons. River Kaduna stretches through Kakuri in the southern part of the state where industrial and domestic waste water empties into it. The River is the main water supply source for Kaduna town and its numerous industries. The water from the river is used for irrigation farming during the dry season (KEPA, 1998). Station 1 (10.49° N, 7.41° E) Upstream; approximately 500 m from a flour mill; designated reference site, Station 2 (10.51° N, 7.43° E) approximately 100 m downstream; directly affected by flour-mill effluent. Station 3 (10.53° N, 7.40° E) approximately 300 m downstream; receives fertilizer company effluent, farm runoff and aquatic macrophytes. Station 4 (10.54° N, 7.42° E) Fishing activities and Station 5 (10.59° N, 7.47° E) Downstream; 700 m from Station 1 and

20 m from a bottling company affected by refuse disposal, fishing, and agriculture.

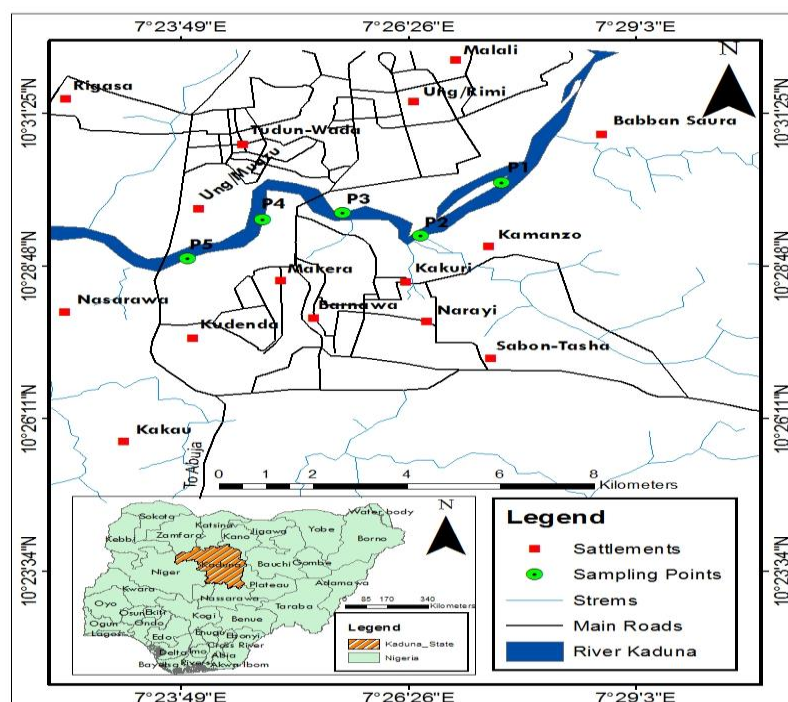


Figure 1: Map of River Kaduna Showing Sampling Stations

Experimental Design

Collection and Culture of *Daphnia Magna*

Samples of *D. magna* were collected from Ahmadu Bello University reservoir (11° 08'N and 7° 39'E). The water containing *D. magna* was collected alongside blue-green algae present in the water at point of collection. *Daphnia magna* samples were collected at twilight (6:00pm) with plankton net (conical shaped, 3.5 m long, 1.2 m inlet opening diameter) and a flash light to attract the *Daphnia*. Collected samples were transferred into transparent plastic containers (measuring 30cm x 30cm x 30cm) having ice blocks for temperature control and carefully transported to the laboratory where they were cultured following USEPA (1993) protocol. The *D. magna* culture medium (water pH: 7.0-7.6 containing 69.8 mg L⁻¹ of CaCO₃) (OECD, 2004) was transferred into a clean plastic tank and thoroughly mixed black soil (Barata et al. 2007) and grower feed (old fish feed) were added to about 5 cm mark in the container. Bore-hole water of 15 mL was added and allowed for 3-5 days to activate, during the activation period, phytoplankton bloom was observed by the change in coloration of the water from dark brown to greenish. *D. magna* was introduced into the plastic tank containing the culture medium and an aerator was connected to the plastic tank to enable aeration of the setup. This ensured that *D. magna* had sufficient oxygen for high growth, biomass production, reproduction and survival.

Daphnia Magna in Situ Bioassays

D. magna in situ bioassays were conducted as described by Barata et al. (2007) using the test chambers and procedures described in McWilliam and Baird (2002). The test chambers were placed at each of the five sampling station for the collection of animals for biochemical analysis and to increase the number of replicates for post-exposure feeding rate measurements. Bioassay tank chambers (25cm x 25cm x 25cm) were constructed from polyvinyl chloride cylindrical

pipings. Each test chamber has two rectangular windows (7cm x 3.5cm) cut into either side of each chamber, covered with 20 µm nylon mesh size. Pipe ends were sealed with polypropylene caps. Chambers were placed inside a 2 wire-mesh cylinder that was positioned in the stream perpendicular to flow.

In Situ Exposure Design

Bioassay chambers (PVC cylinders) with two mesh-covered openings with sealed ends were purchased and deployed. The nylon mesh was of a 20 µm size. Chambers were placed within wire-mesh cylinders in the River. Before deployment, organisms were acclimated to site water hardness for 24 hr. Three replicate chambers, each containing ten *D. magna*, were inoculated for each station. Laboratory and transport controls pressures were taken. After the deployment during dry and wet seasons, measurements were taken after 7 and 14 days.

Physicochemical Measurements

Water temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured *in situ* with a portable Hanna (HI Model 98129 meter). Water samples were collected twice monthly in 250mL transparent and amber bottles. Dissolved oxygen, BOD, alkalinity, nitrate-nitrogen, phosphate-phosphorus, sulfate, and hardness were analyzed in the laboratory following the standard methods for the examination of water and wastewater (APHA, 2005).

Biological Endpoints

After the 7 and 14 days of exposure to the conditions at the different sampling stations per month; growth, survival and reproduction were calculated as described by Shalaby et al. (2006).

Growth

Organisms were measured and recorded before taking to the field. The organisms were then placed gently into the *in situ* chambers on the field. On days 7 and 14 of each month per season, test chambers were gently carried out of the river and 10 individuals of *D. magna* from each of the *in situ* bioassay test chamber were picked with a pipette into test tubes containing the river water. Samples were then transported to the laboratory, individually emptied into crystallizing dishes, from which 10 samples per batch were bloated on filter paper and then weighed using a Sartorius ED2245 weighing balance according to Shalaby et al. (2006).

Survival

Survival of adult *D. magna* was determined by counting individuals of *D. magna* that survived after 7 and 14 days *in situ* exposure. Survival was recorded in percentage.

Reproduction

Number of offspring produced per adult *D. magna* per week were counted and documented after the *in situ* exposure of the organism at day 7 and 14. This was done in the field. Prior to counting, adult *D. magna* were separated from the neonates and individually emptied into crystallizing dishes.

Reproduction = number of neonates expressed as percentage of the total count of *D. magna*.

Statistical Analysis

The data were subjected to Shapiro-Wilk test for normality evaluation. Student's t-test was used to determine seasonal variation in biological end points. Analysis of variance (ANOVA) at $P < 0.05$ was used to determine the mean station variation in physico-chemical parameters, biological end points, Duncan's multiple range test, seasonal *t* tests were conducted using SAS 9.1 and PAST 2.17c.

RESULTS AND DISCUSSION

Physicochemical Conditions

Physicochemical parameters were taken twice biweekly, the minimum and maximum values of physicochemical parameters measured during the study is shown in Table 1. Station 1 had the highest DO concentration (4.15 ± 0.16 mg/l), while station 3 had the least (2.75 ± 0.80 mg/l) during the study period. Dissolved oxygen simultaneous had a negative effect with temperature. Biological oxygen demand varied from the lowest value of 1.0 ± 0.04 mg/l at station 3 to the highest value of 3.7 ± 0.26 mg/l at station 5. Thus, DO correlate negatively with changing temperature levels (Fig. 2).

Table 1: Physicochemical Parameters in Stations of River Kaduna

	Station 1	Station 2	Station 3	Station 4	Station 5
	mean±S.D	mean±S.D	mean±S.D	mean±S.D	mean±S.D
pH	7.40±0.60	7.57±0.75	7.14±0.62	7.68±0.40	7.68±0.37
Temp(°C)	27.38±5.03	27.87±5.49	27.63±5.12	27.87±5.23	27.90±4.08
EC (ppm)	115.00±43.79	138.50±86.04	861.00±366.11	140.50±84.35	789.00±515.75
TDS (µs)	53.17±24.22	76.83±47.59	508.33±341.20	70.50±43.01	510.17±441.93
DO (mg/l)	4.15±0.16	3.78±2.06	2.75±0.80	3.87±2.37	3.88±1.96
BOD(mg/l)	2.13±1.01	1.92±0.91	1.47±0.93	1.90±0.91	2.13±1.05
TH(mg/l)	130.17±77.23	102.33±55.69	120.67±50.75	118.50±63.58	122.33±46.41
Talk(mg/l)	31.33±7.58	33.50±5.09	55.33±4.76	38.17±19.77	44.00±22.93
NO ₃ -N(mg/l)	16.50±5.55	15.08±4.08	21.75±5.64	17.00±3.15	15.58±5.33

Daphnia Magna Responses

The different physiological endpoints and their relationship with physicochemical parameters of River Kaduna during the investigation are presented in Fig. 2. Higher reproduction of *Daphnia magna* was recorded in dry season than wet season. Maximum reproduction ($4.0 \pm 0.71\%$) was recorded at station 1, while the minimum was observed at station 2. ($2.0 \pm 0.01\%$) in dry season. In the wet season, the highest reproduction ($3.0 \pm 0.01\%$) was recorded at station 2, while the lowest rates were observed in stations 1 ($2.0 \pm 0.01\%$) and 4 ($2.0 \pm 1.41\%$) (Table 2). Reproduction of *D. magna* was negatively

correlated with DO, BOD, pH, nitrate, and total hardness. Maximum growth (0.04 ± 0.02 g/day) was observed in the wet season at station 2, while the minimum (0.003 ± 0.00 g/day) was recorded in the dry season at station 1 (Table 2). Changes in growth rate had a negative relationship with DO, BOD, reproduction and survival of *D. magna*. In the dry season, the survival of *D. magna* was higher ($10.0 \pm 0.71\%$) at stations 1, 3 and 4 compared to stations 2 and 5, while in the wet season it was higher ($10.0 \pm 0.01\%$) at stations 3, 4 and 5. The lowest survival was observed at station 5 in the dry season ($8.0 \pm 0.01\%$) and stations 1 and 2 ($9.0 \pm 0.71\%$) in the wet season.

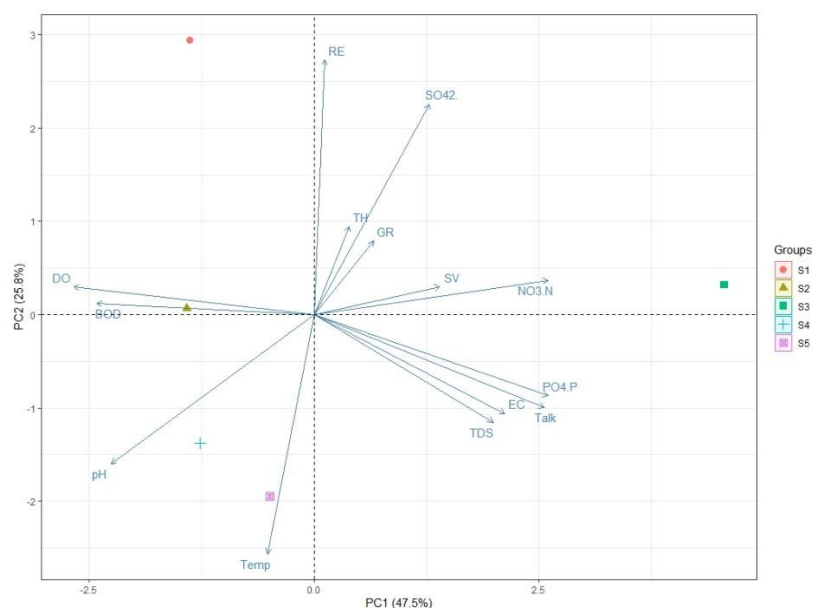


Figure 2: Principal component analysis (PCA) biplot for physicochemical parameters, reproduction, growth and survival of *Daphnia magna*

KEY: RE- Reproduction, SV- Survival, GR- Growth, TEMP-Temperature, pH-Potential of hydrogen, EC-Electrical conductivity, DO-Dissolved oxygen, BOD- Biological oxygen demand, HAR-Total hardness, ALK-Total alkalinity, NO₃-N-Nitrate nitrogen, PO₄-P-Phosphate phosphorus, SO₄²⁻-Sulphate, PC- Principal components

Table 2: Mean Reproductive, Growth and Survival Rate of *D. Magna* In-Situ Exposure in River Kaduna

Season	Station	Reproduction (%)	Growth ($\times 10^{-2}$ g/day)	Survival (%)
Dry	1	4.00 $\pm$ 0.71	0.30 $\pm$ 0.07	10.00 $\pm$ 0.71
Dry	2	2.00 $\pm$ 0.00	0.35 $\pm$ 0.04	9.00 $\pm$ 1.41
Dry	3	3.00 $\pm$ 0.71	0.34 $\pm$ 0.02	10.00 $\pm$ 0.00
Dry	4	2.00 $\pm$ 1.42	0.30 $\pm$ 0.11	10.00 $\pm$ 0.71
Dry	5	2.00 $\pm$ 1.41	0.34 $\pm$ 0.14	8.00 $\pm$ 0.00
Wet	1	2.00 $\pm$ 0.00	0.41 $\pm$ 0.02	9.00 $\pm$ 1.41
Wet	2	3.00 $\pm$ 0.00	0.41 $\pm$ 0.02	9.00 $\pm$ 0.71
Wet	3	2.00 $\pm$ 1.41	0.39 $\pm$ 0.07	10.00 $\pm$ 0.71
Wet	4	2.00 $\pm$ 0.00	0.32 $\pm$ 0.05	10.00 $\pm$ 0.00
Wet	5	2.00 $\pm$ 0.00	0.30 $\pm$ 0.02	8.00 $\pm$ 0.00

Key: RE=Reproduction, GR=Growth, SV= Survival

Discussion

Changes in physicochemical parameters such as DO and BOD influenced the reproduction, growth and survival of *D. magna*. The variation in DO and BOD values is closely associated with the pollution status of rivers (Majeed et al. 2022; Singh et al. 2016; Karaouzas et al. 2017). Based on BOD classification, the river stretch was moderately polluted, with mean BOD values above 1.00 mg/l in all the sampling stations during the study. The higher DO values obtained at station 1 may have relationship with lower temperature, higher phytoplankton densities and higher water velocity. On the other hand, the relatively low DO at station 3 could be attributed to organic effluent received from tributaries of River Kaduna and a nearby fertilizer company. These results are similar to those reported by Prommi aPayakka (2015) on aquatic insect biodiversity and water quality parameters of some streams in northern Thailand. They found out fluctuations in DO and BOD, and its influence on pollution status of the sampling stations, as a result of different anthropogenic activities, with moderate pollution across the sampling stations. Increased anthropogenic activities, high rate of decomposition of organic matter and reduced wind

action can be attributed to lowered DO concentration recorded at station 3. The high BOD observed at station 5 is not surprising because the onset of the rains leads to surface runoff that increases the organic load of aquatic ecosystems, thus, high BOD has been linked to organic pollution of different aquatic ecosystems (Tepe and Mutlu 2005).

From our results, variation in *D. magna* reproduction, growth and survival can be largely as a result of fluctuations in physicochemical parameters especially DO and BOD. The high reproduction in the dry season can be as a result of stability of the aquatic environment and increase in dissolved organic matter which serves as a source of food for these organisms (Chen et al. 2016). Similar findings were reported by Ieromina et al. (2014) where they carried out research on population responses of *Daphnia magna*, *Chydorus sphaericus*, and *Asellus aquaticus* in pesticide contaminated ditches around bulb fields, and reported that reproduction was largely determined by sum of physicochemical parameters especially DO and BOD. Maximum growth observed in the wet season can be as a result of increased DO concentrations and reduced pollution, as a result of dilution factor, and increase in nutrients among others (Medupe and Letshwenyo,

2025; Solomon et al. 2015). Similar findings were reported by Alexander et al. (2013) where they link better growth performance of *D. magna* to higher nutrient base physicochemical parameters in ditches within an agricultural area. The positive correlation observed between DO and survival of *D. magna* indicates the importance of oxygen for the survival of this organism in the river. In a study by Katrennada, (2024) and Baas et al. (2009) DO and BOD concentrations affected significantly the performance of *D. magna*. This finding was confirmed by our results, as survival; a good sign of performance of *D. magna* was influenced positively by DO. Changes in temperature, DO and BOD alter the physiological state of the organism, which can be monitored using sensitive parameters such as antioxidant enzyme activities (Lai 2022; Lushchak 2011). Increasing temperatures can lead to lower DO and higher BOD levels, which induce oxidative stress in *Daphnia* and other zooplankton (Solomon et al. 2015).

Declarations

Ethics approval and consent to participate not applicable
Consent for publication not applicable
Competing interests
The authors declare no competing interests

CONCLUSION

The results of this study revealed that BOD and DO were the primary determinants of changes in growth, reproduction and survival of *D. magna* in river Kaduna. Positive correlation between BOD, DO and survival of *D. magna* was attributed to the organic load that served as food source to the cladoceran. From our results, it is evident that lotic ecosystems with high DO content will support the best performance of *D. magna*.

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