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Assessment of climatic and environmental parameters on fish abundance of an afro-tropical reservoir

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This study assessed the impacts of climatic parameters (rainfall and temperature) and environmental variables (transparency, depth, chloride, TS, TSS, TOC) on the abundance of commercially important fish species in Esa-Odo. The research question was to find out if climatic and environmental factors influence the abundance of fish species in an afro-tropical reservoir. Fish species were collected on a monthly basis for two annual cycles covering both dry and rainy seasons. GIS-based climatic data was used to determine the relationship between climatic conditions and fish species abundance. Results showed that the highest abundance of fish was recorded during the rainy season, with *Oreochromis niloticus* being the most dominant species throughout the sampling period. Trend analysis revealed that variations in climate and environmental parameters influenced the abundance of different fish species in the reservoir. Mann-Kendal analysis indicated that an increase in rainfall led to an increase in reservoir depth, a decrease in transparency levels, and a reduction in temperature, with a Sen's slope value of -38. Additionally, CCA and correlation matrix results demonstrated that climate and environmental parameters significantly influenced fish species abundance. The study emphasized the importance of climatic and environmental factors in the abundance of fish species in the reservoir, providing valuable information for future research on fishery resources. Governments and stakeholders were urged to prioritize the conservation and management of the reservoir's fish population to prevent declines.

Keywords Abundance, Fish fauna, *Coptodon Zillii*, Esa-Odo, *Marcusenius senegalensis*

There is an increasing rise in the temperature of the earth, which was recorded to have risen by 0.74 °C over the last decade, with an expectation to increase from 1.1 °C to 1.6 °C by the end of the century as a result of climate change[1]. These changes can affect both lentic and lotic ecosystems, and in some cases, lake productivity could be altered by the influx of rainfall from the tributaries of the reservoir and evapotranspiration due to significant changes in climate-induced temperature[2,3]. The balance between rainfall influx, water loss from outflows, and evapotranspiration is crucial for aquatic ecosystems at various levels of biological organization[4]. Thus, the impoundment of a reservoir gives rise to a series of changes in the chemical, physical, and biological features[5], leading to significant effects on habitats, obstruction of fish migration and reproduction due to fluctuations in the limnological characteristics of the environment, and to some extent, loss of aquatic biodiversity[6,7]. The resultant effects could also lead to a shift in water classifications from lotic to lentic habitats, both in lacustrine and riverine environments of the reservoir[8,9]. The alterations in the river water system also affect fish assemblages and diversity; some fish species might find it difficult to survive in the reservoir, resulting in extinction or reduction in their population[10–13].

In aquatic habitats, fish constitute an essential component of the biodiversity. They play a crucial role in sustaining the ecosystem functions that benefit human communities[14,15]. As such, fish are vital in sustaining the overall health and balance of aquatic environments, and their importance cannot be overstated. By preserving and protecting fish populations, we can ensure that these crucial ecosystem services continue to support human

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livelihoods and well-being. Freshwater ecosystems, such as rivers, lakes, and swamps, provide habitat for a vast array of fish species, with around 11,952 species, or approximately 43% of all known fish species, found in these environments[16,17]. Freshwater fish are of great importance to the livelihoods of people, particularly those in developing countries[18–20]. They provide a valuable source of food and income for many communities that rely on fishing as a primary economic activity. Despite the significance of freshwater environments and the fish populations they support, the water in which these fish live is in high demand by multiple sectors, including agriculture, energy, industries, and households[21,22]. This has resulted in a decline in freshwater fish diversity, as these ecosystems and their associated fish populations become increasingly degraded. The complex interplay of factors that contribute to this situation underscores the need for a comprehensive approach to water management that balances competing demands and ensures the long-term sustainability of freshwater ecosystems and their biodiversity[23,24]. Industrial, agricultural, and domestic activities are a major source of pollution, and this pollution has harmful effects on both marine and freshwater fish[25]. The impacts of pollution can be detrimental to fish populations, with pollutants affecting their growth, reproduction, and survival. The protection of fish and their aquatic habitats from the harmful effects of pollution is therefore crucial for maintaining the health and resilience of aquatic ecosystems. River systems are among the most vulnerable environments on earth due to a range of human activities, including the construction of dams[26,27]. Dams can have important effects on the natural flow of rivers, altering the hydrology of entire river systems and affecting the habitats and populations of aquatic species, including fish. These impacts can be particularly severe for migratory fish species that depend on rivers that are free to flow in order to complete their life cycles. As such, the building of dams and other forms of river modification must be approached with caution and careful consideration of their ecological impacts to minimize harm to riverine ecosystems and the species they support[28,29].

Since the impoundment of the Esa-Odo reservoir for domestic and industrial purposes, there is currently no available information on the impacts of climatic and environmental parameters on the abundance of fish in the waterbody. The impounded Esa-Odo reservoir presents an opportunity to investigate the ichthyofaunal community, assess fishery potentials, and support subsistence fishing activities. The objective of this study is to examine whether changes in climatic and environmental factors, particularly rainfall patterns, affect fish abundance in a lentic ecosystem. The data collected will serve as foundational knowledge for managing the fishery resources of the waterbody and will aid government officials and policymakers in implementing interventions to uphold healthy fish populations and sustainable fishing practices.

Specific objectives of the study

The specific objectives of the study were to:

(i) Determine the distribution and abundance of fish species.
(ii) Determine the seasonal variation in climatic and environmental parameters of the reservoir,
(iii) Correlate climatic and environmental parameters with fish abundance of the reservoir.

Materials and methods

Study site

The Esa-Odo Reservoir is one of the largest reservoirs at impoundment and is located in the small community of Esa-Odo in Osun State (Fig. 1). It is situated in the humid tropics with high temperatures and rainfall, at Latitude 007°45'0' N to 007°47'18' N and Longitude 04°49'0' E to 04°50'12' E (Table 1). The Esa-Odo area lies on the southern foothills of the Yoruba Hills and Ranges in the area south of the Imesi-Ile Massif, with an undulating to rolling topography and an average elevation of 400 m above sea level. The reservoir was impounded in 1973 with a volume of 8.2 cubic meters of water.

The study area's climate is characterized by two seasons: the wet and dry seasons. It falls under the koppen's $\mathbf{A_f}$ Humid Tropical climate type, with a short dry season from November to February and a rainy season from March to October, featuring bimodal rainfall distribution. The mean annual rainfall is around 1500 mm, with approximately 120 rainy days per year. The mean maximum temperature during the dry season is 31 °C, while in the rainy season, it is 28 °C (Climate–Data.org).

Climatic and environmental parameters

The data for both climatic and environmental parameters were collected from both primary and secondary sources. Water was sampled on a monthly basis for two annual cycles from the reservoir at six evenly distributed different sampling points covering three zones (riverine, transition, and dam site zones) using standard sampling polyethylene bottles. The grid coordinates of each station were measured and recorded using Global Positioning System (GPS). Environmental parameters such as depth, transparency, and temperature were measured in the field using a Secchi disc and a mercury-in–glass thermometer, respectively, while chloride, total suspended solids, total solids, and total organic carbon were determined in the laboratory based on standard protocols[30]. The data for rainfall were retrieved from the NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program (www.power.larc.nasa.gov).

Fish sampling

Fish collections were conducted on a monthly basis for two annual cycles, encompassing both wet and dry seasons, with the assistance of local fishermen. Fish were captured using cast nets, gill nets measuring 80 m in length and 2.5 m in depth, with a mesh size of 50 mm, and traps at various depths of the reservoir from October 2017 to September 2019. The fish were randomly collected early in the morning from different zones of the reservoir (riverine, transition, and dam site zones), stored in an ice-chest box, and transported to the

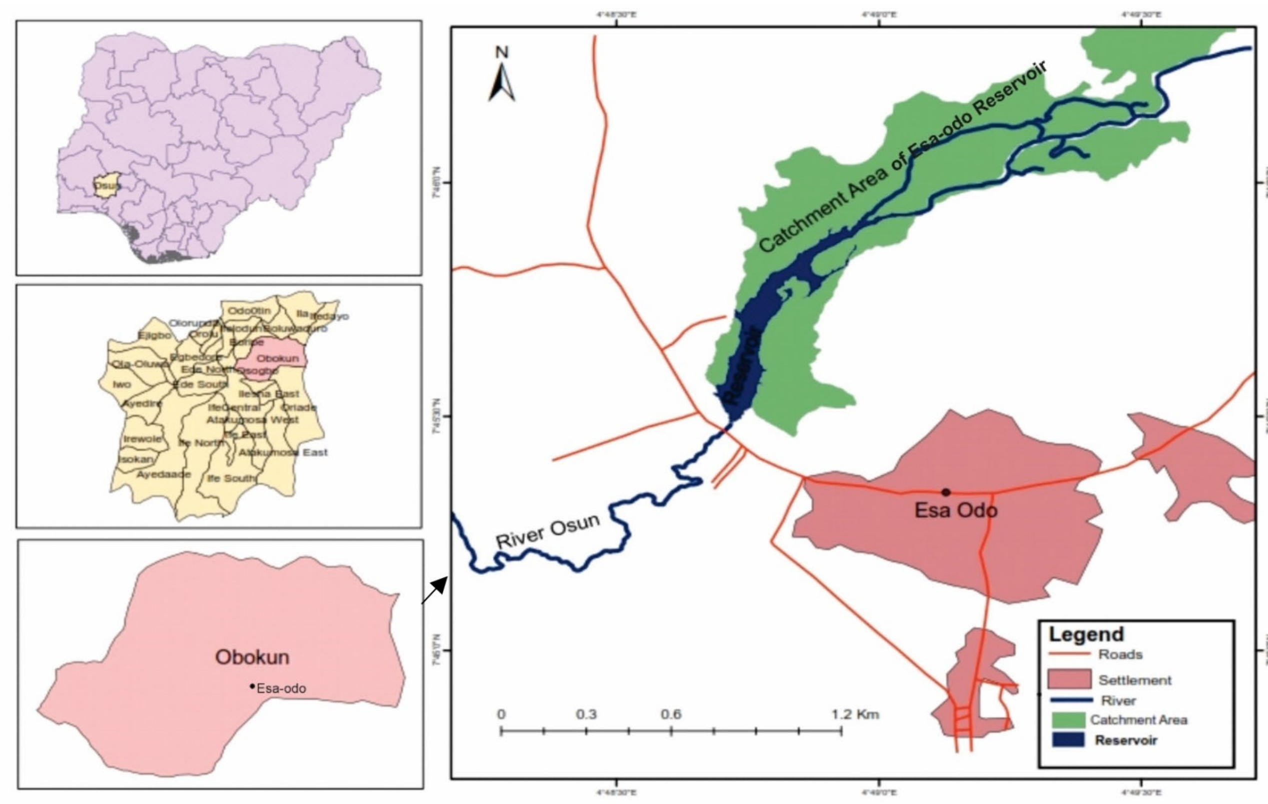

Fig. 1. Map of Esa-Odo reservoir. Software ArcGIS Desktop 10.8 http://my.esri.com.

Study area Esa-Odo	Esa-Odo
Location Coordinates	Latitude 007°45'0' N - 007°47'18' N
	Longitude 04°49'0' E - 04°50'12' E
Altitude	458 m asl
Reservoir surface area	50.2 hectares
Maximum depth	4.23 m
Minimum depth	1.54 m
Crest length	677 m
Crest height	11.3 m
Volume	<8.2 million m^3
Catchment area	120 km^2

Table 1. Morphometric Parameters of Esa-Odo reservoir.

Department of Zoology. They were then identified using standard keys[31], and processed on the same day of capture.

Catch per unit effort

The catch per unit effort of total fish sampled per month over the study period was determined using the number of fish individuals and the sampling efforts using the formula:[32]

$$\mathrm{CPUEn} = \frac{Cn}{E} * 100$$

Cn = Number of fish caught.
E = Sampling efforts (m^2 of net by hours of sampling)
In this study, sampling effort was 90 m^2 of net in 15 h[32].

$$\mathrm{CPUE_w} = \frac{Cw}{E} * 100$$

Cn = Weight of fish caught.

Statistical analysis

The Palaeontological Statistics PAST, version 3.22, was utilized for the multivariate analysis. Calculations such as mean values, percentages, and graph preparations were performed using MS Excel 2013. An independent T-test was conducted to assess the significant differences between the two seasons based on each parameter. Canonical correspondence analysis was employed to ascertain the influence of various environmental and climatic parameters on the abundance of fish species in the reservoir. The position of fish species on CCA indicates their preference for specific environmental or climatic parameters in the aquatic environment. Additionally, Pearson correlation coefficients were used to examine the relationships between water quality parameters, rainfall, and fish species abundance[33,34]. The statistical software package IBM SPSS 26.0 (SPSS, USA) (https://www.ibm.com/products/spss-statistics) was utilized to analyze fish species abundance by seasons. ANOVA was applied to determine significance, while tukey's test was employed to differentiate means, with significance set at a probability level of 0.05. GLMM was also used to assess how climatic and environmental variables affect the abundance of fish species in the reservoir.

Ethical approval

Animal ethics approval was not required for this current study since fish specimens were collected from resident fishermen.

Results

Climatic and environmental variables

Table 2 shows the seasonal changes in climatic and environmental parameters of the reservoir. The mean values of temperature, depth, TSS, TS, TOC, and rainfall were significantly higher during the rainy season compared to the dry season. Additionally, the results of an independent t-test indicated a significant difference ($p < 0.05$) between the mean values of temperature, transparency, and rainfall during the rainy and dry seasons. The time series variation of rainfall is illustrated in Suppl. 1, ranging from 0 mm to 537.89 mm, with annual rainfall fluctuating between 2409.96 mm and 2531.25 mm. The highest annual rainfall was recorded in 2017, while the lowest rainfall was observed in 2018.

Fish abundance and composition of the esa-Odo reservoir

The checklist of fish species from the Esa-Odo reservoir is shown in Suppl. 2. A total of 1043 fish samples comprising seventeen species and eleven families were caught during the sampling period (Suppl. 3). The study revealed that *O. niloticus* was the most abundant fish species, accounting for 21.9% of the total catch, followed closely by *C. zillii* (19.9%), *M. senegalensis* (18.7%), *C. gariepinus* (14.1%), *P. obscura* (11.7%), *C. kingslayae* (3.0%), *Schilbe uranoscopus* (2.6%), and *S. galilaeus* (2.2%). Other species included *H. odoe* (1.88%), *C. guntheri* (1.1%), *(A) macrolepitedus* (0.8%), *L. coubie* (0.8%), and *(B) longipinnis* (0.4%), while *H. longipinnis*, *M.* rume, and *P. senegalensis* each accounted for 0.1% (Suppl. 3). The mean total length and weight ranges of the fishes caught in the Esa-Odo reservoir are depicted in Fig. 2, with mean total lengths ranging from 9.2 cm (*Brycinus longipinnis*) to 25.5 cm (*Parachanna* obscura), and fish weights ranging between 15.3 g (*Brycinus longipinnis*) and 270 g (*Sarotherodon galilaeus*).

Also, the monthly distribution of the fish showed that the month of July 2018 and 2019 recorded the highest fish catch, while the lowest fish catch was observed in May 2018 (Suppl. 3). Statistically, there was a significant difference ($p < 0.05$) in the population of *P. obscura* and *C. zillii* in both rainy and dry seasons (Suppl. 4). Figure 3a showed the mean abundance of fish species in Esa-Odo reservoir. Also, the mean fish abundance (47 ± 16.2) was higher in female fish populations compared to the male fish populations (39 ± 11.6) with a significant difference ($p < 0.05$) between the two fish populations (Fig. 3b). Furthermore, the mean fish abundance (54 ± 17.2) was significantly higher during the rainy season compared to the dry season populations (31 ± 10.2) with a significant difference ($p < 0.05$) between the two seasons (Fig. 3c).

Parameters	Rainy season		Dry season		t	*p*
	Min – Max	Mean ± SE	Min – Max	Mean ± SE		
Temperature (̊C)	24.0–27.2	25.5 ± 0.28	25.7–26.5	26.1 ± 0.06	2.56	0.018*
Depth (m)	2.4–3.5	2.8 ± 0.08	2.5–3.10	2.6 ± 0.08	1.16	0.26
Transparency (m)	0.6–0.9	0.8 ± 0.03	0.8–1.2	1.0 ± 0.04	−5.08	0.00*
Chloride (mg/L)	4.5–11.4	7.7 ± 0.65	5.7–12.6	7.9 ± 0.66	−0.29	0.77
Total suspended solids (mg/L)	22.2–41.3	29.8 ± 1.39	24.2–31.2	28.2 ± 0.80	0.86	0.39
Total solids (mg/L)	95.7–126.5	110.0 ± 2.87	100.0–117.1	109.3 ± 1.49	0.19	0.39
Total organic carbon (mg/L)	2.5–7.8	5.0 ± 0.50	1.6–8.0	4.7 ± 0.77	0.42	0.68
Rainfall (mm)	26.4–490.4	284.8 ± 35.02	0.00–163.5	68.0 ± 20.45	4.80	0.00*

Table 2. Seasonal variation in climate and environmental parameters of the reservoir. *Significant ($p < 0.05$).

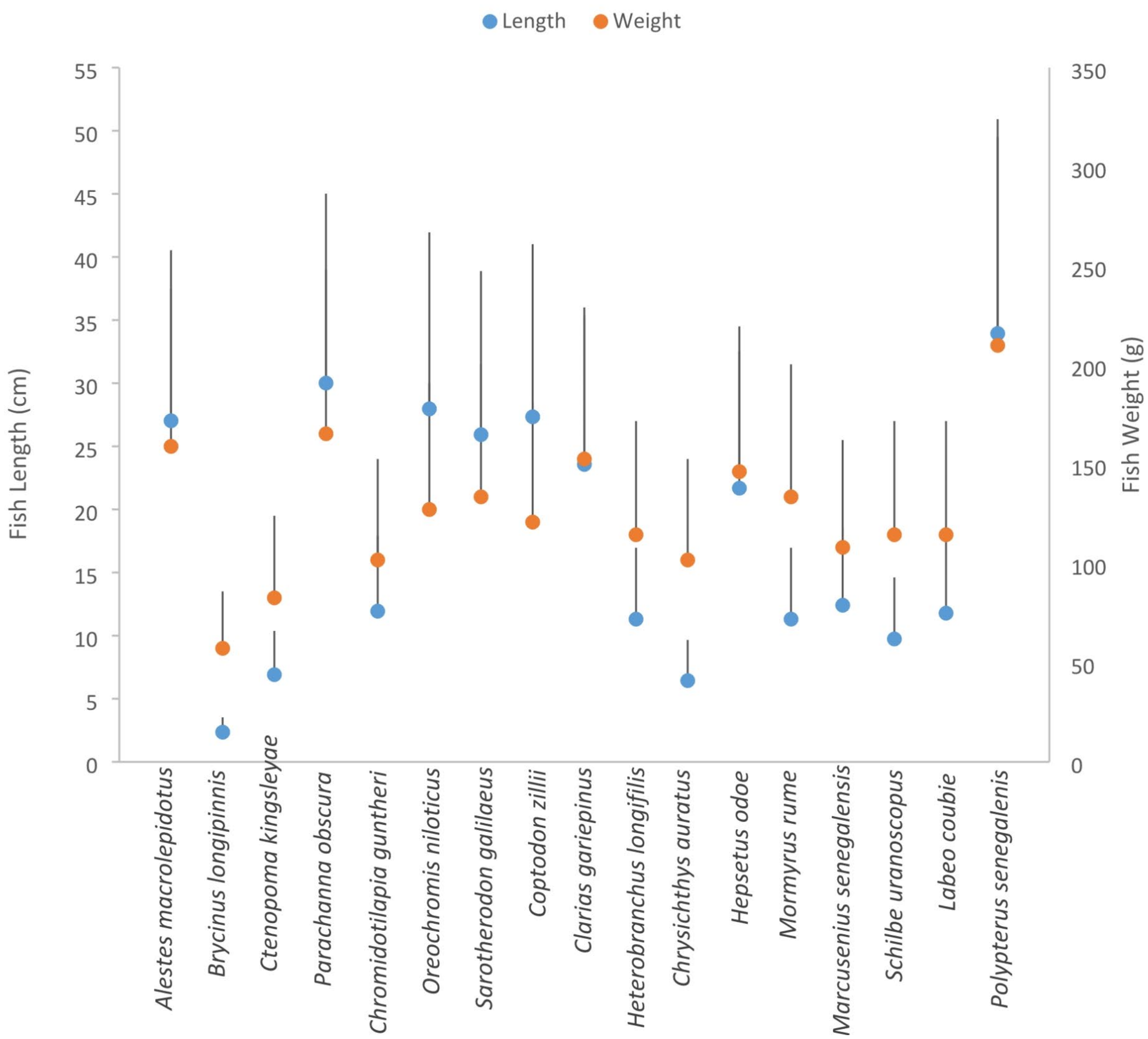

Fig. 2. Mean total length and weight of fish species caught in Esa-Odo Reservoir.

The results of individual rarefaction curves showed that *Oreochromis niloticus* had increased richness, Shannon exp, Simpson, and Shannon all year round. Other fish species that showed an increase in individual rarefactions are *Coptodon zillii*, *Parachanna obscura*, *Marcusenius* senegalensis, and *Clarias gariepinus* (Fig. 4). In summary, the reservoir experienced an abundance of *Oreochromis niloticus* throughout the sampling period.

Catch per unit effort (CPUE)

The results of Catch per unit effort in Esa-Odo reservoir showed that there was a gradual increase in the CPUEn during the 1st annual cycle from the early dry season (October 2017 – December 2017) and reaching its peak in the late rainy season (July 2018 – September 2018). A similar pattern was also observed in the 2nd annual cycle with the early dry season showing an increase in catch abundance, with the highest catch effort recorded in July 2019 – September 2019 (Late rainy season) (Fig. 5). Of the most dominant fish species in the reservoir, only *C. zillii* had the highest CPUEn in July 2016, while other fish species such as *M. senegalensis* had its CPUEn peak in September 2018, and *O. niloticus* in July 2019. During the sampling period, CPUEw was maximum in September 2019, while the least was recorded in December 2018. Additionally, CPUEw showed significantly higher variation when compared with CPUEn.

Trend analysis in temperature, rainfall and fish species

The graph of the monthly temperature, rainfall, and fish species is as shown in Fig. 6A-E. It was observed that July 2018 recorded the key period of fish abundance in relation to the rainfall and temperature, while the month of December 2017 and 2017 recorded the least abundance of fish. The mean temperature and rainfall for each month exhibited significant changes in transparency, TOC, and *Oreochromis niloticus* at $p < 0.05$. Rainfall increased significantly, as shown by the value of Sen's slope estimator in Table 3. Additionally, rainfall, depth, TSS, TS, TOC, *Oreochromis* niloticus Catch, *Coptodon zillii* Catch, *Clarias gariepinus* Catch, and *Marcusenius*

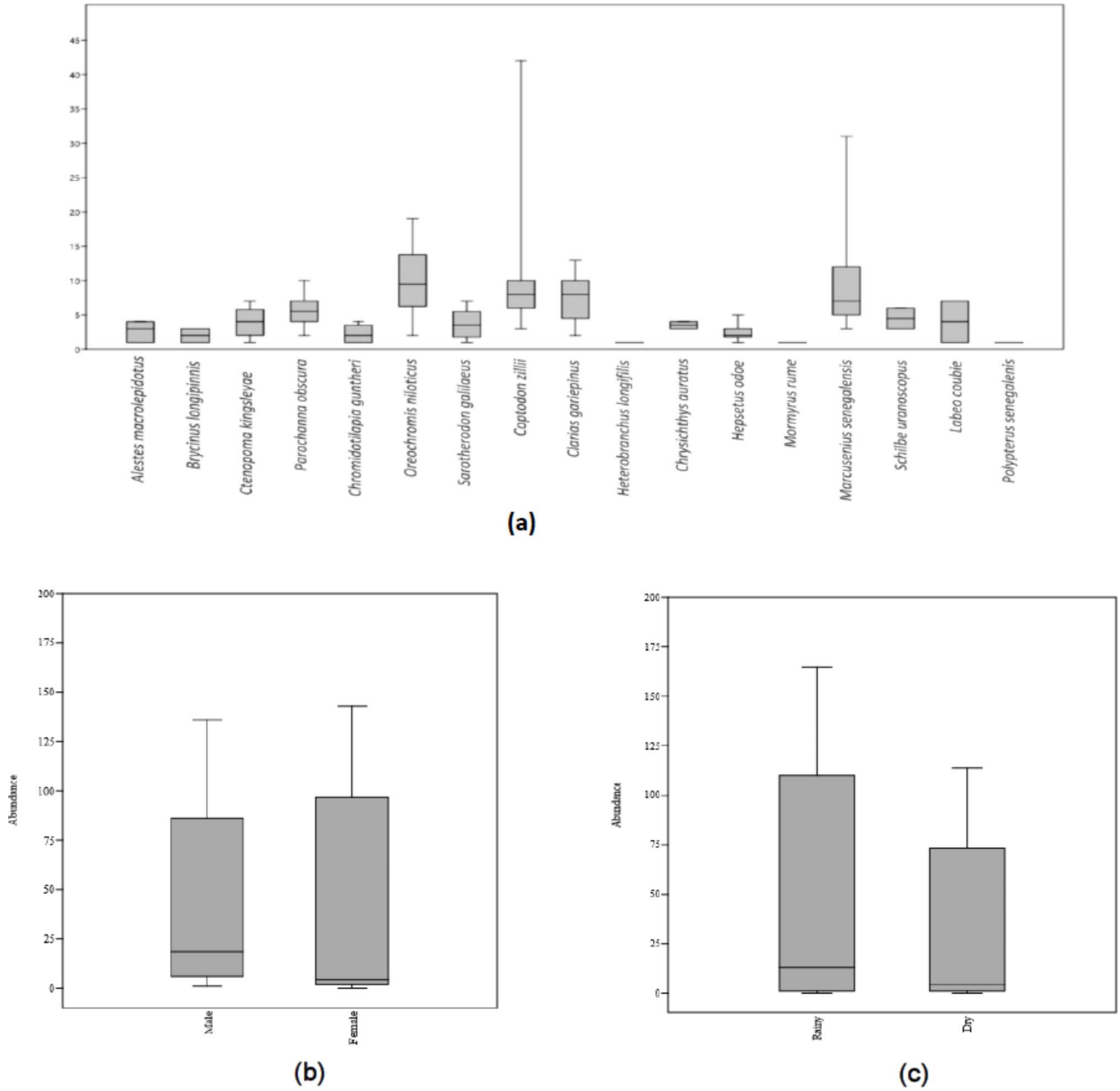

Fig. 3. (**a**) Mean Fish Abundance (± SE) of Esa-Odo Reservoir. (**b**) Mean Fish Abundance (± SE) of Esa-Odo Reservoir based on Sex. (**c**) Mean Fish Abundance (± SE) of Esa-Odo Reservoir based on Season.

senegalensis Catch showed positive trends, while temperature, transparency, chloride, and *Parachanna* obscura Catch exhibited negative trends during the sampling period. The climatic factor (rainfall) that increases reservoir depth decreases the level of transparency, resulting in a reduction in temperature, as shown by the value of Sen's slope (-38). These factors also contributed to the increase in fish species catch, except for *P.* obscura, as revealed by the values of Sen's slope.

Correlates between fish abundance, climatic and environmental variables
Principal components and canonical correspondence analyses
Canonical Correspondence Analysis, a direct statistical technique used to determine patterns in aquatic species data described by environmental variables (Alvarez et al. 2017; Palanivel et al., 2019), was employed in this study. Eight climatic and environmental parameters, including temperature, depth, transparency, chloride, TSS, TS, TOC, and rainfall, were selected for the CCA analysis. A CCA graph (see Fig. 7) was generated to explore the relationship between these environmental parameters and fish species in the reservoir. The eigenvalue for axis 1 was 0.06, while for axis 2, it was 0.02. The vector length indicated positive correlations for transparency, chloride,

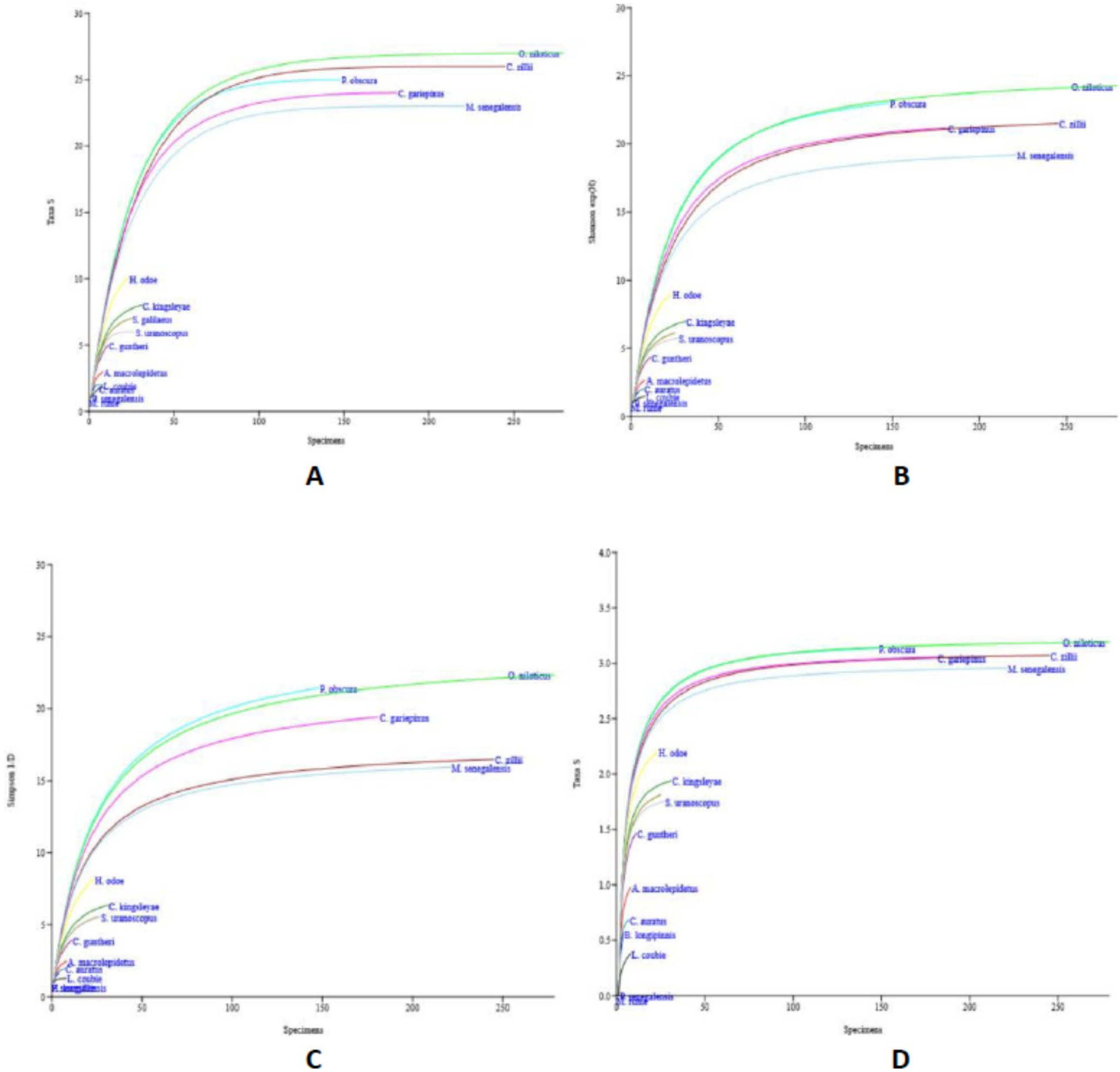

Fig. 4. Rarefaction Curves for Fish Species in Esa-Odo Reservoir. (**A**) Richness (S), (**B**) Shannon exp (H), (**C**) Simpson 1/D, (**D**) Shannon.

rainfall, and TSS, while TS and depth showed negative correlations. This suggests that water quality parameters play a significant role in influencing the overall abundance of fish species.

Axis 1 indicated that *Parachanna obscura* exhibited a positive correlation with transparency, chloride, rainfall, and TSS, while axis 2 showed that *Marcusenius senegalensis* had a negative correlation with TS and depth. The water quality parameters displayed significant interactions concerning the abundance of fish species in the habitat. The relationship between TOC and temperature was linked to the abundance of *C. zillii* in comparison to *C. gariepinus*. The PCA loadings of the climate and environmental parameters of the reservoir revealed that PC1 and PC2 had the most substantial contributions, with temperature, rainfall, depth, transparency, and TOC influencing the abundance of fish species in the waterbody (Table 4).

Correlation matrix and general linear mixed model

Table 5 presents the relationship between fish species catch and climatic and environmental variables as per the correlation analysis. A highly significant ($p \leq 0.01$) relationship was observed between rainfall and TSS (0.585), TOC (0.909), and the catch of *Parachanna obscura* (0.836). Additionally, temperature exhibited a very highly significant relationship with chloride (0.959), the catch of *Oreochromis niloticus* (0.990), the catch of *Parachanna obscura* (0.904), and the catch of *Marcusenius senegalensis* (0.971). Similarly, depth demonstrated a highly significant relationship with TS (0.635), the catch of *Coptodon zillii* (0.894), the catch of *Clarias gariepinus*

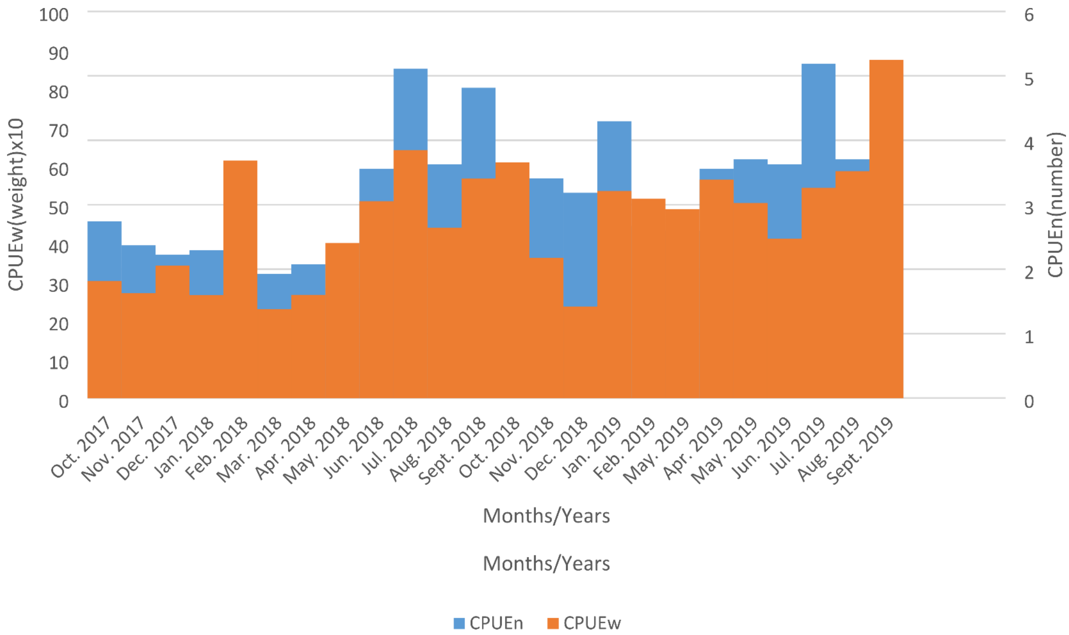

Fig. 5. Catch per unit effort (CPUE) in number and weight of fishes caught in Esa-Odo reservoir.

(0.625), and the catch of *Parachanna obscura* (0.673). Furthermore, transparency showed a highly significant relationship with TSS (0.642) and TS (0.577). Chloride exhibited a positive significant relationship between TOC (0.718) and the catch of *Parachanna obscura* (0.723). The findings also revealed that TSS had a highly significant relationship with TOC (0.718), the catch of *Clarias gariepinus* (0.870), and the catch of *Marcusenius senegalensis* (0.816), while TS showed a positive correlation with TOC (0.686). Moreover, TOC displayed a positive relationship with the catch of *Oreochromis niloticus* (0.630), the catch of *Clarias gariepinus* (0.741), the catch of *Parachanna obscura* (0.583), and the catch of Marcusenius senegalensis (0.581).

The GLMM results for the impact of rainfall on environmental variables and fish species indicated significant effects on transparency, chloride, temperature, and *Clarias* gariepinus, as presented in Table 6. Additionally, temperature was significantly influenced by transparency, total solids, rainfall, *Coptodon zillii*, *Clarias gariepinus*, and *marcusenius senegalensis*, as shown in Table 7.

Discussion
Water quality
In this study, we investigated the influence of climatic and environmental factors on the fish abundance of an afro-tropical reservoir. Our study addresses the potential impacts of rainfall and water quality parameters on fish species abundance in a lentic ecosystem. Continuous monitoring of water quality parameters is crucial to assess water quality, as changes in climatic and environmental factors can affect the distribution, abundance, and composition of aquatic animals, particularly fishes[35–37]. Our findings indicate that the environmental parameters of the reservoir are comparable to other tropical regions. During the dry season, the temperature was higher compared to the wet season, with a significant difference ($p < 0.05$) between the two seasons. Changes in atmospheric temperature are influenced by seasonal variations and play a vital role in determining waterbody gas activities[38–40]. The temperatures recorded in our study support fish growth by providing a suitable habitat[41,42]. The rainy season experienced a higher volume of rainfall, impacting the reservoir's depth, a common feature in afro-tropical regions. Additionally, variations in reservoir transparency were noted. Rainfall in the study area exhibited a fluctuating pattern, with the highest mean rainfall in 2017 (2695 mm), slightly lower in 2018 (2407 mm), and an increase in 2019 (2531 mm). Recent global phenomena may have influenced rainfall amounts in the tropics, with many researchers attributing it to climate change[43–45].

The mean value of Chloride in this study was higher than the reports of[46] in Agodi reservoir; however, it was lower than the values recorded by[47] in Eleyele reservoir. Additionally, the mean chloride value of the reservoir indicated good water quality and is adequate for the survival of the fish. Total Suspended Solids in the reservoir ranged between 20.00 mg/L and 46.00 mg/L. The mean values recorded in both the rainy (29.76 ± 6.33) and dry (28.02 ± 3.95) seasons are less than[48] standard for drinking water. These values were also lower than the value recorded by[49] in Iju River, with a mean value of 240.00 mg/L. The Total Solids values of 93.15 mg/L to 131.20 mg/L recorded during this study are higher than the values reported by[50] in Opa reservoir, who reported a mean total solids value of 190.00 mg/L. The mean values recorded in the rainy season were slightly higher than the dry season, possibly due to the movement of organic and inorganic materials during the rainy season. Total Organic Carbon values ranging from 0.17 mg/L to 10.70 mg/L, with an overall mean of 4.87 ± 2.25 mg/L, were observed in Esa-Odo reservoir during this study. This value was lower than the mean TSS value of 31.54 mg/L recorded upstream and the 12.55 mg/L of TSS reported downstream in the Inland Reservoir in South China.

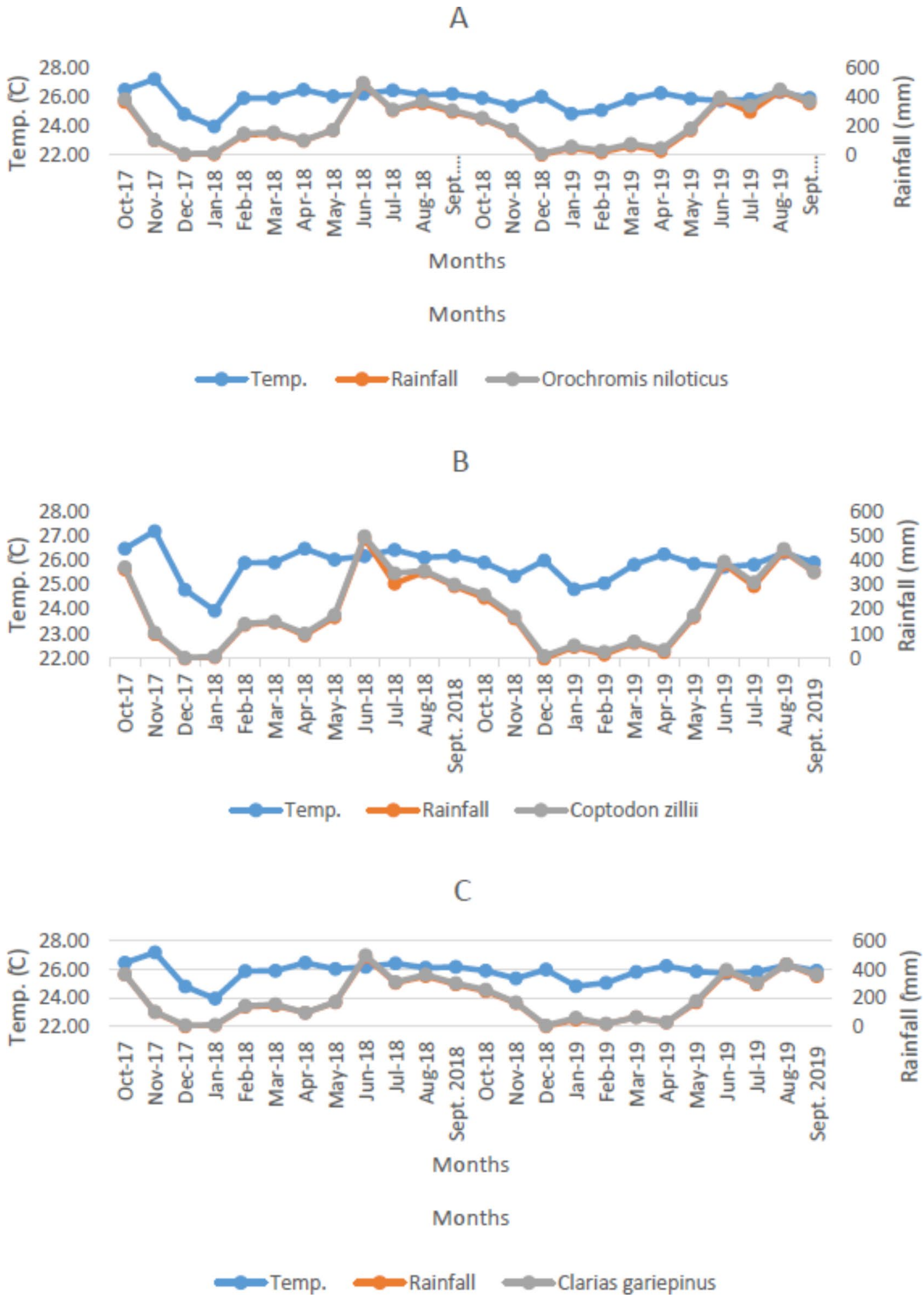

Fig. 6. (**A**–**E**) Distribution Pattern in Temperature, Rainfall and Fish Species Catch in Esa-Odo Reservoir. (**A**) *Oreochromis niloticus*, (**B**) *Coptodon zillii*, (**C**) *Clarias gariepinus*, (**D**) *Parachanna obscura*, (**E**) *Marcusenius senegalensis*.

Fish abundance and composition

In this study, the abundance of fish collected from Esa-Odo reservoir is relatively high when compared with other water bodies. The fish in the reservoir consist of seventeen species and eleven families, aligning with similar records from other inland water bodies. This finding is consistent with Erinle reservoir, which documented nineteen species from ten families[51], and Osinmo reservoir, which reported fourteen species from

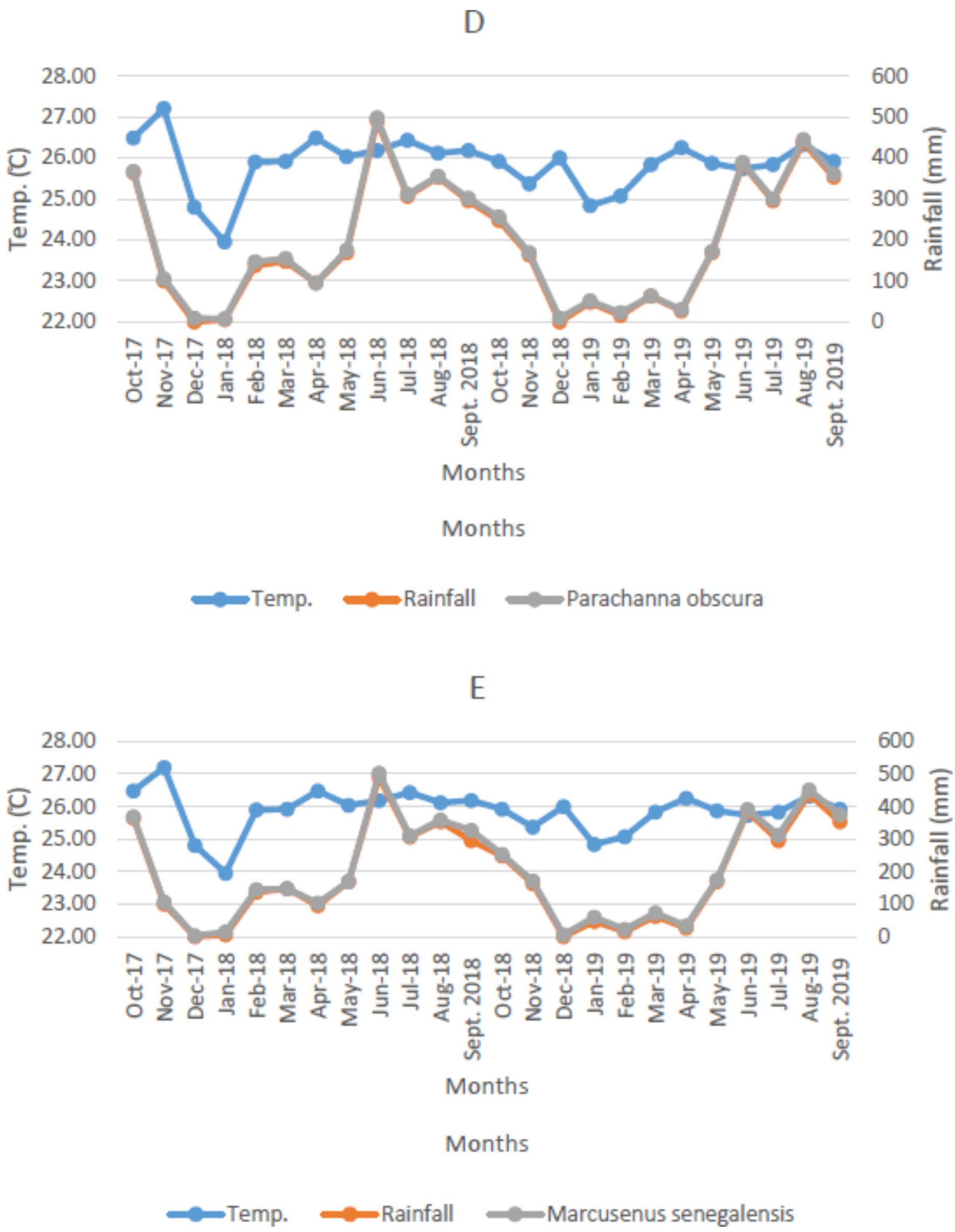

Figure 6. (continued)

eight families[52,53]. noted seventeen species from ten families, while Owalla reservoir documented eighteen fish species. It can be inferred that habitat characteristics and ecological interactions may play a significant role in the number of fish species in this study compared to other water bodies. The reservoir exhibited a high abundance of fish samples compared to other afro-tropical reservoirs, with a total of 1221 fishes collected over two annual cycles. Similar observations were made by[54] in Jebba Hydroelectric Power Dam, Jebba. The abundance of fishes in the reservoir could be attributed to the high plasticity of the fish in the water body[55–57]. In this study, we observed fluctuations in the monthly abundance of fish, likely influenced by environmental factors of the reservoir.

Mann-Kendal	*p*-value	Sen's slope
Rainfall	0.263	46
Temperature	0.358	−38
Depth	0.691	17
Transparency	0.006*	−122
Chloride	0.784	−12
Total suspended solids	0.487	29
Total solids	0.823	10
Total organic carbon	0.006*	111
Oreochromis niloticus Catch	0.010*	104
Coptodon zillii Catch	0.094	68
Clarias gariepinus Catch	0.306	42
Parachanna obscura Catch	0.900	-6
Marcusenius senegalensis Catch	0.018*	96

Table 3. Mann-Kendal trend analysis for fish species catch, climate and environmental parameters of the reservoir. *Significant ($p < 0.05$).

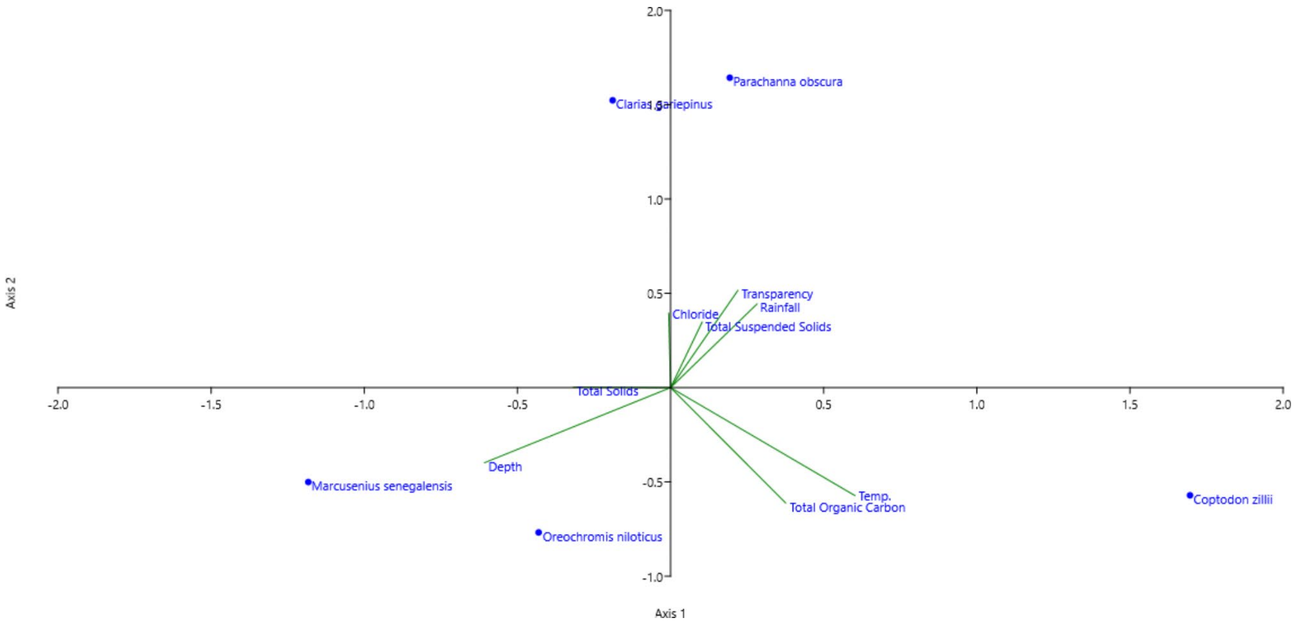

Fig. 7. Canonical Correspondence Analysis of the Fish Species Abundance, Environmental and Climatic Variable.

Parameters	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8
Temperature	0.5948	0.1463	0.0838	−0.1686	−0.0315	0.064	0.1371	0.752
Rainfall	0.9999	−0.0098	0.012	−0.0012	−0.0039	−0.0022	0.0004	−0.0003
Depth	0.3894	−0.1535	−0.473	−0.4421	0.2072	0.5477	−0.2505	0.0003
Transparency	0.3965	0.2301	−0.3513	0.4858	0.6521	0.0547	0.0464	0.0024
Chloride	−0.1231	-0.1448	0.9688	−0.0877	0.1308	−0.0133	−0.0169	−0.0003
Total Suspended Solids	−0.0597	0.0747	0.6659	0.6194	−0.3265	0.2027	−0.1268	0.0044
Total Solids	−0.0179	0.0014	0.5322	−0.0748	−0.1631	0.5564	0.6119	−0.0165
Total Organic Carbon	0.0411	0.9978	0.0475	−0.0204	−0.0019	0.0011	−0.0028	−0.0004

Table 4. Principal components loadings of the climate and environmental parameters of the Reservoir.

	Rainfall	Temp.	Depth	Transp.	Chloride	TSS	TS	TOC	Oreochromis niloticus Catch	Coptodon zillii Catch	Clarias gariepinus Catch	Parachanna Obscura Catch	Marcusenius Senegalensis Catch
Rainfall	1												
Temp.	0.033	1											
Depth	0.032	0.283	1										
Transp.	0.001	0.027	0.195	1									
Chloride	0.494*	0.959***	0.052	0.145	1								
TSS	0.586**	0.835**	0.009	0.642**	0.013	1							
TS	0.239	0.447	0.635**	0.577**	0.017	0.038	1						
TOC	0.909**	0.771**	0.337	0.025	0.718**	0.686**	0.916**	1					
Oreochromis niloticus Catch	0.400	0.990***	0.094	0.089	0.135	0.207	0.332	0.630**	1				
Coptodon zillii Catch	0.332	0.291	0.894**	0.313	0.141	0.412	0.052	0.078	0.824**	1			
Clarias gariepinus Catch	0.144	0.212	0.625**	0.243	0.182	0.870**	0.416	0.741**	0.758**	0.925***	1		
Parachanna obscura Catch	0.836**	0.904***	0.673**	0.999***	0.723**	0.443	0.316	0.583**	0.564**	0.945***	0.274	1	
Marcusenius senegalensis Catch	0.143	0.971***	0.054	0.047	0.197	0.816**	0.978***	0.581**	0.073	0.482*	0.566**	0.895**	1

Table 5. Correlation Matrix table showing relationship between Fish species catch, climatic and Environmental Variables. *Transp.* Transparency, *TSS* Total Suspended Solids, *TS* Total Solids, *TOC* Total Organic Carbon, *Temp.* Temperature. ***Very highly significant ($p \leq 0.001$). **Highly significant ($p \leq 0.01$). *Significant ($p \leq 0.05$).

	Value	SE	Z	p
Residual effect				
Variance	0.273	0.045	5.996	0.000
Fixed effect				
Intercept	−25.833	5.418	−4.768	0.000
Depth	0.326	0.214	1.522	0.134
Transparency	−1.249	0.624	−2.002	**0.051**
CL	0.064	0.031	2.056	**0.045**
TSS	0.012	0.011	0.994	0.325
TS	−0.009	0.008	−1.190	0.240
TOC	−0.039	0.038	−1.011	0.317
Temperature	1.168	0.219	5.336	**0.000**
Oreochromis niloticus	0.003	0.006	0.479	0.634
Coptodon zillii	0.007	0.008	0.827	0.412
Clarias gariepinus	0.119	0.020	6.068	**0.000**
Parachanna obscura	0.021	0.022	0.951	0.346
Marcusenus senegalensis	0.006	0.009	0.700	0.487

Table 6. General Linear Mixed Modelling for Climatic Factor (rainfall) influence on environmental variables and fish abundance. Numbers in Bold are Significant at $p<0.05$.

	Value	SE	Z	p
Residual effect				
Variance	0.273	0.045	5.996	0.000
Fixed effect				
Intercept	3.166	0.0410	77.134	0.000
Depth	0.003	0.0055	0.600	0.551
Transparency	−0.042	0.0123	−3.390	**0.001**
CL	0.000	0.0009	−0.518	0.607
TSS	0.000	0.0005	−0.305	0.762
TS	0.001	0.0003	3.944	**0.000**
TOC	0.000	0.0010	0.037	0.971
Rainfall	0.000	−0.000	6.271	**0.000**
Oreochromis niloticus	−0.000	0.0002	−0.438	0.663
Coptodon zillii	0.001	0.0002	3.071	**0.003**
Clarias gariepinus	−0.004	0.0007	−5.083	**0.000**
Parachanna obscura	0.002	0.0008	1.921	0.060
Marcusenus senegalensis	−0.001	0.0002	−2.772	**0.008**

Table 7. General Linear Mixed Modelling for Climatic Factor (temperature) influence on environmental variables and fish abundance. Numbers in Bold are Significant at $p<0.05$.

The Cichlidae family in this study recorded the highest numerical percentage of fish captured in the reservoir at 45.87%. The high numerical percentage of the cichlids could be attributed to their fecund ability and good parental care in the reservoir[58–60]. This study aligns with previous findings[61] in Opa reservoir[51], in Erinle reservoir, and[62] in Asejire dam, representing the lower course of the Osun River. Various studies have shown that freshwater bodies in Nigeria and afro-tropical inland water bodies are dominated by Cichlids[63–66]. This dominance was evident in the fish species caught during both rainy and dry seasons. In this study, *O. niloticus* was the most abundant species, comprising 22.9% of the population, followed closely by *C. zillii* (20%). Tilapine species have thrived in most afro-tropical reservoirs due to their high fecundity, enabling them to colonize these water bodies[67,68]. O. niloticus, in particular, is known for its highly invasive behavior, adaptability to various niches, rapid growth rate, and impressive reproductive capacity[69–71]. These fish species, valued for their commercial importance, are targeted by resident fishermen in the study area.

In this study, the fish population consists of several fish species such as *Chromidotilapia guntheri*, *Oreochromis niloticus*, *Sarotherodon* galilaeus, and *Coptodon zillii*. Others include *Alestes macrolepidotus*, *Brycinus* longipinnis, clarias gariepinus, Heterobranchus longifilis, Mormyrus rume, and *Marcusenius senegalensis*. Additionally, *Ctenopoma kingsleyae*, *Parachanna obscura*, *Chrysichthys auratus*, *Hepsetus odoe*, *Schilbe uranoscopus*, *Labeo* coubie, and *Polypterus senegalensis* were caught during the sampling period. The fish species encountered in our study were similar to observations made by authors who worked on checklists of fish species in afro-tropical reservoirs[69,72–74]. The similarity in geographical location, habitat characteristics, and human activities such as land use could have been the major reasons for the similar fish community checklists.

There was an abundance of *M. senegalensis* in the reservoir, especially during the flooding months of September 2018 and 2019. The high abundance of *M. senegalensis* during the flooding period could be attributed to this fish species being flooded from the tributaries into the reservoir, potentially boosting the population and impacting the ecosystem[75–77]. Additionally, there is a high abundance of *P. obscura* and *C. gariepinus* in the reservoir. The muddy nature of the reservoir may have supported the abundance of these benthic fish species, known for feeding on smaller fishes in the water body[78–80]. A significant number of predatory fish species like *S. uranoscopus*, *H.* odoe, and *C. auratus* indicate a suitable environment for these species. Predatory fishes are known to play crucial roles in fish communities and ecosystem functioning[81,82]. The morphometric parameters, such as length and weight of the fishes, varied among different fish species. Similar observations in these morphometric measurements were reported by[10] in Tugwi-Mukosi Reservoir. Differences in these morphometric parameters could be influenced by the environmental conditions of the various reservoirs.

Correlates of climatic and environmental parameters on fish abundance

Pattern in temperature, rainfall, and fish species catch in Esa-Odo reservoir showed that different fish species were influenced by the investigated water quality parameters. This study indicated that temperature increases have an influence on the abundance of *O. niloticus*, *P. obscura*, and M. senegalensis in the reservoir. It has been predicted that warming of the aquatic environment, based on the temperature-size rule, could increase fish growth rates leading to an abundance of fish in the aquatic ecosystem[83,84]. Moreover, rainfall had a positive correlation with *P.* obscura, while depth had a similar correlation with *Coptodon zillii* catch, *Clarias gariepinus* catch, and *Parachanna obscura* catch. With the depth of the reservoir ranging from 2.4 to 3.1 m, this shows that the fish species expanded their depth ranges over time and increased in abundance[85,86]. Also, floods resulting from intense rainfall and allochthonous materials might have led to an increase in the population of *P. obscura* in the reservoir.

Chloride also showed a positive correlation with transparency, while TSS, TS, and TOC exhibited a positive correlation with *M. senegalensis.* Water quality parameters play a significant role in influencing the growth, survival, and reproduction of fishes in water bodies, thereby contributing to the abundance of different fish species[36,87,88]. The behavioral effects of TSS conditions on the predators of M. senegalensis could have influenced the abundance of the fish, given the positive correlation between TSS and *M. senegalensis*[89–91]. Additionally, the range of TSS values in the reservoir during the sampling period was within the recommended limits for the survival of the fish[92,93]. However, the positive correlation between TSS and *C. gariepinus* could be due to the tolerant and microhabitat nature of the fish that favored the biological functioning of the benthic fish[94–97]. The abundance of *M. senegalensis* and *C. gariepinus* with TSS was also associated with the rainy period in the study area as demonstrated by the rainfall pattern.

Evidence from this study also showed that environmental variables affect the abundance of different fish species, especially their high affinity to rainfall and temperature. Other environmental parameters also influence fish species abundance either negatively or positively based on the CCA analysis. Rainfall has been observed to increase the reservoir volume, thereby impacting the abundance of fish species[98–100]. The study also provided insights into the role of climatic and environmental variables in explaining fish abundance in the reservoir. This further highlights that rainfall and temperature are good predictors of seasonal changes in the aquatic environment. The association between climatic, environmental factors, and fish abundance could be a result of seasonal changes in allochthonous materials (food items) and habitat preferences of the fish.

Conclusion and future of Esa-Odo reservoir

The information recorded in this study is essential for the management of the fisheries resources of the Esa-Odo reservoir. This study has provided the first record of the fish community in an afro-tropical reservoir post-impoundment. The findings indicate a diverse range of fish species in the reservoir, with climatic and environmental variables supporting their growth and development. Further research is needed to assess the fish community in the small rivers and streams that flow into the reservoir. It is crucial for stakeholders, particularly the government, to document the fish community of rivers before impoundment. Additionally, we recommend conducting continuous surveys of the fish community to monitor any changes in the fish population.

Data availability

All data generated during this study are included in this published article (and its supplementary information files).

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Obayemi, O.E.: designed the study, wrote the manuscript, collected fish samples and analysed the dataKomolafe, O.O.: designed the study and read the manuscriptAyodeji, O.A.: collected fish samples, analysed the dataAjayi, O.: read the manuscript and analysed the dataAdewumi, P.O.: collected fish samplesAdeniran, I.I.: collected fish samplesOlalekan, K.O.: read the manuscript and analysed the dataOladimeji, T.K.: read the manuscript and analysed the data.

Declarations

Competing interests
The authors declare no competing interests.

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