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Implication of Climate Variability on the Depletion of Fish Reserves in Coastal Waters of Southwestern Nigeria

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Abstract

This study examines rainfall and temperature trends from 1974 to 2021 across Lagos, Ogun, and Ondo states in Southwest Nigeria, analyzing their implications on fish reserves. The region, characterized by a humid tropical climate with distinct wet and dry seasons, experienced a long-term increase in rainfall at 3.69 mm/year and a mean annual temperature rise of 0.28°C per decade. Long-term climatic data (1974 and 2021) from NIMET for Lagos Island, Ijebu-Ode, and Ondo synoptic stations reveal significant variability in climatic patterns, including four distinct rainfall periods and oscillating temperature trends. Based on the established meteorological and fisheries data and using time series analysis, climate variability impacts aquatic ecosystems affecting fish habitats through altered salinity, flooding-induced eutrophication, and habitat shrinkage during dry spells. The findings underscore the critical need for adaptive management strategies, including wetland restoration, pollution control, and sustainable fishing practices, to mitigate these effects. Drawing from global examples like the Mekong Delta and the Great Barrier Reef, the study highlights the urgent need for integrated climate resilience measures.

Keywords: ***climate variability, fish reserves, rainfall, temperature, southwest Nigeria***

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Introduction

The Lagos, Ogun, and Ondo areas of southwestern Nigeria, in particular, are especially susceptible to climate change and vulnerability, which can result in extreme weather patterns including heat waves and intense rains (Abatan *et al.,* 2018). Strong inter-annual and inter-seasonal variations, such as those caused by the North Atlantic Oscillation, Southern Oscillation Index, and Atlantic Multi-decadal Oscillation, are key characteristics of this region's climate. The management of water resources, forestry resources, agriculture, and natural ecosystems are major parts of the environments that might suffer greatly from these (IPCC, 2014; Ogbuabor and Egwuchukwu, 2017; Ogunjo *et al.,* 2020). Additionally, it has major physiological effects, which is why researchers (e.g. Marine biologists, environmental scientists), policymakers (e.g. Government agencies, international bodies), and the general public (e.g. fishermen, coastal communities, seafood industries) are interested in its study.

Climate variability and climate change are sometimes used interchangeably. Climate change, in general, refers to the climate's intrinsic dynamic character over a variety of time intervals of at least 30years, including daily, monthly, seasonal, yearly, decadal, periodic, quasi-periodic, and non-periodic time scales (Odjugo, 2010). Climate variability is a word used frequently to describe changes brought on by natural processes. Plate tectonics, volcanic eruption, solar variability, and the El Nino Southern Oscillation (ENSO) are a few examples of these natural processes. On the other hand, climate change is frequently used to refer to changes in the climate brought on by humans (Amadi and Udo, 2015; Shafique *et al.,* 2024).

Large variations over the previous several decades have been shown through historical analysis of changes in temperature and rainfall (Iqbal *et al.,* 2019; Alamgir *et al.,* 2019). According to studies (Shiru *et al.,* 2020b; Sa'adi *et al.,* 2020), climate threats will either continue or intensify in the future. The earth's surface temperature increased by 0.8°C on average in the first decade of the twenty-first century compared to the twentieth, with the warming becoming more evident in the last three decades (Herrig and Lindsey, 2022). According to research, Nigeria's temperature and rainfall have changed significantly since the 1980s (Federal Government of Nigeria, 2014), and these changes are expected to continue in the near future (Akande *et al.,* 2017; Ayeni and Oloukoi, 2022).

Even while these effects are felt everywhere, they are more pronounced in tropical areas, notably in Africa, where the global readiness to build resilience is quite low (Williams *et al.,* 2018). (ND-GAIN, 2021). With an estimated 6% of its geographical area subject to extreme weather occurrences, Nigeria is one of the top ten nations most vulnerable to the effects of climate change (World Bank, 2019). Although, vegetation is now struggling with variations in the sequence of rainfall, which have a detrimental effect on the water supply and wetlands in the area, even though the southwest region of Nigeria is mostly recognized for its heavy rainfall (Okon *et al.,* 2021). These could cause habitat flooding and eutrophication, while rising temperatures would induce oxygen depletion and thermal stress, reducing fish reserves.

There is a wealth of literature indicating that land use and land cover change (Fourcade *et al.,* 2019) and sea level rise (Varela *et al.,* 2019) will provide serious long-term issues, particularly in the coastal regions of Nigeria. These issues include but not limited to coastal erosion, habitat loss, saltwater intrusion, and flooding, threatening ecosystems and communities. The study's goal is to ascertain the frequency of rainfall and temperature intensity in the tropical regions of Lagos, Ondo, and Ogun. Rainfall and average temperature climate parameters, their' yearly trend and outliers were identified. For improved management of coastal water and fisheries operations in the Lagos, Ogun, and Ondo regions, it is important to understand the uncertainties linked to rainfall and temperature trends (Panda and Sahu, 2019). It is also vital in the development of appropriate mitigation and adaptation measures for the reduction of risk of damages and habitat loss and degradation in the area (Shiru *et al.*, 2020a).

Methodology

Study area

Lagos, Ogun and Ondo states alongside Ekiti and Osun states are states in the southwestern region of Nigeria. Lagos, Ogun and Ondo states were selected for their coastal fisheries activities. These states located between Latitude 6.35^{o} to 8.617^{o}North and Longitude 2.52^{o} to 6.11^{o}East of the Greenwich Meridian. Kogi and Kwara States, Edo and Delta States, the Gulf of Guinea, and the Republic of Benin form its northern, eastern, southern, southern, and western borders, respectively (Fasona *et al.,* 2020). According to Ayeni and Oloukoi (2022), the two primary seasons in the region—the rainy season (April to October) and the dry season (November to March)—are heralded by the southwesterly monsoon wind, which transports moisture from the Atlantic Ocean, and the north-easterly dry wind from the Sahara Desert. The area has year-round average temperatures of 27°C and double maximum annual rainfall of about 2000 mm (Fasona *et al.*, 2019). The southwest marshy forest of the coastal region surrounding Lagos, the coastal region of the states of Ogun and Ondo, the lowland and highland rainforest sections toward the northeastern area, and the Savannah Forest of the upper Oyo area are the dominant ecosystems in the region (Agboola et al., 2021). These ecosystems support diverse fish habitats, influencing spawning, nutrient availability, and water quality, enhancing or limiting fish abundance regionally.

Data source and analysis

The observed rainfall (mm) and average temperature (^{o}C) from 1974-2021 were sourced from the archive of the Nigerian Meteorological Services (NIMET) for Ijebu-Ode, Ondo and Lagos Island synoptic stations. The choice of 46 years is adopted to ensure consistency across stations since some stations do not have data before 1974 (Fasona *et al.*, 2013).

The monthly mean, annual mean and anomaly of the rainfall and average temperature for each station were computed using from monthly rainfall and average temperature using equations 1 & 2:

$$A_R = \frac{1}{12}\sum_{i=1}^{12} Ri \quad \text{..........} 1$$

$$A_T = \frac{1}{12}\sum_{i=1}^{12} Ti \quad \text{..........} 2$$

Where

R= monthly rainfall amount

T= monthly temperature amount

A_R = annual rainfall

A_T = annual temperature

i= months of the year

The mean monthly rainfall and average temperature and rainfall for the study were computed using equations 3 & 4:

$$RX = \frac{\sum_{j=1}^{45} R_j}{46} \quad \text{..........} 3$$

$$TX = \frac{\sum_{j=1}^{45} T_j}{46} \quad \text{..........} 4$$

Where:

RX and TX = mean monthly rainfall and average temperature

j= period of years (46)

The standardized values were calculated for all the years from the use of long-term mean, yearly mean and standardized deviation using equation 5:

$$SD = \frac{X-\Delta}{\sigma} \quad \text{..........} 5$$

Where:

SD = Standardized departure

X = actual value of each parameter

Δ = long-term mean

σ = Standard Deviation

(Equations 1 – 5 are adopted and modified from Akinsanola and Ogunjobi, 2014)

Fisheries data:

The qualitative data on status of fish stock were collected from both Fisheries statistics report of FAO and Nigeria Bureau of Statistics, and community engagement through verbal communication and questionnaire administration.

Results and Discussion

The annual long-term trend in rainfall

The long-term trend in mean annual rainfall from 1974 to 2021 (Figure 1) shows an increase of 3.69 mm/yr-1 or 36.9 mm per decade. In the 47 years, there had been roughly 1676mm of rain on average per year in Lagos, Ijebu-ode, and Ondo. The trend in rainfall values and mean annual rainfall are at odds with findings by Fasona et al. (2019) and Oguntunde *et al.* (2011), which both indicated a drop-in rainfall by 1.75 mm per year-1 from 1892 to 2015 and a loss in rainfall in the area from 1901 to 2000. Additionally, the years 2014, 2019, and 1996 had annual mean rainfall levels exceeding 2000 mm/yr-1 (2160, 2185 and 2022 mm/yr-1 respectively). Contrarily, with a mean annual rainfall of 1218mm, 1283mm, and 1324mm, respectively, 1998, 1977, and 1986 had the lowest amounts. The area's fluctuating rainfall pattern reflects both local and global trends (IPCC, 2021; Adebayo *et al.,* 2014).

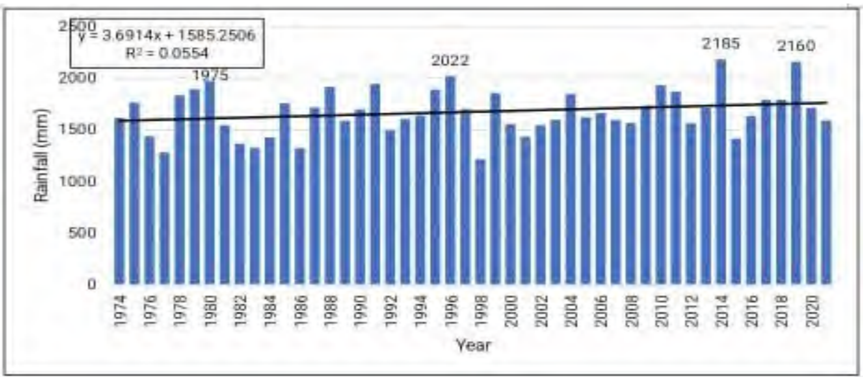

Fig. 1: ***Long-term trend in mean annual rainfall from 1974-2021***

The long-term annual rainfall at the Lagos Island station (Figure 2) was 1722 mm, with an upward trend of around 0.12 mm each year. The years with the greatest annual rainfall values were 2014 (2526 mm/yr-1), 1988 (2432 mm/yr-1), and 1996 (2432 mm/yr-1) (2276mm/yr-1). The findings of Fasona *et al.*, (2019), who reported an 1812mm long-term mean, are consistent with this (from 1892-2015).

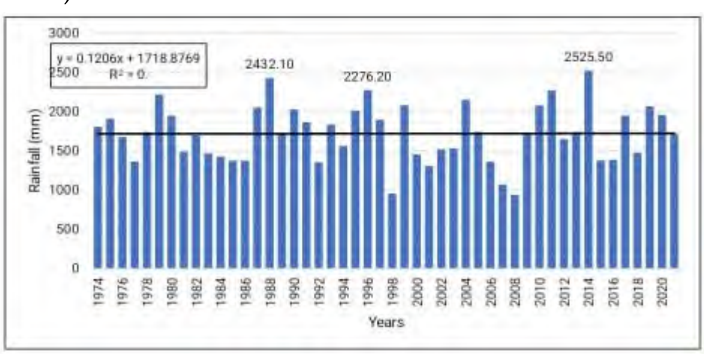

Fig. 2: ***Lagos Island's long-term trend in mean annual rainfall from 1974-2021***

The long-term annual mean for Ijebu-ode was mm/yr-1, with a positive trend of 7.86mm/yr-1 (Figure 3). This result agreed with those of Fasona *et al.* (2019), who found in Ijebu-ode a long-term mean of 1602mm. The years with the highest amounts of precipitation were 2019, 2007, and 2006 (2152, 2136 and 2126 mm/yr-1, respectively).

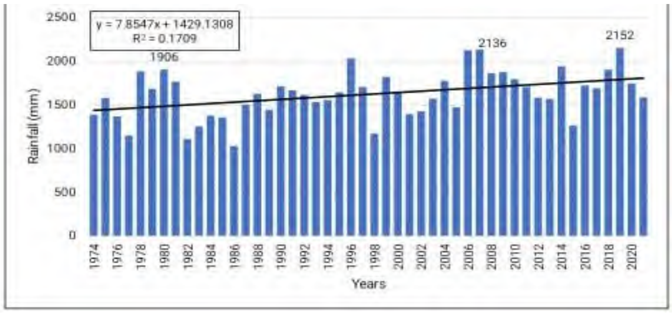

Fig. 3: ***Ijebu-Ode long-term trend in mean annual rainfall from 1974-2021***

The long-term annual mean for Ondo (Figure 4) synoptic station from 1974 to 2021 was 1684 mm/yr-1. The region had an increase in rainfall of 3.10mm per year-1. The three years with the most rain were 1985 (2542 mm/yr-1), 1991 (2310 mm/yr-1), and 2019 (2259 mm/yr-1), in that order.

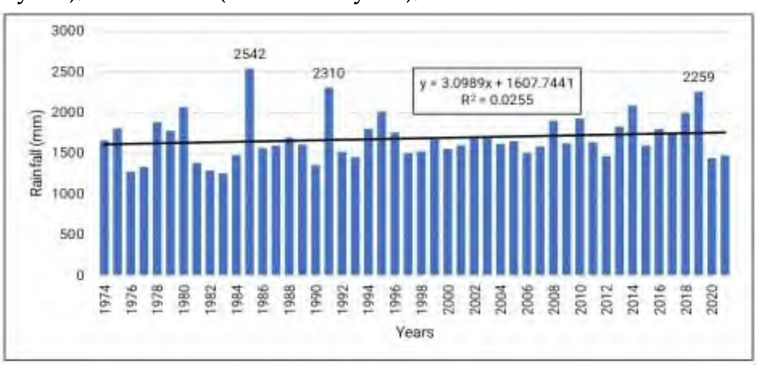

Fig. 4: ***Ondo long-term trend in mean annual rainfall from 1974-2021***

The annual long-term trend in maximum temperature

The average yearly maximum temperature during the period 1974–2021 (Tmax) shows an oscillating rising trend of 0.028°C. Tmax for Lagos, Ondo, and Ijebu-ode varied from 29.66°C to 31.74°C. The trend indicates a rising trend of up to 0.028°C/yr-1 or 0.28°C each decade from 1974 to 2021. This is in line with the overall warming trend and increases in temperature seen globally (IPCC, 2021), in Nigeria (Abiodun *et al.*, 2013), and the area (Fasona *et al.*, 2019). Additionally, the highest annual mean Tmax readings were made in 2016, 1998, and 2021, respectively, at 31.75°C, 31.72°C, and 31.67°C. On the other hand, the lowest Tmax in the region was recorded in 1976 (29.55°C), 1975 (30.11°C), and 1980 (30.22°C), respectively. Data show a persistent rise in the region's average temperature, which has been linked to climate change among other things in reports from throughout the world (IPCC, 2021).

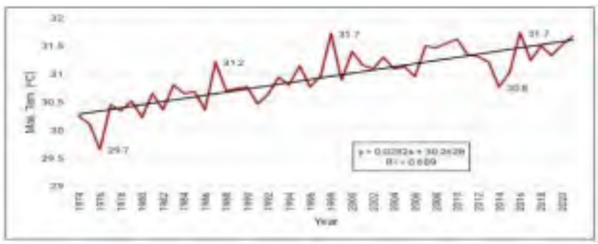

Fig. 5: ***Long-term trend in mean annual temperature from 1974-2021***

The mean annual Tmax for the Lagos Island station from 1974 to 2021 was 30.29°C, with an increasing trend of 0.028°C/yr-1 or 0.28°C per decade. This is consistent with the rise in temperature of the region (Fasona *et al.*, 2019). Lagos Island had temperatures ranging from 29.7°C to 31.7°C, with the greatest readings occurring in 2016, 2018, and 2019. (31.61°C, 31.32°C and 31.17°C). The lowest temperatures in the area were measured between 1975 and 1977, with readings between 29.24 and 57°C. This observation shows a gradual rise in the region's average temperature, with the five warmest years—with Tmax values of over 31°C occurring from 2016 to 2020, supporting the IPCC's conclusion of an increase in world temperatures (IPCC, 2021).

Fig. 6: ***Lagos Island's long-term trend in mean annual Tmax from 1974-2021***

Similar to Lagos Island, Ijebu-ode (Figure 7) observed a positive trend of 0.025°C/yr-1or 0.25°C per decade in the mean annual Tmax from 1974 to 2021. The temperature ranged from 30.22°C and 32.85°C. The lowest temperature values were also recorded from 1974-1976 at values ranging from 30.22-30.71°C. The years with the lowest recorded temperatures were 1974–1976, with readings ranging from 30.22–30.71°C. The years with the highest recorded temperatures were 2021 (32.85°C), 1998 (32.47 °C), and 2020 (32.45°C), in that order. Studies have shown that the patterns observed in Ijebu-ode show a consistent rise in the area similar to those recorded in Lagos Island (Ojeh et al., 2016; Aiyelokun and Odekoya, 2016; Fasona *et al.*, 2019),

Fig. 7: ***Ijebu-ode long-term trend in mean annual Tmax from 1974-2021***

Similar to Lagos Island, Ondo (Figure 8) observed a positive trend of 0.032 °C/yr-1 or 0.32 oC per decade in the mean annual Tmax from 1974 to 2021. The temperature was between 29.51°C and 32.7°C. The years with the lowest recorded temperatures were 1976 (29.51 °C), 1980 (29.82°C), and 1974 (30.06°C), in that order. The three warmest years in the region were, respectively, 2008 (32.71 °C), 2007 (32.73°C), and 2009 (32.73°C).

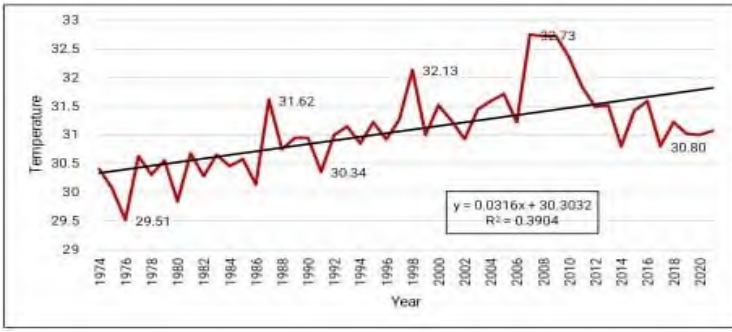

Fig. 8: ***Ondo Long-term trend in mean annual Tmax from 1974-2021***

Standardized Precipitation Index

Similar to the findings of Fasona *et al.,* (2019) the standardized rainfall anomaly across Lagos, Ogun, and Ondo (Figure 9) reveals near-annual variations in rainfall. The four distinct rainfall periods are suggested by the standardized rainfall anomaly: a general wet period from 1978 to 1980; a protracted dry period from 1981 to 1994, which was broken up by wet years in 1985, 1987, 1988, and 1991. Brief wet years in 1999 and 2004 were interspersed between a long dry spell from 1988 to 2008 and the short wet years from 1995–1997. A prolonged rainy spell from 2013 to 2020 was broken up by dry stretches in 2015 and 2016. The 1980s were the region's driest decade in the previous 100 years, according to FGN (2014) and Fasona *et al.* (2019) are extended dry period records. The findings point to a nonlinear trend in rainfall in the area and suggest oscillation and variability in that rainfall, which might have an impact on the region's ecosystems and human activities (Fasona *et al.,* 2019).

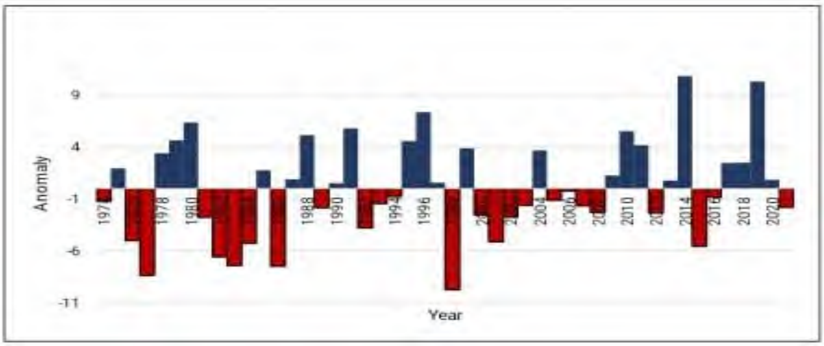

Fig. 9: Standardized rainfall anomaly for Lagos, Ogun and Ondo

The distinct and persistent low-temperature periods from 1974–1996 with intermissions in 1987 and 1997 are suggested by the standardized temperature anomaly for Lagos, Ijebu–Ode, and Ondo (Figure 10). Then, from 2000 to 2021, there was a period of prolonged high temperatures, with breaks in 2014 and 2021, respectively. According to Fasona *et al.* (2019) and Umeh and Gil-Alana, (2024), the global warming trend and the high-warming temperature trend seen in this region are both congruent.

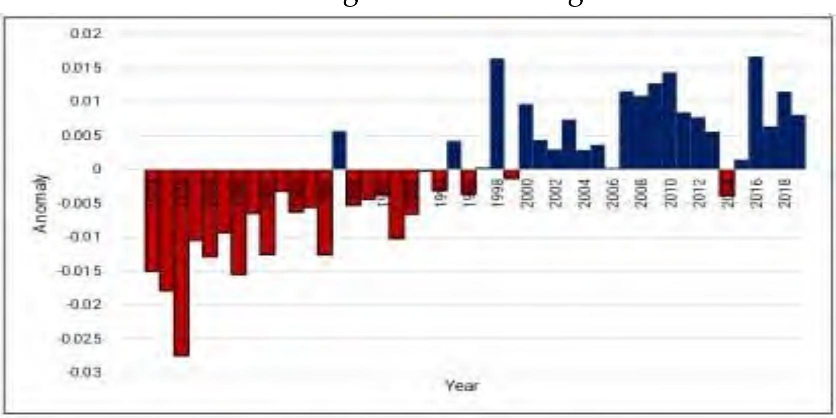

Fig. 10: Standardized Temperature anomaly for Lagos, Ogun and Ondo

Fisheries

According to the National Bureau of Statistics (2017), the total fish production by sector (in metric tons) showed the total contribution as at 2015 to be

1,027,058.00 (see Table 1), which was lower than the value for 2014. In the same manner the Industrial inshore fishery and artisanal coastal brackish water recorded a sharp decline from 2014 to 2015. In Figures 11 and 12. Oladimeji (2017) reported a decline in Total Domestic fish production in Nigeria from around 2005 to 2015 when the data was computed for the years 1970-2014.

Table 1: Nigeria's fish production (2010 – 2015)

		Sectors /Year	2011	2012	2013	2014	2015
1	Artisanal	Coastal & Brackish water	346,381.00	370,918.00	418,537.00	435,384.00	382,964.00
		Inland: Rivers & Lakes	292,105.00	297,836.00	326,393.00	324,444.00	311,903.00
		Sub-total	638,486.00	668,754.00	744,930.00	759,828.00	694,867.00
2	Aquaculture (Fish Farm)	Sub-total	221,128.00	253,898.00	278,706.00	313,231.00	316,727.00
3	Industrial (Commercial Trawlers)	Fish (inshore)	19,736.00	27,977.00	37,652.00	29,237.00	10,727.00
		Shrimp (Inshore)	13,749.00	17,654.00	22,219.00	20,715.00	4,737.00
		EEZ	-	-	-	-	
		Sub-total	33,485.00	45,631.00	59,871.00	49,952.00	15,464.00
	Grand total		893,099.00	968,283.00	1,083,507.00	1,123,011.00	1,027,058.00

Source: National Bureau of Statistics (2017)

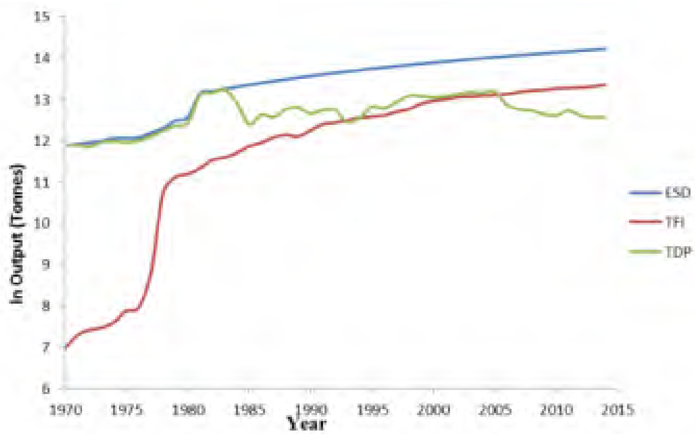

Fig. 11: Total domestic production (TDP) in 1970-2014. Nigeria Estimated Demand (ESD), Total Domestic Production (TDP) and Total Fish Imported (TFI) IN 1970-2014 (Source: Oladimeji, 2017).

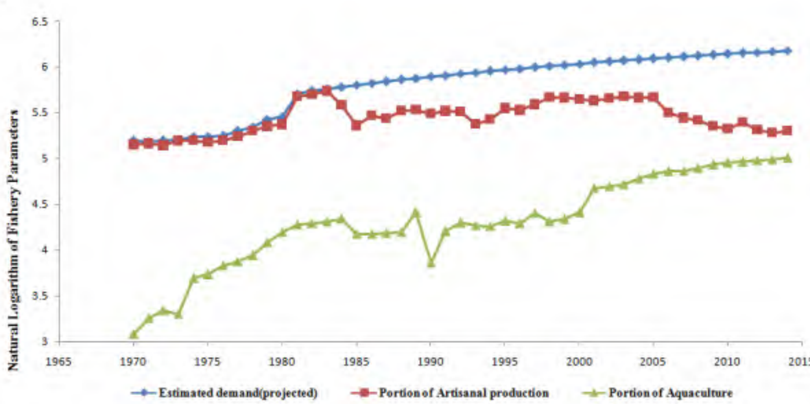

Fig. 12: Trend analyses in ESD, AFP, and AQU Production in Nigeria (1970-2014) Source: Computation and graph by Author; Data source: C.B.N. and N.P.C. records (Source: Oladimeji, 2017)

Implications of Climate Variability on Fish Reserves Depletion

The trends in annual rainfall and maximum temperature from 1974 to 2021, as presented for Lagos, Ijebu-Ode, and Ondo in Southwest Nigeria, have significant implications for fish reserves depletion in the region. These trends are reflective of larger climatic shifts influenced by global warming, and their impact can be better understood by drawing comparisons to global examples (Kalkuhl and Wenz, 2020; Ghanem, 2024; Fallah *et al.*, 2024).

According to a 2019 study reported in Adebola and de Mutsert (2019), 80% of the fish stocks in Nigeria's inshore seas have either failed or been overfished, with several of these species having completely disappeared. According to the study, this drop is the result of consistent increases in fishing activity between the 1970s and the 2000s, which reduced marine biodiversity and produced less productive coastal fisheries. This was also reflected in the report by Oladimeji (2017). Fish distribution has changed and fish populations have decreased as a result of the negative effects of climate change on marine ecosystems (Minrui, *et al,* 2021), including rising sea temperatures, ocean acidification, and changed salinity levels. Nigerian fishermen have seen less catches as a result of these environmental changes, which have also upset customary fishing patterns (Adebola and de Mutsert, 2019). The fall in fish stocks has also been made worse by habitat degradation brought on by climate change, which includes the loss of coral reefs and mangroves (Brander, 2013). Food security and the livelihoods of coastal populations are at risk due to the combined effects of these causes, which have presented serious problems to Nigeria's fisheries sector.

Rainfall

Hydrological Changes and Habitat Alteration: The fluctuating rainfall patterns, with wet periods followed by extended dry spells, have direct consequences on aquatic ecosystems (Bond *et al.,* 2008; Qiu *et al.,* 2021). In Southwest Nigeria, high rainfall years (e.g., 1988 and 2014 with 2432.10mm and 2525.50mm respectively) can lead to increased freshwater inflow into rivers, lagoons, and coastal zones, potentially altering salinity levels. Conversely, dry spells like those observed in 1998 and 2017 with average of 31.7°C can reduce water levels, increasing salinity in estuarine and coastal ecosystems. Such conditions disrupt the breeding and feeding habitats of many fish species, contributing to their decline. For example, in the Mekong Delta, Vietnam, reduced water flows due to altered rainfall patterns and dam construction have led to significant declines in fish populations reliant on seasonal floodplain inundation for breeding (Cowx *et al.*, 2024).

Flooding and Water Quality: Years with excessive rainfall, such as 2014 with 2525.50mm, often result in flooding. Flooding washes agricultural runoff, urban pollutants, and sediments into water bodies, leading to eutrophication and hypoxic conditions detrimental to fish populations. According to NBS (2017), as seen in Table 1, there was a decline from the fish production in Artisanal and Industrial sectors from 2014-2015, except in Aquaculture production. In Nigeria, flooding is a recurring issue, particularly in Lagos, where poor drainage exacerbates water pollution, harming aquatic ecosystems (Umar and Gray, 2022). In the Mississippi River Basin, nutrient runoff from excessive rainfall contributes to a hypoxic zone in the Gulf of Mexico, severely depleting fish stocks (Rabalais and Turner, 2019).

Prolonged Dry Periods: Extended dry spells (e.g., 2013–2020) reduce river flows and water levels in reservoirs, leading to habitat shrinkage and crowding of fish populations (Humphries and Baldwin, 2003). This increases competition for resources and vulnerability to predation and overfishing. In addition, dry conditions promote higher evaporation rates, concentrating pollutants in water bodies (Faulstich *et al.,* 2023). In East Africa, declining water levels in Lake Victoria during drought periods have disrupted the fish breeding cycle and reduced fish harvests (Kimaro and Fidelis, 2007). Similarly, reduced water levels in Lagos, Ijebu-Ode, and Ondo disrupt fish breeding, alter habitats, and decrease fish reserves over time.

Rising Temperatures

Thermal Stress and Species Migration: The upward trend in maximum temperatures (e.g., 0.28°C per decade in Lagos Island) poses thermal stress to fish. Many species have optimal temperature ranges for survival and reproduction. Increased water temperatures can exceed these thresholds, leading to reduced growth rates, reproduction failures, and migration of species to cooler waters (Mitra *et al.*, 2023). In Nigeria, studies show a decline from 11% to 7% in nearshore fish catch between 2010 to 2015, impacting and forcing artisanal fishers' offshore (Subasinghe *et al.,* 2021), . In the North Sea, rising sea temperatures from 0.8–1.5°C have caused the shift in cod and haddock populations, with species migrating northward from 50–100 km (Adebola. and de Mutsert, 2019; Campana *et al.*, 2020).

Metabolic Demands and Food Web Alterations: Warmer water accelerates fish metabolism, increasing their need for food. Simultaneously, rising temperatures may reduce the abundance of plankton and other primary producers, leading to a mismatch in food availability (Hoegh-Guldberg *et al.*, 2017). This dynamic can cascade through the food web, ultimately reducing fish biomass in the region. In the Great Barrier Reef, increased water temperatures have disrupted coral ecosystems, diminishing habitats for reef fish and impacting fisheries (Hoegh-Guldberg *et al.*, 2017).

Oxygen Depletion: Higher water temperatures lower dissolved oxygen levels, creating hypoxic conditions that are lethal to fish (Echebiri *et al.*, 2023; Ayeni *et al.,* 2023). In the Niger Delta, rising temperatures, combined with pollution, exacerbate oxygen depletion, leading to fish kills (Echendu *et al.*, 2022). Warming-induced hypoxia has been reported in the Baltic Sea, affecting its fisheries (Carstensen and Conley, (2019).

Mitigation

To address these challenges, integrated management strategies are essential. Restoring wetlands, regulating fishing practices, reducing pollution, and enhancing climate resilience in water resource management can help mitigate the impacts of rainfall variability and rising temperatures on fish reserves in Nigeria. Learning from global case studies, such as the Mekong Basin's floodplain restoration projects, can offer valuable insights for Nigeria.

Conclusion

The study provides valuable insight into the temporal trend of rainfall and average temperature for the Lagos, Ogun and Ondo areas of Southwest Nigeria. The study revealed 4 distinct rainfall periods between 1974 and 2020, with a general wet period from 1978-1980, a protracted dry period from 1981-1994, a brief wet period from 1999-2004 and a dry spell from 2013-2020. Revealing the 1980s as the driest decade in the previous 100 years and pointing to a nonlinear trend in rainfall in the area. The implication of the findings is very significant because of the highlighted impact of climate change on the environment, the ecosystem, human health and the general well-being of the area. In conclusion, the trends in rainfall and temperature in Southwest Nigeria exemplify how climatic variability affects fish reserves. Without adaptive management, these changes could further deplete fish stocks, threatening livelihoods and food security in the region.

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