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Impact of climate change on aquaculture and fisheries in Nigeria; A review

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Abstract
Climate change have been reported to have direct and indirect impacts on fisheries and aquaculture globally. Nigeria is a coastal states with growing contribution of inland aquaculture to national development and individual livelihood; thus on the overall well-being of her citizens. The paper review the different impacts of climate change on the physical, chemical and biological quality of water to sea level rise, it suggested strategies for adaptations and how to cope with the impacts of changing climate on water quality, in other to sustain the industry. The findings will serve as a management tool for government and stakeholders in addressing some of the lingering issues in understanding some of the resultant impacts on fisheries to sustain the growing industry in the face of climate change. Some of the strategies suggested are adapted not only to manage future decline in fish production but contribute to poverty reduction, wellbeing of the people and improving the socioeconomic potentials of the country, presently in economic crises and conflict, resulting from government policy failures.

Keywords: climate change, water quality, pollution, livelihood, temperature

1. Introduction

Nigeria is a maritime country with tremendous aquatic and fisheries resources that make significant contributions to livelihood, food security and the overall economy of the nation. The country's fresh water and marine fisheries resources are enormous with tremendous opportunities for fish production through capture and cultured fisheries (fig.1).

The country's freshwater bodies (Table. 1) was estimated about 14 million hectares, comprising of seasonal and perennial rivers, lakes, reservoirs and dams (Table.1). While the coastal waters (creeks, lagoons and estuaries) housing most aquaculture cover about 37, 934km^2, with an undisputed marine jurisdiction over the physical, chemical and biological resources exploitation within a distance of 320 km nautical kilometers (853 km2) into the Atlantic Ocean (FAO, 2014).

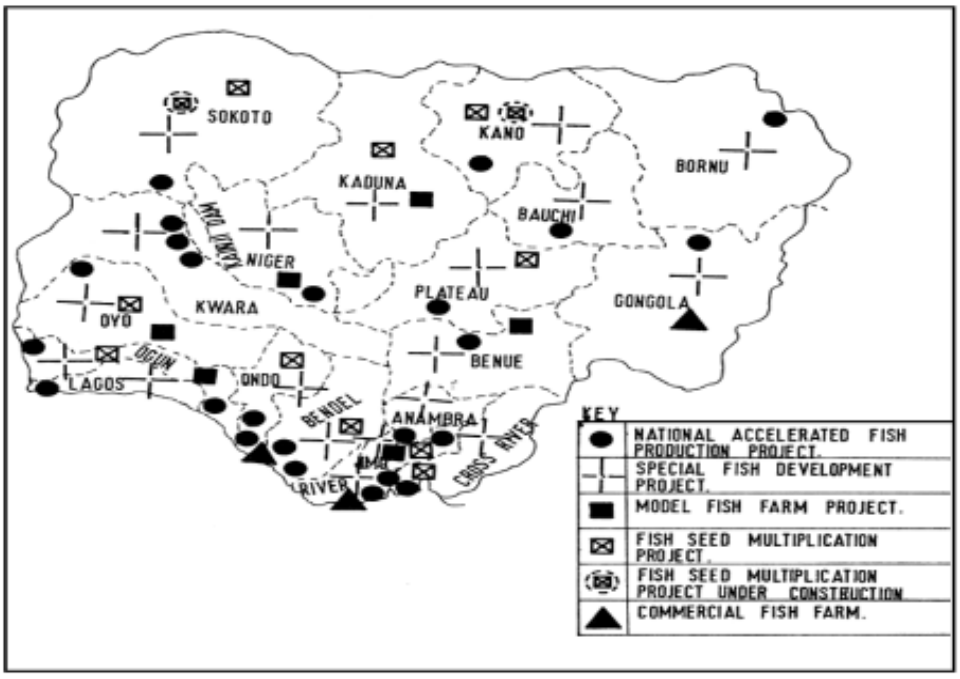

Fig 1: Map of Nigeria showing aquatics resources and distribution for livelihood enhancement.

Most fisheries exploitation in freshwaters and coastal waters are carried out by artisanal (small scale) fishermen, employing simple fishing gear and equipments. This subsector employment, according to FDF (2008) has over 8 million fishermen, with another 18 million people engaged in fish processing, distribution and marketing, thereby accounting for a well over 80% of the total annual domestic production of the country.

Table 1: Nigeria fisheries resources and production

Parameters	Magnitude
Area (km^2)	923,768
Length of coastal (km2)	37, 934
Exclusive Economic zone	853
Inland waters (m ha^{-1})	37, 934
Available land for Aquaculture (m ha^{-1})	853
Fisheries resource category fish estimated yield / annum (mt)	
Coastal resources	142,000
Inshore resources	16,620
Offshore demersal resources	6,370
Tuna and pelagic resources	15,000
Shell fish	
Coastal artisanal	48,000
Industrial	3,760
Fresh water resources	
Rivers / flood plain	226,550
Lake chad	160,000
Kainji lake	30,000
Aquaculture (m)	2.5m

***Source*:** Federal Department of Fisheries (FDF, 2008).

While, the industrial fishing sub-sector dominate the Atlantic Ocean, especially as the country's portion of the Atlantic is not an isolated entity (Ipinjolu *et al*. 2014) [24]. While several studies have implicated climate change on rapidly changing physical, chemical and biological properties of known water bodies to sea level, with significantly impacts on fisheries; a subsector known to contribute about 4% Nigeria annual domestic fish production, are made up of significant few large-scale investors.

The climatic and geomorphic characteristics of Nigeria has placed the country among vulnerable and one of the most threatened countries globally. Although, these impacts are widely reported as direct and indirect or positive and negative consequences, including in aquaculture; their impacts are becoming more evident. However, the country's highest contributions to global fisheries estimated in 2014 was from inland aquaculture, in line with the 2008 Central Bank of Nigeria Statistics office (fig. 2) (FAO, 2014), and believed to be most threatened by changing climate.

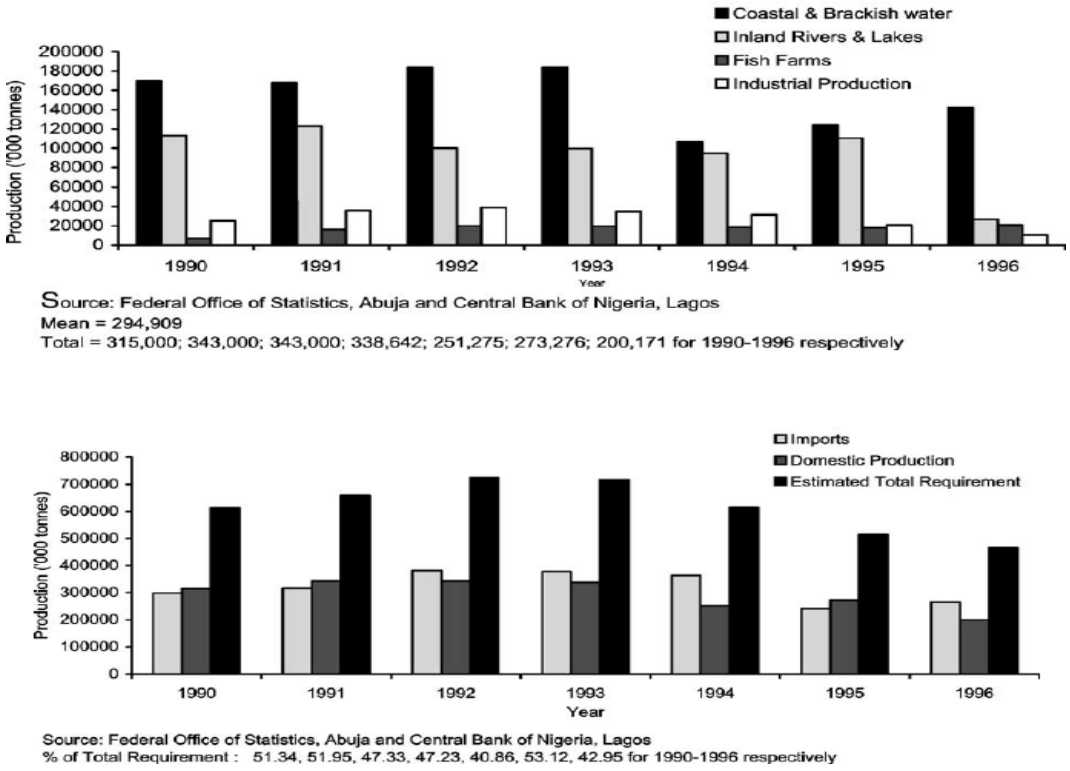

Fig 2: Information on Nigeria fisheries, aquaculture and production

According to FAO (2008) [16], climate change impact is expected to cut across ecosystems, societies and economics, livelihood and food supplies in West and Central African countries most vulnerable due to their fragile ecological and geological formation (WorldFish Centre, 2007) [37], coupled with their climate characteristics. In climate change scenario, fisheries and aquaculture are particularly vulnerable because aquatic habitats directly absorbed and store part of the solar energy, especially as most fish species are cold blooded, except Pangasius species with ability to thrive in both tropical and temperate environment; a concern for top producing countries like Vietnam and China.

Climate change impact directly on water quality by changing the physio-chemical conditions through temperature increase, and consequently on other important assessment which can increase the risk indices for aquatic lives. Several empirical studies have been conducted to investigate the different impacts of climate change on Nigeria fisheries and aquaculture which includes the work of Idowu *et al*. (2011) [19] on the Impact of climate change in Nigeria; Ipinjolu *et al*. (2014) [24], the potential impacts of climate change on fisheries and aquaculture in Nigeria; Anyanwu *et al*. (2015) [3], climate change, effects and mitigation strategies on aquaculture: a review; Essam and Senebe (2013) [15]; Impacts of climate change on fisheries: implications for food security in Sub-Saharan Africa; Aphunu and Nwabeze (2012), Fish farmers' perception of climate change impact on fish production in Delta State, Nigeria (Leon and Antonio, 2015).

According to these authors, climate change scenario especially through temperature and carbon dioxide increase will continuously warm the earth with resultant effects on fisheries and aquaculture, and that Nigeria vulnerability is high. Leon and Antonio (2015) asserted that warming has increased thermal stratification, reduction in surface water cold and warm mix thereby preventing upwelling effects of nutrients, and consequently affect primary productivity, the distribution and fecundity of marine fishes.

Surprisingly, it was also observed that changing climate through temperature will temporarily increase dissolved oxygen in water which will deplete afterwards due to increase in biochemical Oxygen demand; a natural phenomenon in water noted to regulate water quality. This have been observed to increase nutrient content of water bodies causing algal bloom, thus eutrophication of waters in Netherlands (Verweij *et al*., 2010) [35].

Increase in temperature can adversely increase food consumption by fish, especially small sized fishes, and resultantly increase the cost of inland aquaculture. Consequently, increase biological oxygen demand (BOD), deplete available dissolved oxygen (DO) and thus, pollution of water bodies and death in some cases. The quality of a water body is key to the survival of fish life, which is an important consideration for both marine and inland aquaculture assessment.

Changes or poor water quality has been reported to result to large scale fish death in ponds or marine ecosystems, especially as fish and shellfishes known to have suitable environmental conditions to thrive in some of these aquatic systems. In Vietnam for example, the 2008 Vedan factory pollution incident and 2016 large scale surface water pollution was reported to cause ecosystem damage and unquantifiable fish kill (Ngoc, 2008 and Vietnam News).

Although aquaculture have been reported to contribute to greenhouse gas emission and thus global warming (a phenomenon associated with temperature increase from normal); the contribution is still at minute level, when compared to other anthropogenic sources. Increase in carbon dioxide will lead to acidification of waters and decalcification of shell fishes and complete change in ocean chemistry occur. The influence of climate change on surface water is very striking and should be studied in-depth to provide improve information in assessing water quality.

Climate change through temperature increase will temporarily increase dissolve oxygen concentration; consequently increase biochemical oxygen demand (BOD), which will deplete the available oxygen causing an anoxia in water bodies. Increase in dissolve oxygen (DO) have been observed to regulate water quality by reducing carbon dioxide concentration in waters (Verweij *et al*. 2010) [35].

The livelihoods in Nigeria lies between longitudes 2°49' E – 14°37E and latitudes 4°16N'13° 52N and with two distinctive seasons (dry and wet) suitable for agricultural production, with an average rainfall above 2800mm and high relative humidity of about 80 – 92%.

The aim of this paper is to highlight some of the attendant impacts of changing climates and strategies for adaption to sustain an industry contributing to National and livelihood development in Nigeria.

2. The nexus and impacts of Climate Change nexus on Fisheries in Nigeria

Natural climatic fluctuations, particularly those at medium (decadal) scale, have always affected fisheries as well as their management performance (Garcia and Rosenberg, 2010). The atmosphere and the ocean will continue to warm over the next 50 –100 years, sea level will rise due to thermal expansion of water and melting of glaciers, ocean pH will decline (become acidic) as more carbon dioxide is absorbed, and circulation patterns could change at local, regional and global scales (Bindoff *et al*., 2007 in Munday *et al*., 2008) The major coastal habitats will be affected including estuaries, mangrove swamps, and deltas (Hlohowskyjl *et al*., 1996).

The diversity of the habitats and the species they support will respond differently to different impacts of climate change. Even though it is not possible to generalize the impacts of climate change on fisheries in Nigeria, they share common global climate change which lead to fluctuations in fish stocks. Fluctuations in fish stocks will have major economic consequences for many vulnerable communities and national economies that heavily depend on fisheries (Brander, 2010) [7].

The impacts of climate change on fish stocks in Nigeria and sub- Sahara Africa can be classified as physical and biological changes. Physical changes include sea surface temperature rise, sea level rise, changes in salinity and ocean acidification. Biological changes include changes in primary production, and fish stock distribution. These factors when combined together will have adverse impacts on the already strained resource.

2.1 Physical Changes

Surface water temperature rise play a significant role in regulating global climate. Rosemary (2015) [30] describe the ocean and aquatic bodies as both victim of climate change and the solutions. Their heat capacity is about 1000 times larger than that of the atmosphere (Barange and Perry, 2010), and therefore absorb significant amount of heat emitted globally. Such changes in ocean temperatures can change the dynamics of aquatic environments of the region. Changes in ocean dynamics could lead to changes in migration patterns of fish and possibly reduce fish landings, especially in coastal fisheries (African Action, 2007) [2]. For example, increased ocean temperature may affect upwelling along the coastal areas, especially the Atlantic, which can make the ocean more unsuitable for fisheries, causing a reduction in and possible collapse of fishing activities (African Action, 2007) [2]. Inland waters are also equally vulnerable and could be impacted strongly by climate change (IPCC, 2007) [22].

The international dialogue on Water and Climate (2004) noted that water stress will increase significantly those regions in sub-Sahara, which included the northern part of Nigeria already dry with adverse effect on inland aquaculture in that region.

One of the stresses that inland waters in Nigeria (including aquaculture) is faced with; is increase in surface water temperature. According to Christensen *et al*. (2007 in Barange and Perry, 2010) seasonal warming is very likely going to be larger than the global annual mean warming throughout the region and Nigeria in all seasons.

Rising water temperature also threatens fish biodiversity;

generally fish have a thermal preference that optimize physiological processes (Abowei, 2010) [1]. If water temperature rises above the maximum tolerable threshold of a species, then its existence is threatened. Urama and Ozor (2010) provide an example from the Lebialem Highlands in Cameroon where women have started to hunt for tadpoles and frogs because there were no fish in most of Bangwa Rivers, and that the number of tadpoles and frogs have significantly declined (partly) due to the warming rivers that have increased the amount of predator fish in an un-habited area.

2.2 Sea Level Rise

Globally, sea level has already risen by 10 to 20 cm during the 20th century, largely due to thermal expansion, and by 2100 a global rise in sea level of between 9 cm and 88 cm has been predicted, based on the Intergovernmental Panel on Climate Change's full range of 35 climate projection scenarios (Church *et al*., 2001 in OECD, 2010) [27]. In coastal areas, sea level rise may alter the salinity of estuarine habitats, inundate wetlands, and reduce or eliminate the abundance of submerged vegetation, adversely affecting those species which rely on these coastal habitats for reproduction and recruitment (Hlohowskyjl *et al*., 1996). In addition, with high sea levels, sea ports, existing fishing facilities like jetties and fish storage centers built on the coastal fringes slightly above the mean high tide lines, will be subjected to more frequent tidal and storm inundation (Ibe and Awosika, 1991) [18].

Therefore, sea level rise is very likely going to have a negative impact on fishery production (due to salt stresses on the fish stock and its habitat) and fish landing, processing and marketing facilities. There are very limited studies done to assess the impacts of sea level rise in the coastal zones in Africa including Nigeria. However, some information on the impact of sea level rise in some of the most populous coastal cities in West and East Africa place Nigeria vulnerability high, due to the vastness of Nigeria fragile coastal areas.

For example, Nigeria's 800 kilometer low-lying coastline from Lagos to Calabar South South, Nigeria) makes the region prone to seawater intrusion into coastal freshwater resources. This will have a negative impact on inland fisheries and aquaculture. The people in the coastal areas who used to depend on fishing have seen their livelihoods destroyed by the rising waters (Urama and Ozor, 2010) and currently placed on red alert from previous notable studies.

2.3 Increasing Water Salinity

Climate change can cause an increase or decrease in water salinity in multiple ways. While tropical oceans are increasingly becoming saltier, oceans closer to the poles have become fresher. This highlights that tropical oceans and countries (Nigeria is one) are very likely to suffer more from the potential impacts of increasing water salinity relative to waters in higher latitudes. Changes in water salinity have different effects depending on the tolerance level of the organisms and the nature of their ecosystem, whether freshwater, marine or estuarine. The salinity of some freshwater ecosystems are predicted to increase as a result of anthropogenic climate change (IPCC, 2001). Such physical changes will negatively impact the population of both plankton and bigger prey fish species by affecting the organisms' ability to osmoregulate (Schallenberg *et al*., 2003) [31].

Some empirical studies illustrate that change in salinity has a negative impact on zooplankton population, particularly in freshwater ecosystems. Schallenberg *et al*. (2003) [31] depict that zooplankton communities of low-lying, coastal, tidal lake and wetlands are adversely affected by small increases in salinity levels with a considerable negative impact on fishery.

Salinity is also considered one of the most important variables determining the survival of organisms in estuarine ecosystems; either by having a direct impact on the organisms or indirectly by destroying their habitat, including their breeding and nursery grounds (Abowei, 2010) [1]. Blaber (1997) stated that all estuarine fish are euryhaline (able to cope with salinity fluctuations), but their ability to do so varies from species to species and hence changes in salinity may influence their distribution. Even though salinity changes may not have a direct negative impact on estuarine fish species per se, it can have a negative impact on their habitat. For example, increase in water salinity has contributed to destruction of 60 per cent of mangrove areas in Senegal and Nigeria (IPCC, 2007) [20].

According to Parkins (2000), each acre of mangrove forest destroyed leads to an estimated 300 kg loss in marine harvest. Therefore, change in water salinity are going to have a tremendous negative impact on fishery in Nigeria, threatening the livelihoods of many impoverished coastal communities.

2.4 Ocean Acidification

Oceans are believed to have the capacity to absorb most of the anthropogenic CO_2 emissions (Caldeira and Wickett, 2003) [9]. CO_2 is soluble in water and reversibly converts to carbonic acid. As a result of this chemical reaction, the world's oceans are acidifying at an alarming rate (Dupont and Thorndyke, 2009) [14]. While this has a positive impact in slowing down global warming, increased acidity as a result of dissolved CO_2 in seawater has negative impact on aquatic ecosystems.

Although, the impact to the ecosystem is difficult to estimate as different species at different stages of life history respond differently to different pH changes, it is devastating. According to Dupont and Thorndyke (2009) [14], ocean acidification research is in its infancy and although the field is moving forward rapidly, good data is still scarce, especially in the tropics.

Although the science base is still limited, there is a clear need to provide timely advice and a balanced perspective on the possible impacts on marine fisheries (Le Quesne and Pinnegar, 2011) [25].

Nigeria is one of the highest oil producing country in the world, and as such characterized by resource exploration, exploitation and processing to gas flaring observe to dormant the countries sphere and its attendant effects on water acidification and health indices. These human communities, according to Cooley *et al*. (2011) [12] require assessing the direct and indirect chemical impacts on valuable marine ecosystem services such as fisheries, although already evident in species biodiversity losses.

According to Le Quesne and Pinnegar (2011) [25], direct effects include changes in physiological processes such as reduced growth of calcified structures, otolith development and fertilization success. These may ultimately lead to direct impacts at the whole-organism level, including reduced growth and reproductive output, increased predation and mortality, alteration in feeding rates and behavior, reduction in immunocompetence and reduced thermal tolerance.

Indirect effects include alteration in predator or pray abundance, effects on biogenic habitats such as coral reefs, and changes in nutrient recycling. While adult fish seem well-equipped to deal with low pH waters, or higher levels of CO_2 in seawater, their egg and larval life stages may not be so fortunate (Painting, 2011) [28].

For example, increased CO_2 level in oceans can potentially narcotize male gametes indicating that acidification may impair fertilization, exacerbating problems of sperm limitation, with dire implications for marine life (Byrne *et al*., 2010) [8]. Ocean acidification could potentially slow the growth of plankton and invertebrates that are at the bottom of the food chain. Thus acidification can alter the productivity at certain trophic levels, thereby disrupting the complex food chain of aquatic ecosystems with effects on the productivity of fisheries. One of the very likely socio-economic impacts of ocean acidification in Nigeria is a decrease in populations of calcifying organisms such as mollusks with tremendous effect in the market and development of this sub-sector.

2.5 Biological Changes

Climate change is already affecting the trends of some important biological processes, resulting in changes in primary production (Taucher and Oschlies, 2011) [33] and changes in fish distribution (Sumeila *et al*., 2011). Climate induced changes in primary production and fish stock distribution have negative implication on food security in many tropical coastal states in general and Nigeria in particular.

Climate change relationship with future ocean primary production is likely to be a key constraint on fish and fisheries production (Dulvy *et al*., 2010) [13]. Survival of fish larvae during the planktonic stage thought to depend strongly on the availability of sufficient and suitable food.

Climate change can induced changes in distribution and phenology of fish larvae and their prey which can also affect recruitment and production of fish stocks (Brander, 2010) [7]. Even though there are some studies done to assess the impact of climate change on primary productivity of aquatic environments in high latitude waters, there is very limited study conducted in the tropics.

2.6 Changes in Fish Distribution

Change in fish distribution is among the most commonly reported ecological responses of marine species (Sumaila *et al*., 2011 and Ipinjolu *et al*. 2014) [32, 24]. Fish species are believed to respond to environmental changes such as warming water temperatures by shifting their latitudinal and depth ranges. Changes in ocean dynamics could lead to changes in migration patterns of fish and possibly reduce fish landings, especially in coastal fisheries of many African countries (African Action, 2007 in Urama and Ozor, 2010) [2].

Marine fisheries are an important food source, and therefore, changes in the total amount or geographic distribution of fish available for catch could potentially affect food security (Cheung *et al*., 2009) [11]. The effects of changes in fish-stock distribution vary across latitudes. Some fish species will migrate north in search of habitats with optimal water temperature and thus potentially increasing fish harvest in higher latitudes.

On the other hand, counties in lower latitudes such as Nigeria are very likely going to lose some fish species and stocks. Cheung *et al*. (2009) [11] depicted that changes in fish-stock distribution could range from a 30–70 per cent increase in high latitude regions to a drop of up to 40 per cent in the tropics. This signals a threat to predominantly artisanal fishers in Nigeria mainly because it is economically prohibitive to follow the fish-stock, i.e. placed restriction to economic exclusive zones. Therefore, according to OECD (2010) [27], such changes in fish stock distribution will change the distribution of benefits and costs of fisheries with some winning and some (including fishers from Sub-Saharan African countries) losing.

3. Adaptation Strategies

In order to assuage the impacts of climate change in fisheries in Nigeria, the under listed adaptation strategies have been suggested, which are in line with development goals and initiatives.

The federal, State and Local government should adapt all in-inclusive and people friendly principles in promoting climate change awareness and sustainable development through the following;

1. Establish community and stakeholders on the impacts of climate change and how to identify one.
2. Strengthen government institution and empower them to work closely with local people in mitigation the effects of changing climate, especially in the riverine communities.
3. Government at all levels should enforce laws targeted at reducing anthropogenic pollution of water bodies and activities capable of exacerbating climate change attendant effects, especially from production industries.
4. Adequate training on modern fishing techniques (including mariculture) and provision of incentives to subsides (Seeds, Fertilizers, Agro-chemicals, improved local breeds of livestock, Outboard Engines, fishing nets, etc) to fish farmers.
5. The government should provide access roads, foot bridges during flood and other maritime transportation to rural and riverine communities.
6. Rain-water collection systems should be provided for all stakeholders, including public boreholes outside the flood reaches of the possible flood belts and waterfronts.
7. Increase support to stakeholders through empowerment, frequent training, equipment provision, credit/loan assistance and training workshop support/provision.
8. Strengthening of support for service providers at the community level through credit assistance such as transportation systems and farming equipment supply, expecially processing centres.
9. The federal, state and local governments should engage in participatory community projects' implementation through the management of policies and regulations relevant for the moderation of agricultural production laws that can assure sustainable livelihoods and as well help mitigate change impacts.
10. The government should properly regulate and monitor industrial activities, expecially oil and gas using international acceptable standards.
11. The restive and aggrieved communities should engage government constructively to attract development rather than hostility and destruction of oil facilities, which has further degraded the environment.

3.1 Some Limitations to Adaptation

1. Limited access to credit facilities by farmers to replace lost equipment's and farms.
2. Inadequate technical know-how in fishing technology and aquaculture.
3. Poverty has led to increase exploitation and violation of marine protected areas (MPA's) and theft of inland fisheries and as livelihood improvement is key.
4. Government insensitivity to climate change impacts to resource and livelihood development in these poor communities.
5. The oil exploitation is characterized by mass pollution and degradation of supporting ecosystems functions.
6. The available research and technical work are still limited and needed to be improved upon.

4. Conclusion

Undoubtedly, Sub-Sahara Africa including Nigeria are looming in the face of climate change. These impacts are more evident in fishery and fisheries, as Nigeria capacity for fish production, so also its contributions comes from inland fisheries. It has become imperative to address these attendant problems of climate change which have worse future consequences. The present study have provide useful analyses and strategies to cope with climate change in Nigeria and Sub-Sahara Africa, if taken into considering it will help the fast growing fisheries industry and save the ever growing population in high demand for protein sources and earn more income tremendously from export. Government at all level, international organizations and stakeholders should be integrated in environment and thus, climate change mitigation.

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