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MAN-MADE LAKES: A MEANS OF ERADICATING MAN-MADE POVERTY

BY

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Great University of Ilorin Students,
Ladies and Gentlemen

Preamble

I give thanks to Almighty Allah, the beneficent, the merciful, who has been so merciful to me from birth till today, Thursday, 25th November, 2021 that I am delivering the 210th Inaugural lecture of this great University which happens to also be my Alma Mater. The inaugural lecture entitled "**MAN-MADE LAKES: A MEANS OF ERADICATING MAN-MADE POVERTY**" is the 7th to be delivered from the Zoology discipline in this University, coming after those that has been delivered by my mentors, teachers and senior colleagues, right from the inception of the discipline at the former Departments of Biological Sciences and now Zoology in 1976 and 2005 respectively. I have been part and parcel of the Departments since 1986 when I was admitted to study Zoology at Undergraduate, then going on to obtain Master's and Doctorate Degrees in the discipline at the Departments. I was employed as an Assistant Lecturer in the Departments in June, 1999 and became a Professor of Zoology in October, 2017.

My area of specialization is Fisheries, Aquaculture and Hydrobiology, with special emphasis on the ecology of man-made lakes, reservoirs and ponds. This sub-discipline of Zoology known as **LIMNOLOGY** is the study of the structure, relationships, productivity, dynamics and functional interactions among the physical, chemical and biotic properties of inland water ecosystems which include rivers, lakes, reservoirs and ponds. Limnology, a term derived from Greek word 'Limne' meaning lake, first used by François-Alphonse Forel (1841–1912). Limnology is a paradigm interdisciplinary science that helps in understanding the factors upon which life and its continued existence depends, and at the same time, through which life could be better off for humanity through sustainable use of water and its resources impounded in lakes, reservoirs and ponds**.** I picked interest in limnology as a result of a lecture I attended in 1989 during my undergraduate years in this University delivered by Emeritus Professor A.M.A. Imevbore of Obafemi Awolowo University, Ile Ife, Nigeria and ever since, I have been studying, working, researching and doing community services on various man-made lakes, reservoirs and ponds and their resources for the benefit of mankind and society at large through fundamental and applied limnological researches. My B.Sc. project, M.Sc. dissertation and Ph.D. thesis were all on the limnology and fisheries of different man-made lakes, reservoirs and pond ecosystems. My limnological researches and community services on these lakes as well as researches in fisheries, aquaculture and toxicology continued after my employment as an Assistant Lecturer till today. It is some of these works, achievements and contributions for the past 31 years including on-going researches and future research plans which were/are aimed at eradicating man-made poverty that I will be synthesizing and chronicling through my scholarship and pedagogy in this 210th inaugural lecture.

Introduction

Made-made lake, a term coined by Lowe-McConnel (1966), also called dam, reservoir or impoundment (used interchangeably) is an artificial basin created by man by building a dam across a river to impound water for various purposes. It differs from natural lakes which are naturally formed through processes like glaciations, volcanic eruptions and meandering of rivers. Water is the substance of life, comprising more than 60 percent of human body. It covers about 70 percent of the earth surface, but only one percent of that is fresh water which is usually impounded by man in lakes, reservoirs, ponds and other impoundments for his benefits. Diverse use and increased demand for freshwater and its resources owing to expanding population has put enormous stress on supply, quality, quantity, and the aquatic life it sustains, thus making it to become the world's most precious resource, at the same time, most mistreated and ignored natural resource (Schindler 2001). Water is predicted to become a limited resource by the next century, with Nigeria predicted to run short of water by 2050 (Lukenga 2019). According to the World Water Development Report (WWDR), problems of poverty are inextricably linked with those of water - its availability, proximity, quantity and quality.

Improving the access of poor people to water and its resources has the potential to make a major contribution towards poverty eradication and improvement of quality of life. Poverty caused by man himself could be eradicated through the functions and benefits of man-made lakes. At the same time, these benefits and functions could be eroded through his misuse and abuse leading to square one of his poverty index. Thus, there is the need to control, conserve and manage these lakes along with their resources very well, because very soon, water and the resources contained in it might become scarce which could exacerbate poverty among the people.

History of man-made lakes

Construction of man-made lakes and excavating canals for navigation and irrigation are two human activities that possibly co-originated with agriculture (Dumont, 1999). The first known man-made lake to be built was the Java Lake in modern-day Jordan constructed around 3,000 BC. This was followed by Sadd el-Kafara Dam in Egypt, built around 2950-2750 B.C. Subiacolake (Italy) was the first lake to be constructed in the first century of the first millennium AD. Major technological and engineering advances in man-made lake construction were made during the last century.

Nearly all the major rivers in the world have been dammed to create these lakes for different purposes. An estimated 900,000 man-made lakes are in operation worldwide (ICOLD, 2018). There are more than 57,000 large dams with dam height 15m or more across the world, while about 60,000 lakes have a volume larger than 10×10^6 m^3. Dams worldwide impound between 500,000 and 1,500,000 km^2 of water, the latter value equalling the surface area of all natural lakes. China has the highest number of man-made lakes with 23,000, followed by USA with 10,000. However, the largest man-made lake is in Africa (Lake Kariba) located in Zambia and Zimbabwe. In Nigeria, there are more than 300 man-made lakes and reservoirs with surface areas of 275,534.91 hectares constituting 12% of her total surface area. Yet, the number is still few in order to eradicate poverty, diseases, hunger, water, sanitation and hygiene (WaSH) challenges which are the core mandates of Sustainable Development Goals (SDGs). Out of the 17 goals of SGDs, man-made lakes could help in achieving 10, which include eradication of hunger and poverty, achievement of healthy livelihoods and good sanitation, provision of affordable and reliable energy, sustainable economic growth, productive employment and building of resilient infrastructure, promotion of industrialization and sustainable development of societies. Man-made lakes are able to integrate the three dimensions of sustainable development of man through their social, economic and environmental benefits.

Fig. 1. Lake Kariba, (Zambia and Zimbabwe) the largest man-made lake in the world

Poverty

Poverty is a condition of having insufficient resources, income or low wages. Poverty could also be described as multidimensional which is inability to provide basic human needs, such as food, water, shelter, clothing, sanitation, electricity and education, that are necessary for survival. Poverty could be absolute or extreme. Both have been defined by World Bank as an index of income inequality with extreme poverty to be people living on less than US $1 per day, and moderate poverty as less than $2 a day. The World Bank said the number people living on the less than $1.9 a day, which is the international poverty line - has fallen overall from 36% to 10%, but with rates rising in sub-Saharan Africa, with the region having half of the world extreme poor. In a 2018 UNDP survey, 1.3 billion people in 104 developing countries, which accounts for 74% of the world's population, live in multidimensional poverty. According to UNU-WIDER, The recent COVID-19 pandemic will plunge an extra 400 million people into extreme poverty with people living on less than $1.9 a day rising to 1.7 billion in developing countries with sub-Saharan Africa recording half of the rise. The ripple effects of the disease will increase poverty globally by 7% and stop 20 years of progress towards Sustainable Development Goals (SDGs).

According to Brookings Institution, as at the end of 2018, Nigeria overtook India as the country with the most number of people living in extreme poverty, with 90.8 million people in dire financial hardship - or nearly half the country's population. The World Poverty Clock estimated that six Nigerians slip into extreme poverty every minute and the country is now the poverty capital of the world (Table 1). It also reported that between now and 2030, 45.5 percent of the population or 120 million people will be living in extreme poverty and the country will host 25% of world extremely poor people The recent COVID-19 crisis will probably increase the number to about 160 million or 60% of the population, making the country to host 30% of global extremely poor people. The National Bureau of Statistics also reported in 2016 that, no fewer than 112 million Nigerians live below poverty line, with the poverty seen more in the informal sectors where 80% of Nigerians work. It should however be noted that, poverty exists all over the world (even in developed countries), it is the line in each country that determines the poverty index of that country.

Causes of poverty are multifaceted, but according to Omoniyi (2018), he listed primary factors leading to poverty to include: overpopulation, unequal distribution of resources, inability to meet good standards and high costs of living , inadequate education and employment opportunities, environmental degradation, certain economic and demographic trends, and lack of welfare incentives. The devastating effects of poverty include, lack of income for sustainable livelihoods, lack of access to education and other basic services, malnutrition and starvation, high rates of infectious disease, inadequate housing, social discrimination and exclusion, unsafe environments, crime and violence among others.

Table 1: Countries living in extreme poverty as share of world total

Country	Percentage of poverty as share of world total
Nigeria	15.7
Congo	10
India	8
Ethiopia	4.6
Tanzania	3
Bangladesh	2.3
South Africa	2.3
Indonesia	2.1
Yemen	1.6
Brazil	1.1
China	0.9
Pakistan	0.3
US	0.3
Mexico	0.3

Source: World Poverty Clock 2019.

Poverty is not from God, it is man-made. The Quran 6:151 says "We provide sustenance for you and for them". Quran 2:268 also says "the evil one threatens you with poverty and bids you to conduct unseemly. Allah promises you his forgiveness and bounties". Prophet Muhammad (SAW) also said "Poverty is an unwanted situation from which every Muslim should protect him/herself" (IbnMajah). The Bible in Deuteronomy 15:4-5 says "However, there will be no poor among you, since the Lord will surely bless you in the land (including water) which the Lord is giving you as an inheritance to possess, if only you listen obediently to the voice of the Lord, to observe carefully all this commandment which I am commanding you today". Poverty is also not by accident, it is caused by actions of man through his commissions or omissions and only HE (man) can eradicate it through his actions and commissions, one of which are Man-made lakes. The Yorubas always say "Igbelowowa" meaning wealth is in the bush, but today, "Inuomilorowa" meaning riches are inside water.

Fig. 2a. Exhibition of poverty

Fig. 2b. Poverty in display

Man-made lakes and poverty eradication

Man-made lakes provide an entry point into every aspect of human life and could eradicate poverty by uprooting the causes and dealing with the effects. This could be achieved through unparalleled benefits derivable from the lakes in the following ways:

Domestic water supply, sanitation and hygiene: Man-made lakes offer safe drinking water sanitation and hygienic (WaSH) facilities which is a precondition for healthy living andsocio-economic development as well as success in the fight against poverty and hunger. In Africa, an estimated 40 billion hours of each year is spent by women and children seeking water, thereby perpetuating poverty and poor health. In Nigeria, 80% of the populace have no access to potable water. One person in 50 has little choice but to use potentially harmful sources of water, while billions of people are locked in a cycle of poverty and diseases which stem from inaccessibility to safe drinking water, inadequate sanitation and poor hygiene as a result of lack of provision of man-made lakes to provide treated domestic water supply. The recent Covid-19 pandemic was exacerbated in many countries due to lack of potable water to wash hands regularly and inadequate social distancing when fetching water from long distances mostly from unhygienic sources.

Fig. 2c. Lack of drinking water is the first prerequisite of poverty

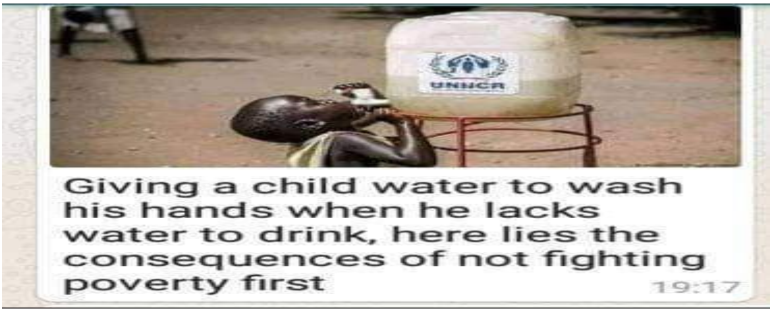

Fig. 2d. Provision of water is the first step in fighting poverty

Industrial water supply: Man-made lakes have facilitated industrial growth with the lakes supplying water to the industries. This has helped in development of the communities where such lakes are situated through provision of employments, roads, markets, hospitals, etc.

Irrigation: About 20% of cultivated land worldwide is irrigated through man-made lakes. This irrigated land produces about 40% of worldwide food supply and employs 30% of the population. Irrigation also accounts for about 75% of the world water consumption outweighing domestic and industrial water supplies. Irrigation has helped in achieving sustainable development goals of poverty and hunger reduction in many developing countries through food security, employment and income generation. It is estimated that 80% of additional food production will come from irrigation by 2025.

Hydroelectric power generation: The importance of electricity in today's life cannot be overemphasised as provision of electricity is tied to poverty reduction. Man-made lakes provide renewable hydropower energy with supply from large dams accounting for about a quarter of the world's total supply of electricity. About 25% of the worldwide generation of electricity and 90% of renewable electricity is attributable to hydroelectric dams. For instance, The Gorges dam in China generates 22,500 megawatts daily, while all hydropower lakes in Nigeria generate an average of 3700 megawatts daily. No wonder, we are experiencing energy crisis in Nigeria which is exacerbating the poverty level in the country.

Fish and bird production: Man-made lakes have productive fisheries than the original rivers on which the lakes were built. Fish species in these lakes could be artisanally and commercially exploited to provide protein, employment, income and livelihoods to the people. Fish contributes significantly to the GDP and foreign exchange earnings of a country. Fish contribute generally to 17 percent of animal protein and 6.7 percent of all protein consumed by the world population (FAO, 2018). Potential for cage fish culture in man-made lakes is great. A

$30m^3$ cage can produce 9 tons of catfish annually; the number of tons of fish that can be produced through this system will depend on the size of the lake. Cage fish culture if practiced in these lakes will increase fish supply for local consumption, create employment and generate millions of dollars through exportation thereby helping in eradicating poverty. Man-made lakes are sources of ornamental fishes for aquarium trade which could similarly increase foreign exchange earnings of the country. Aquatic birds (including their eggs) which are abundant in these lakes could be harvested and used as food (protein source), pets, ornaments, medicines, etc. all of which could generate employment and income for poverty eradication.

Waterborne diseases control: Creation of man-made lakes could help in eradicating vectors of waterborne diseases, thereby increasing livelihoods. The lacustrine conditions of lakes usually affect the survival of many vectors of waterborne diseases. Thus, man-made lakes offer good water quality, sanitation and hygiene (WaSH) which are fundamental for healthy living, poverty reduction and socio-economic development. Building of man-made lakes will reduce the amount of money spent on control and treatment of waterborne diseases. About $500 million is spent annually in USA and $60 billion in India to treat water-related illnesses.

Recreation and Tourism: Man-made lakes are good sites for recreation and tourism. Sport fishing, angling, swimming, diving, boating, bird watching, sightseeing, picnicking, camping, etc. are all activities done on the lakes which generate employment, income, revenue and contribute to the economy of the area where the lakes are situated through lodging, transportation, levies etc. 100-acre lake could generate millions of Naira in revenue from recreation and tourism. For example, $10 billion is generated annually from man-made lakes in the state of Michigan, USA from recreation and tourism, while $105 billion is spent annually by bird watchers at Lake Manyas in Turkey. The lakes themselves are sights of attraction and enhancement of the environments and landscapes.

Navigation: Man-made lakes provide one of the cheapest, safest and convenient ways of transportation through inland waterways navigation. Nigeria has about 10,000 km waterways (second longest in Africa) which if developed through dredging could provide transportation of goods and people, thereby complementing highway transportation and giving impetus for industrial growth, tourism, job opportunities and socio-economic uplift of the people. These lakes could generate revenue to the tune of 100 billion Naira annually and provide employment to about 100,000 people directly and indirectly through water transportation.

Flood and sediment control: Amongst the functions of man-made lakes is flood and sediment control. Hoover dam, Tennessee Valley dam and Three Gorges dams are examples of man-made lakes that are have been used for flood control. In 2005 and 2011, extreme amounts of precipitation, inadequate and possible mismanagement of man-made lakes contributed to widespread flooding around New Orleans in the USA (during Hurricane Katrina) and in Bangkok, Thailand. More than 30000 deaths were recorded in both incidents, along with destruction of homes and the closing of more than 1,000 industrial facilities. The flood had severe repercussions for global economy as supply chains in the electronics, automotive and food industries were affected. This scenario has also occurred recently in Nigeria, where severe flooding of farmlands around River Niger on account of lack of man-made lakes to contain the flood. This incident affected farmers and food production, leading to food shortages, rise in inflation, and loss of income, thereby aggravating the existing poverty among the people. Sedimentation could jeopardize water supply, recreational and aesthetic values, biodiversity assemblages and other beneficial uses of a lake. This could make the eradication of poverty through these lakes intricate. With construction of lakes for sediments control, eradication of poverty could be easily attainable. Man-made lakes trap 25% of the sediment load before it reaches the oceans (Vorosmarty and Sahagian 2000).

Water and biodiversity conservation: Man-made lakes are the best method of conserving water to ensure water is available all the year round for various uses. Also, aquatic biodiversities can be conserved against extinction in these lakes through the application of conservation strategies as highlighted by Helfman (2007) and Mustapha (2009). The use of the lakes for conservation of water and biodiversity will bring poverty to the barest minimum through provision of employment, income and sustenance of resources to meet today and future livelihood needs.

Other resources of man-made lakes that could be harnessed to eradicate poverty: Many invertebrates and vertebrates species which live in these lakes are sources of food, ornaments, and medicine for humans. These species could be harvested and cultured to provide food security, income and employment among the people. They include many species of zooplankton, annelids, molluscs, insects, crustaceans, echinoderms, amphibians, reptiles, birds and mammals. Similarly, many phytoplankton species and aquatic macrophytes inhabiting man-made lakes are used as food, fish feed, fodder, medicine, ornaments, production of biofuels, fertilizers and treatment of waste water. Like the animals, these plants could also be harvested or cultured in the lakes to eradicate poverty through their uses as food, medicine, income and employment generations.

Fig. 3. A recreational lake

Mr. Vice Chancellor sir, Man-made lakes have been critical to the establishment of civilizations throughout human history. From ancient times, civilizations have been established based on proximity to water which is usually impounded by man in lakes and reservoirs. Man-made lakes have facilitated industrial, economic and societal growth and have been able to reduce, alleviate and eradicate poverty in many developed and developing countries. Nigeria should not be an exception, we should therefore key in to the program. Direct economic values of man-made lakes have been estimated at $6.5 trillion USD/year, (Costanza et al. 1997). This is possible because of the numerous benefits of man-made lakes. But, for most of these benefits to be achievable, sustainable and maintenance of good quality and quantity water and biodiversitiesin these lakes are of utmost importance.

My research contributions

Mr. Vice Chancellor sir, this brings me to the works, studies, researches and community services I have done on various man-made lakes which have contributed to science of limnology, fisheries, aquaculture and toxicology, and benefiting the society to eradicate poverty and advance human development.

Limnological researches on man-made lakes, reservoirs and ponds

University of Ilorin (University mini-campus) pond, Ilorin, Kwara State

Mr. Vice Chancellor sir, I started my limnological researches from this University (*Ile latikoeso rode*) on a temporary pond located at the former mini-campus of the University and this gave rise to my first publication exactly 21 years ago. The aim was to use the pond for the breeding of fishes for the University community using extensive or semi-intensive system of culture. Limnological variables and biotic components such as planktons, neustons and macrophytes in the pond were found to be optimal for fish breeding. The notorious water hyacinth *Eichhorniacrassipes* was found in the pond and this showed that the weed is not only a nuisance in lakes and rivers, but could also infest ponds and temporary waters (Mustapha, 2000; Mustapha and Omotosho, 2002).

University of Ilorin (Main Campus) Lake, Ilorin, Kwara State, Nigeria

Pre-impoundment studies of the limno-chemistry, flora and fauna of Oyun Lake at the University of Ilorin main campus before the construction of the lake started was carried out to document the hydrobiological status, productivity and physico-chemistry of the impounding river. The data is now been used for subsequent post-impoundment studies, including changes in the limnoecology and biotic composition of the lake. The water quality of the lake was found to be good, while a high number of phytoplankton, zooplankton, benthos and fish species were present (Mustapha and Yusuf, 2002; Mustapha 2003) (Table 2). Thus, the lake was found to be excellent for the purpose of its creation and for other functions such as recreation that could be superimposed on it. No obnoxious aquatic weed was recorded in the lake, but suggestion was made for the lake to be constantly monitored for water quality changes, weed invasion and eutophication.

Fig. 4. University of Ilorin Lake, Ilorin, Nigeria

Table 2**:**Limnologicaland biotic properties of University of Ilorin Lake, Ilorin, Nigeria

Mean physico-chemical factors.	Phytoplankton	Zooplankton	Benthic species	Fish species
Temperature(^oC) - 24.5	*Spirulina*sp	*Daphnia*sp	*Bulinusglobosus*	*Tilapia zillii*
Transparency(cm) - 17.1	*Anabaena*sp	*Bosmina*sp	*Bulinusforskalii*	*Sarotherodon galilaeus*
Current(cm^{-s}) - 27.9	*Coelosphariemum*sp	*Sida*sp	*Biomphalaria*sp	*Brycinus nurse*
DO (mg^{-l}) - 6.4	*Closterium*sp	*Cyclops*sp	*Aspathariasinuata*	*Labeosenegalensis*
PO_4 (mg^{-l})- 2.01	*Netrium*sp	*Diaptomus*sp		*Barbusoccidentalis*
NO_3 (mg^{-l}) - 3.75	*Melosira*sp	*Keratella* sp		*Schlibesmystus*
Ca^{2+} (mg^{-l})- 19.45	*Synedra*sp	*Ceratium* sp		*Synodontisgambiensis*
Mg^{2+}(mg^{-l}) - 14.1	*Asterionella*sp	*Stentor*sp		*Clariasgariepinius*
SiO_2(mg^{-l}) – 84.3	*Chlorella*sp			
Conductivity (μS^{-cm}) – 91.5	*Pediastrum*sp			
pH – 7.03				

Sources: Mustapha and Yusuf (2002); Mustapha (2003)

Moro Lake, Sobi, Ilorin, Kwara State, Nigeria

The lake is the second largest of the four lakes in Ilorin, Kwara State. It is used primarily for domestic water supply and artisanal fish production. My researches on the lake were the first to be done by any researcher. Limnological factors, biotic components and effects of human activities on the lake watershed were investigated to evaluate the water quality, productivity and check list the fisheries resources for better management and sustainable exploitation of the fish species. High nitrate and phosphate concentrations were found in the lake which was attributed to run-off of nitro-phosphate fertilizers from nearby farm lands (Mustapha, 2005; Mustapha and Omotosho 2006b) which led to cultural eutrophication in the lake, thereby deteriorating the water quality, altering the food web structure and loss of the lake's productivity and thus increasing the cost of water treatment. The fisheries of the lake revealed the dominance of planktivorous species (Cichlids) and benthophagous species (Mochokidae) (Table 3). Heavy metal concentrations in the tissues and organs of two exploited fish species in the lake (*Parachannaobscura* and *Mormyrusrume*) were assessed, the heavy metals accumulated by the species fell within permissible limits recommended by FAO/WHO (2011) for human consumption and thus no health risk was found in the consumption of the species (Amali and Mustapha, 2019). However, obnoxious fishing practices (fishing with chemicals) and municipal abuses of the lake stemming from population increase around the lake were some of the human activities observed to be causing degradation to the lake functional use (Mustapha, 2006a). There was explosiveness of aquatic macrophytes on the lake which was linked to the cultural eutrophication. The effects of these excessive weeds affected the fish and fisheries in the lake and posed some public health implication to the users of the lake where *Bulinus* and *Biomphalaria* snail species which are vectors of schistosomiasis (water borne disease) were found attached to the weeds (Mustapha 2008a; Mustapha 2008b). The problematic water hyacinth *Eichhorniacrassipes* was found on the lake and the management authority of the lake approached me to help in eradicating the weed. However, government bureaucracy did not allow the research of eradicating the weed to begin, let alone succeed.

Fig. 5a.Moro lake, Ilorin, Nigeria

Fig. 5b. Canoe used for artisanal fisheries in Moro Lake

Table 3:Limnological parameters and fish assemblages of Moro Lake, Ilorin, Nigeria

Mean physico-chemical factors	Aquatic macrophytes	Benthic species	Fish species
Temperature (^oC) – 25.1	*Cyprus iria*	*Nais*	*Oreochromisniloticus*
Transparency (cm) - 40.7	*Ludwigiahyssopifolia*	*Tubifex*	*Sarotherodongalilaeus*
Current velocity (cm^{-s}) – 43.8	*Salvnianymphellula*	*Bulinus*	*Tilapiazillii*
DO (mg^{-l}) – 5.02	*Eichhormiacrassipes*	*Melanoides*	
PO_4 (mg^{-l}) – 0.3	*Nymphae lotus*	*Asphatharia*	*Synodontisgambiensis*
NO_3(mg^{-l}) – 6.8	*Pistiastratiotes*	*Biomphalaria*	*Brycinus nurse*
Ca^{2+}(mg^{-l}) - 24.7			*Labeocoubie*
Mg^{2+} (mg^{-l}) - 13.5	*Heterantheriacallifolia*		*Barbusoccidentalis*
SiO_2(mg^{-l}) – 31.0			
SO_4 (mg^{-l}) – 10.1			
Conductivity (μS^{-cm}) – 76.5			
pH – 7.3			

Sources: Mustapha and Omotosho (2005; 2006) Mustapha (2006)

Oyun Lake, Offa, Kwara State, Nigeria

Mr. Vice Chancellor sir, I conducted a comprehensive detailed research of the limnology, fish, fisheries, conservation, management, etc. of the lake, to the extent that if you search the internet about researches on Oyun lake/reservoir at Offa, Nigeria, my name will come up. The report of the researches could take the whole of this inaugural lecture. However, I will summarize some of my significant findings and contributions to the lake ecology, utilization sustainability and management.

The choice of the lake was borne out of Prof. V.L.A Yoloye's (of blessed memory) thought that three big industries situated in the town would be dumping effluents into the lake and I should investigate the effects of these effluents on the water and biotic components of the lake. To our greatest disappointment, these industries (none exists today) were situated downstream of the lake and could not be dumping their effluents at the upstream where the lake is situated. In spite of this disappointment, I decided to study the lake, since no limnological and fisheries researches has been done on the lake making it the first research work on the lake.

The Oyunlake was constructed in the sixties for supply of water to the people of Offa and environs. Sixteen physico-chemical properties of the lake were used to assess its water quality which showed the lake to be soft, with low salinity and turbidity, high transparency and dissolved oxygen and low chemical oxygen demand (Table 4).Electrical conductivity and total dissolved solids were in the tolerable limit for drinking water. The lake has excellent water quality index using WHO (2017) standard. However, nitrate and phosphate concentrations were a bit higher than normal for drinking water. Run-off of nitro-phosphate fertilizers and cow dungs into the lake where human activities (farming, grazing, cassava fermentation etc.) and other competing uses of the lake by various stakeholders were pronounced were found to cause cultural eutophication (Mustapha 2008c). The eutrophication resulted in the presence of some toxic blue-green algae (Mustapha, 2009a; Mustapha

2009b, Mustapha, 2010d). The result was published in an impact factor journal and is one of the most downloaded publications of the journal. The publication also became a reference all over the world for assessing water quality of tropical lakes and reservoirs using physico-chemical factors with over 200 citations (and still been cited) locally and internationally (Google Scholar). The lake is highly productive in its fisheries with a lot of artisanal fisheries carried out in it. The potential fish yield was estimated at 125.75kg/ha which was higher than lakes of similar nature. The high fish yield was due to the high conductivity and low mean depth of the lake (Mustapha 2009c). Eighteen fish species in fourteen genera and nine families were recorded with cichilds dominating the fisheries (Mustapha 2010a). The high diversity and abundance of the fish species was attributed to the presence of rich phytoplankton and zooplankton assemblages of the lake (Mustapha, 2009d). Two important commercially exploited fish species *Heterotisniloticus* and *Barbusoccidentalis* were found to be declining, threatened and could face extinction in the lake. Various interacting factors such as overexploitation, watershed abuses and eutrophication were adduced for the declining population (Mustapha, 2012a). Conservation strategies were suggested to save the species from further decline, possible extinction and loss of livelihoods (Mustapha 2009e; Mustapha 2010b). Many invertebrate taxa were recorded in the riverine, unpolluted and devoid of human activities section of the lake as compared to the dam site where human activities were more pronounced resulting in the discharge of high content of organic loads (Mustapha and Yakubu 2015). A molluscan bivalve *Asphathariasinuata* constituted 35% of the taxa, it is an economic species (rich in protein) that could be harvested in large numbers and sold after deshelling. The shell could also fetch money because it is used for various purposes such poultry and fish feed (rich in calcium), ornaments etc. Trend in the levels of heavy metals concentrations in the lake was Ni > Fe > Zn >Pb> Cd > Cu >Hg, with the dam site showing elevated concentrations (Mustapha and Ewulum, 2016c). In general, the concentrations of the heavy metals were still within the range recommended by WHO (2017) in drinking water, except nickel and cadmium which showed concentration above the WHO limit in the dam site (Table 5).

Fig. 9a.Oyun Lake, Offa, Nigeria

Fig. 9b. Artisanal fisherman on Oyunlake, Offa, Nigeria

Table 4: Water quality parameters, fish and macrobenthic assemblages in OyunLake, Offa, Nigeria

Mean Water quality parameters	Fish species composition and abundance	Macrobenthic species composition and abundance.
Temperature (^oC) – 26.3	*Oreochromisniloticus* – Highly abundant	*Asphatharia* – Highly abundant
Transparency (m) – 1.12	*Tilapia zillii* – Highly abundant	Umio – Highly abundant
Current velocity (cm^{-s}) – 36.3	*Sarotherodongalilaeus* – absent	*Bulinus* – Sparse
DO (mg^{-1}) – 6.5	*Hemichromisfasciatus* – sparse	*Biomphalaria* – Common
COD(mg^{-1}) – 1.9	*Mormyrusrume* – Abundant	Tubifex – Common
CO_2(mg^{-1}) – 2.3	*Mormyropsdeliciosus* – Common	Nais – Common
NO_3 (mg^{-1}) – 3.9	*Gnathonemuscyprinoides* – Sparse	Chironomous - Abundant
PO_4(mg^{-1}) – 1.5	*Hyperopsusbebe* – Sparse	
SO_4(mg^{-1}) – 13.2	*Syndontisschall* – Common	
SiO_2 (mg^{-1}) – 45.0	*Synodontisgambiensis* – Absent	
Ca^{2+} (mg^{-1}) – 32.0	*Labeocoubie* – Abundant	
Mg^{2+} (mg^{-1}) – 19.0	*Barbusoccidentalis* – Rare	
Hardness (mg^{-1}) – 50	*Clariagariepinus* – Common	
Alkalinity (mg^{-1}) – 42.5	*Clariasangularis* – Common	
pH – 7.5	*Heterotisniloticus* – Rare	
Conductivity (μS^{-cm}) – 129.6	*Brycirus nurse* – Abundant	
TDS (mg^{-1}) – 86.9	*Schilbemystus* – Common P*arachannaobscura* -Common	

Sources: Mustapha (2008c; 2009a, b, c, d, e; 2010a, b)

T a b l e 5. Comparison of the concentration levels of heavy metals in Oyun Lake, Offa, Nigeria with WHO (2017) standard.

Heavy metals	Maximum concentration in Oyun reservoir (mg/l)	WHO standard (mg/l)
Nickel (Ni)	0.50	0.02
Iron (Fe)	0.42	0.5
Zinc (Zn)	0.40	3
Lead (Pb)	0.021	0.01
Cadmium (Cd)	0.29	0.003
Copper (Cu)	0.12	2
Mercury (Hg)	0.01	0.001

Source: Mustapha and Ewulum (2016c)

Asa Lake, Ilorin, Kwara State, Nigeria

Aquatic birds assemblages of the lake was surveyed which was the first of such research in the lake or any lake in Kwara State. A total of seventeen species in nine families were found (Table 6) with high abundance in the rainy season (Mustapha and Aiyeleso, 2018). The limnological heterogeneity of the lake provided a good habitat for the assemblages of the birds. Waterfowl and whistling duck were the most abundant birds. These birds (including their eggs) could be caught and used as food (source of protein), pets, ornament, traditional and orthodox medicines. The lake could also serve as recreation for bird watching which could generate millions of naira to the economy of the state. Recommendations were made for the continued residency and visit of the birds to the lake, which include Lake Best Management Practices (LBMP) to prevent water quality deterioration, sedimentation, anthropogenic inflow, while continuous monitoring of the birds (ornitho-monitor) should be done regularly.

Fig. 6. Bird species of Asa Lake, Ilorin, Nigeria

Table 6**:** Birds species of Asa Lake, Ilorin, Nigeria

Common name	Scientific name	Family	Percentage abundance	Sighting and percentage frequency.
Grey Heron	*Ardeacinerea*	Ardeidae	3.81	Fs; Lc
Black Heron	*Egrettaardesiaca*	Ardeidae	3.11	Fs; Lc
Purple Heron	*Ardeapurpurea*	Ardeidae	3.89	Fs; Lc
Cattle Egret	*Bubulcus ibis*	Ardeidae	10.63	C; Co
Water Fowl	*Anasacuta*	Anatidae	42.21	C; Co
Whistling Duck	*Dendrocygnabicolour*	Anatidae	10.39	C; Co
Blackhead Lapwing	*Vanellustectus*	Charadriidae	2.37	R; Re
Spur winged lapwing	*Vanellusspinosus*	Charadriidae	2.11	R; Re
Wattle lapwing	*Vanellussenegalus*	Charadriidae	1.35	R; Re
Blue breasted Kingfisher	*Halcyon malimbica*	Alcedinidae	3.27	Fs; Lc
Pied Kingfisher	*Cerylerudis*	Alcedinidae	2.04	R; Re
Pygmy Kingfisher	*Ispidniapicta*	Alcedinidae	1.51	R; Re
Sand Piper	*Actitishypoleucos*	Scolopacidae	2.12	R; Re
Laughing Dove	*Streptopeliasenegalensis*	Columbidae	5.16	Fs; Lc
Shikra	*Accipiter badius*	Accipitridae	2.22	R; Re
Fish Hawk	*Pandionhaliaetus*	Pandionidae	1.94	R; Re
African jacana	*Actiphilornisafricanus*	Jacanidae	0.67	R; Re

Key: R= rare; Fs= Frequently seen; C= Common; Re= 0.00- 3.00%; Lc= 3.01- 9.99%; Co= 10.00- 100%
Source: Mustapha and Aiyeleso (2018).

Apodulake, Malete, Kwara State, Nigeria

This is a small lake created for the supply of water to Kwara State University, Malete and other towns. My research was the first on the reservoir where limnological variables and fish species assemblages were assessed to determine the water quality and fish fauna of the reservoir for sustainable exploitation, conservation and management. Nitrate and phosphate were high showing a case of cultural eutrophication, heavy metal concentrations were low and generally the water quality is good (Table 7). However, cyclops species which are intermediate hosts of *Dracunculusmedinensis*, the nematode that causes dracunculiasis (Guinea worm) were found in the reservoir where the locals drink the water without any form of treatment, since the water treatment plant has not been completed over the years. This could lead to public health problem of guinea worm infestation and epidemics in the area if the water continues to be consumed unfiltered or untreated. Seventeen fish species in eight families were recorded, with *Gnathonemus*, *Tilapia* and *Brycinus* species highly abundant. An uncommon fish in many lake waters of Kwara State, the West African lungfish (*Proptopterusannectens*) was found in the lake, though their numbers were very minimal (Oladipo et al. 2018). Conservation efforts were advocated for the protection of the species.

Fig. 8a.Apodu Lake, Malete, Nigeria

Fig. 8b. Wooden canoe used for artisanal fisheries in Apodulake

Table 7:Limnological assessment and fish assemblages of Apodulake, Malete, Nigeria

Mean Water quality parameters	Fish species composition and abundance
Temperature (^{o}C) – 28.4	*Oreochromisniloticus* – Highly abundant
Transparency (cm) – 147.1	*Tilapia zillii* – abundant
Current velocity (cm^{-s}) –14.2	*Sarotherodongalilaeus* – sparse
DO (mg^{-l}) – 5.5	*Hemichromisfasciatus* – sparse
NO_3(mg^{-l}) – 18.8	*Mommyrusrume* – Abundant
PO_4(mg^{-l}) – 0.97	*Mormyropshasselquisti*– Common
Cl_2(mg^{-l}) – 0.88	*Gnathonemuscyprinoides* – Sparse
Fe (mg^{-l}) - 0.16	*Gnathonemussenegalensis*- Abundant
Cr (mg^{-l}) - 0.08	*Hyperopsusbebe* – Sparse
Conductivity (µS^{-cm}) -90.14	*Synodontisschall* – Common
TDS (mg^{-l}) - 47.00	*Synodontisgambientis* – Common
	Labeocoubie – Abundant
	Auchenoglanisoccidentalis– Rare
	Clariasgariepinus – Abundant
	Clariasangularis – Common
	Heterotisniloticus – Rare
	Brycinus nurse – Abundant
	Protopterusannectens – Rare

Source: Oladipo et al. (2018)

Agbalake, Ilorin, Kwara State, Nigeria

This is the first man-made lake in Kwara State created in 1952 for water supply to Ilorin town. The limnological assessment of the lake based on the physico-chemistry and biological characteristics shows the water quality to be good and are within limits for Nigerian Standard for Drinking Water Quality (NSDWQ). Heavy metal concentrations were very low, and the lake contained various phytoplankton, zooplankton, benthic and fish species diversity (Table 8). The most serious problem facing the lake is that of siltation where heavy loads of sediments are eroded into the lake yearly leading to reduction in depth, high turbidity, low transparency and low plankton and fish assemblages in the lake (Mustapha and Abodunrin 2021). Siltation of the lake was due to high rate of property development and indiscriminate dumping of anthropogenic materials within the watershed of the lake. Since the lake has not been designed to trap sediments, the lake may totally lose its drinking, aesthetic, tourism and fisheries functions and turned into a marsh in a few years to come if siltation is not halted.

Fig. 7.Agba Lake, Ilorin, Nigeria

Table 8**:** Limnological variables and biotic components of Agba Lake, Ilorin, Nigeria

Mean physico-chemical factors	Plankton species	Benthic species	Fish species
Temperature (^oC) – 24.5 ºC	*Synedra*	*Nais*	*Oreochromisniloticus*
Transparency (cm) - 55.3 cm	*Diatoma*	*Tubifex*	*Sarotherodongalilaeus*
Current velocity (cm^{-s})– 0.10 cm/s	*Melosira*	*Lymanea*	*Tilapia zillii*
DO (mg^{-1})– 5.08	*Pleurococcus*	*Melanoides*	*Clariasangularis*
PO_4 (mg^{-1}) – 0.28	*Anabaena*	*Aspatharia*	*Synodontisgambiensis*
NO_3 (mg^{-1}) – 1.47	*Spirulina*	*Biomphalaria*	*Brycinus nurse*
Ca^{2+} (mg^{-1}) - 1.40	*Ceratium*		*Labeocoubie*
Mg^{2+} (mg^{-1}) - 4.59	*Dapnia*		
SO_4 (mg^{-1}) – 51.32	*Artemia*		
Conductivity (μS^{-cm}) – 62.72	*Nauplius*		
TDS (mg^{-1}) – 41.82			
Turbidity (NTU) – 1.8			
pH – 7.56			
BOD (mg^{-1}) – 2.40			
Alkalinity (mg^{-1}) – 88.6			

Source: Mustapha and Abodunrin (2021)

JebbaLake, Jebba, Nigeria

The lake is a hydroelectric dam on the River Niger. Ichthyofaunal diversity and distribution on the lake were studied where a total of 9605 freshwater fishes belonging to 83 species, 43 genera, 24 families and 11 orders were recorded and identified using combined morphological and genetic analyses which facilitated accurate identification of some fishes to species level such as *Auchenoglanisoccidentalis, Claroteslaticeps, Hemichromisbimaculatus* and enabled the discovery of possible potential new species (*Ctenopoma*sp, *Malapterurus*sp and *Protopterus*sp) (Oladipo et.al. 2021). Family Mochokidae had the highest number of species, while Anabantidae, Dasyatidae, Notopteridae and Protopterridae had the lowest. High fish catch was recorded at the upstream, with Cichlidae dominating, while Mochokidae dominated the downstream. Higher fish catch and diversity were recorded from the downstream during the rainy season, while higher fish catch was observed from the upstream in the dry season. For sustainable fisheries in the lake, effective fishing regulations and community-based conservation are strongly advocated.

Fisheries and Aquaculture Researches

Mr. Vice Chancellor sir, my researches transcend limnology as I did a couple of researches in fisheries and aquaculture. This should be expected as fisheries and aquaculture take place in aquatic ecosystems.

Potential effects of climate change on artisanal fisheries and aquaculture in Nigeria

Nigeria is vulnerable to impacts of climate change through rise in annual mean temperature. Gas flaring in the Niger delta region is responsible for the increase in temperature and the associated global warming scenarios in Nigerian freshwater ecosystems. This has impacted negatively on artisanal fisheries and aquaculture which contribute 95% of our fish production and 0.5% of GDP in Nigeria. Climate change in the sector poses great danger to sustainable livelihoods and food security of the people, which could lead to increasing poverty level. The effects of climate change include fish kills, collapse of dams and fish ponds, damage to cages, low productivity of the water body, low fish production, low catch, and reduced fish species diversity, transport of invasive species into ponds, loss of fish stocks through flooding and vulnerability of cultured fish species to diseases (Mustapha, 2013a; Mustapha 2013b).

Fish welfare in artisanal fisheries and aquaculture

Fish welfare is not considered in fisheries and aquaculture in developing countries, whereas fish do feel pain (Huntingford et al. 2006). Various watershed activities in artisanal fisheries such as use of active and passive fishing gears, obnoxious fishing methods (use of chemicals, poisonous baits, explosives), use of motorized canoes which pollute the water body with oil, emissions, noise, and the engine's propeller impair fish welfare through stress, fear, injury and mortality (Mustapha, 2013c). Fish welfare is even more impaired in aquaculture, as the fishes are held in captivity against their ''will'' thus infringing on their rights to live in their natural habitat. Some of the aquacultural practices that compromise fish welfare include, aquaculture holding devices (AHD), water quality issues in the AHD, high stocking density, food and feeding regimes, handling, transport, netting, sorting, and harvesting, slaughter methods, unnatural light-dark photoperiods (Mustapha et al. 2014a) , induced breeding and genetic manipulations (Mustapha 2014b). The ways to achieve best fish welfare in aquaculture is to maintain the rights of fish, otherwise known as the five freedoms, as spelt out by FAWC (1996) (Table 9). Lack, deficiency or difficulty in providing any one of the freedoms is an indicator of poor welfare for the fish. We should remember that fishes also have rights in their own world.

Table 9**:** Five freedoms of animal welfare

Freedom from	Indicator of welfare impairment
Hunger and Thirst	Poor growth
Discomfort	Physical damage
Pain, Injury, Disease	Poor water quality
Abnormal behavior	Erratic swimming
Fear and distress	Increase in cortisol layer

Source: FAWC (1996)

Fish preservation with low-cost solar driers

One of the problems in fisheries is post-harvest losses of fishes, because they are perishable products. In order to minimise the losses, we developed five different low-cost solar fish driers made up of plastic, mosquito net, aluminium, glass, and glass containing black igneous stones to dry two fish species (*Clariasgariepinus* and *Oreochromisniloticus*) and compared them with traditional open sun drying, smoking kiln and electric open. The performance, efficiency and effectiveness of the driers were evaluated using time of drying to a final dried weight and organoleptic assessment of the final dried samples. The five driers were able to dry the fish samples. Plastic drier was least effective, drying *C. gariepinus* completely for 13 days and *O. niloticus* for 11 days, while the glass drier containing black stone was the most effective drying *C. gariepinus* and *O. niloticus* completely for 11 and 8 days respectively. Organoleptic assessment showed that the taste, flavour, odour, appearance, texture, shelf-life, and palatability of the fish samples were very good (Mustapha et al. 2014c). The proximate analysis of the dried fish samples showed that nutrient composition especially the moisture contents of the species was significantly reduced and the protein content was higher and compared favourably with the other methods of drying. The nutritional qualities of the fish samples dried by the solar driers were high, hygienic, better, more preserved and acceptable than the other methods (Mustapha et al. 2014d). Although, it took longer time to dry fish samples with the solar driers, their qualitative performances and cost-benefit analysis as compared with the other methods showed them to be pollution-free, (use renewable energy), save man-hour, energy and money, with no skill to operate, no maintenance, long life span and no cost in drying fish amongst their many advantages (Mustapha et al. 2014e). The glass drier containing the black stone was exhibited at the NUC research fair ‘laboratory to product’ research innovation held at Nnmadi Azikiwe University Awka, Anambra State in 2016, where it attracted a lot of visitors and patronage. We are in the process of improving it for patency.

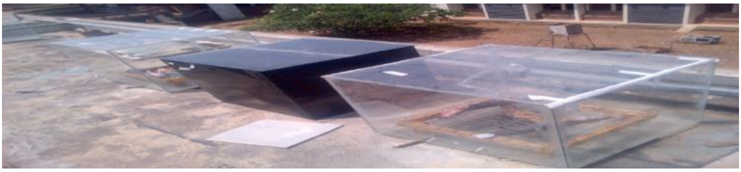

Fig. 10. The different low-cost solar fish driers

Antibacterial activities of aqueous extract of water lily (*Nymphaea lotus*) for fish preservation

Fish becomes perishable because of bacteria infestation. Many antibiotics for fish preservation pose health risk to humans and are becoming resistant. This led us to investigate the antibacterial properties of water lily (*Nymphaea lotus*) - an aquatic plant for the preservation of fish. We recorded 9 bioactive metabolites which showed antibacterial properties against gram-negative bacteria such as *Escherichia coli, Vibrio anguillarum, Pseudomonas fluorescens, Aeromonashydrophila* and *Salmonella typhi* (Adelakun et al. 2015). The plant is a promising source of organic antibiotic drug for fish preservation.

DNA bar coding of economically important freshwater fish species from North-central
Nigeria to uncover their cryptic diversity

We explored DNA bar coding as a molecular tool for identification of fish species from North-central Nigeria which was compared with morphological method to uncover cryptic lineage in the fish species. Our study showed that DNA bar coding was very efficient in species identification, which also uncovered their lineage diversity with 95.60% success (Iyiola et al. 2018). The study has contributed to the construction of DNA reference barcode data such as GenBank and BOLD for the identification of Nigerian freshwater fish species. This will aid in the management and conservation of the fishes in Nigerian inland water bodies and assist in resolving issue of ambiguousness in identification of morphologically similar species.

DNA Barcoding of Silver Butter Catfish (*Schilbeintermedius*)

The boundaries, patterns of genetic diversity, population structure and historical demography of *S. intermedius* (an economically important fish) across African river systems were investigated using mitochondrial DNA phylogeography and species delimitation tests. Our results revealed that *S. intermedius* comprises at least seven geographically defined matrilines, and their patterns of genetic diversity and population structure were consistent with adaptive responses to historical biogeographic factors and contemporary environmental variations across African river systems (Nneji et al. 2020). This suggests the influence of historical biogeographic factors and climatic conditions on population divergence of *S. intermedius* across African river systems. Thus, declining *S. intermedius* could be conserved through its DNA barcoding.

Optimizing the growth of *Clariasgariepinus* and *Oreochromicniloticus* through photoperiodic manipulations

Clariasgariepinus (African catfish) and *Oreochromisniloticus* (Nile Tialpia) are two of the most cultured fish species in Nigeria. In order to obtain faster growth of the species in less time, we designed a low-cost technique using photoperiodic manipulations where the fishes were reared in 24-hour total light and 24-hour total darkness and compared with their 12-hour normal day and 12-hour night life cycles. Our results showed that *C. gariepinus* grew better (length and weight) and reached table size in less time in 24D: 0L, while *O.*

niloticus showed faster growth in 24L: 0D. The reasons adduced for this growth was better food conversion efficiency and reduction of stress in the dark for *C. gariepinus* and in the light for *O. niloticus* (Mustapha et al. 2012b; Mustapha et al. 2012c). This simple low-cost technique of photoperiodic manipulations could be used by fish farmers to obtain faster growth of fish in less time.

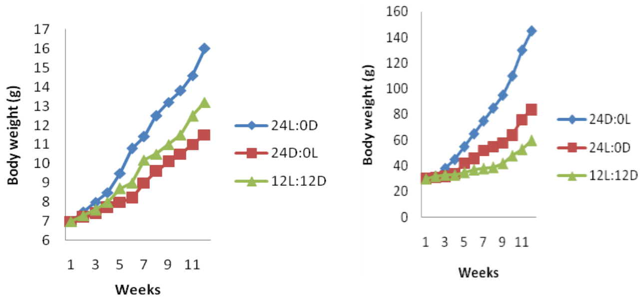

Fig. 11a.Photoperiodic manipulations in *O.niloticus*Fig. 11b. Photoperiodic manipulations in*C. gariepinus*

Sources: Mustapha et al. (2012b, c)

Induced breeding of *Clariasgariepinus* using different doses of saline diluted ovaprim

Artificial propagation of *C. gariepinus* involves inducing the fish with costly synthetic hormones such as ovaprim. To reduce the high cost of induced breeding in this fish using ovaprim, we diluted the hormone with different doses of normal saline to see the efficacy in the spawning, hatchability and survival of the fries. We found out that normal saline diluted ovaprim at 50% inclusion level will induce breeding with similar effectiveness comparable to generic ovaprim (Olumuji and Mustapha 2012d). With this, 50% of the cost incurred on the hormone can be saved without jeopardizing its performance.

Comparative effects of local and foreign commercial feeds on the growth and survival of *Clariasgariepinus*

Feed accounts for 60% of the cost of fish production. Due to high cost of imported feed, many cheaper, local feeds were formulated, leading to the proliferation of fish feed industries in Nigeria. Most fish farmers opt for these local feeds without knowledge of their proximate composition, formulation and processing. We compared the growth response and survival of *C. gariepinus* fed with local and imported commercial feeds. The result showed that local feeds produced poor growth and high mortality compared to imported feeds. The poor growth and high mortality was due to the poor quality of the feed, which contained high carbohydrate, fibre and anti-nutritive factors, low protein, lipid and ash contents as well as inability of the feeds to float in water (Mustapha et al. 2014f). Comparing the economics of two feeds, foreign feeds which the farmer thought was expensive, produced higher growth in less time as compared to local feeds. So it is a case of kobo wise, naira foolish for the farmer.

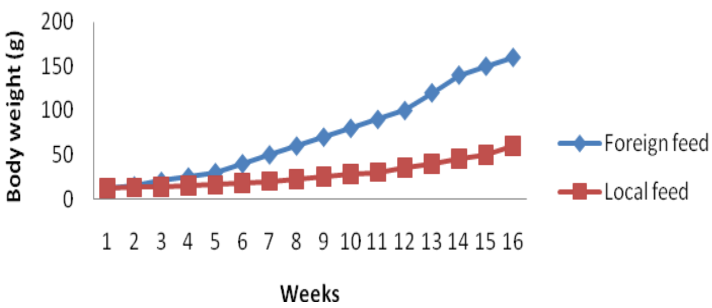

Fig. 12. Growth response of *C. gariepinus* to local and foreign feeds
Source: Mustapha et al. (2014f)

Use of wild plants as potential fish feed ingredient in *Clariasgariepinus*

In an attempt to formulate local fish feed using locally available ingredients for *C. gariepinus*, we looked at the use of some wild plants, *Sterculiasetigera* and *Cissuspopulnea* as potential fish feed ingredients. This is to reduce the competition between man and fish in the use of grains and legumes for fish feed. Our result showed that nutrient composition of *S. setigera* seeds was high in carbohydrate and fats for energy. The seeds also contained essential minerals and vitamins necessary for fish growth and reproduction. Similarly, improved weight gain and no mortality was recorded when *Cissuspopulnea*root meal was fed to the fish (Adelakun et al. 2014a; Adelakun et al. 2014b). The inclusion of *S. setigera* seeds and *Cissuspopulnea* root meal in fish feed ingredients will make fish feed to be cheaper and a replacement (up to 50%) for the traditional grains and legumes used in fish feeds.

Edible frog (*Hoplobatrachusoccipitalis*) culture/farming

Against the increasing cost of fish and overexploitation of edible frog *Hoplobatrachusoccipitalis* from the wild in Nigeria, we decided to look at the possibility of culturing the species from the tadpole stage to full metamorphosis. Since frogs live in water, the success of their culture will depend on the operational water quality of the pond where they are raised. A good range of water quality values were established for the successful culture of the species (Mustapha, 2018a). One of the challenges to culturing frogs in ponds is the acceptability of artificial diets at tadpole stage. We experimented on three types of diets namely; duckweed (*Lemma paucicostata*), pawpaw leaf (*Carica papaya*) and coppens fish feed. The tadpoles accepted and grew better when fed with duckweed, followed by pawpaw leaf, while fish feed was least accepted (Mustapha and Bello 2018b). We concluded that edible frog could be cultured from tadpole stage with good water quality and feeding with duckweed.

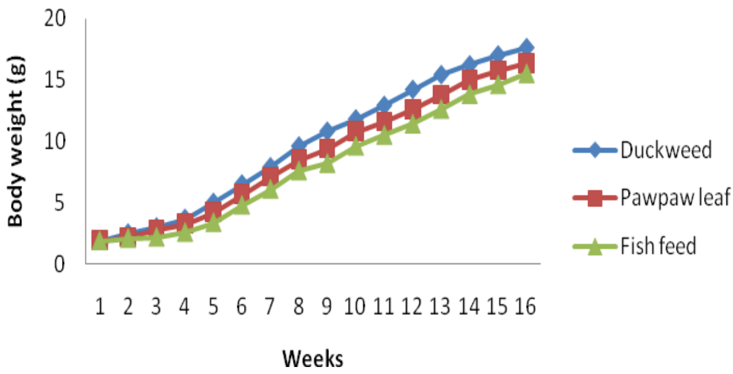

Fig. 13. Growth rate of Edible frog *Hoplobatrachusoccipitalis*to three types of feeds
Source: Mustapha and Bello 2018b

Aquatic toxicological researches

Mr. Vice Chancellor sir, my journey into aquatic toxicology researches was accidental. One day, I was called upon by a fish farmer who noticed that his fishes were dying in his ponds. Ordinarily, fishes don't just die en masse except when there are issues with water quality and/or incidence of diseases and parasites in the pond. Fortunately, I was able to detect the problem in the ponds and found a solution to it. With that experience, I decided to conduct some toxicology researches in fish ponds.

Comparative assessment of water quality of four types aquaculture ponds under different culture systems

Water quality parameters in natural, earthen, concrete and collapsible ponds under extensive, semi-intensive and intensive fish culture systems were investigated to know sources of toxic materials which could affect fish health and performance in the ponds. Surprisingly, natural pond under extensive system showed the best water quality, followed by earthen pond under semi-intensive system. Concrete and collapsible ponds have their water quality compromised. This was due to the intensive system carried out in the ponds where feeding is done by using commercial feeds (Mustapha 2017a). There is no pond or culture system that is absolutely perfect; they all have their merits and demerits and different water quality challenges, which could be addressed by good pond management such as regular measurement of the water quality parameters to check for abnormalities in values to which corrections should be made immediately.

Ammonia, chromium and copper toxicities in fish ponds

We looked at most common toxic compounds and elements causing fish mortality in ponds and found that ammonia, chromium and copper were the most culpable. Sources of these toxic materials in ponds include feed and materials used in the ponds. High feeding rate in intensive system is often the cause of elevated unionized ammonia concentration in ponds. Ammonia, copper and chromium concentrations above 0.2 mg/l, 0.02 mg/l and 0.05 mg/l in ponds are toxic to fish and often lead to severe mortalities (Mustapha and Akinshola 2016a; Mustapha and Agunloye 2016b; Mustapha 2017b).

Effect of simulated acid rain on African catfish (*Clariasgariepinus*) and Nile tilapia (*Oreochromisniloticus*)

Urbanization, modernization and increasing population in developing countries like Nigeria will result in pollution of rain water with oxides of sulphur and nitrogen leading to acid rain, and acidification of water bodies. The resultant effect is declining fish population in these water bodies. We simulated this acid rain in breeding *C. gariepinus* and *O. niloticus* in order to observe the effects on their survival, behaviour and morphology. We found that fingerlings, juveniles and adults of these species were unable to tolerate simulated acid rain of pHs 3, 4 and 5 as various degrees of mortalities, morphological and behavioural abnormalities were recorded according to their life stages (Table 10). (Mustapha and Mohammed 2018c; Mustapha and Atolagbe 2018d).

Table 10: Percentage survival of “Clarias and Tilapia” fingerlings under simulated acid rain

	C. gariepinus			*O. niloticus*		
pH	Fingerlings	Juveniles	Adults	Fingerlings	Juveniles	Adults
3	0	0	0	0	0	0
4	20	38	64	4	56	66
5	70	74	88	30	78	82
6	88	90	96	58	88	86
Control 8.01	90	94	98	84	92	96

Sources: Mustapha and Mohammed (2018c) Mustapha and Atolagbe (2018d)

Effects of nanoparticles on fish and aquatic food chain

Rapid development has brought about the use of nanoparticles in our daily lives which eventually found their ways into aquatic ecosystems. We (I and my first Ph.D. student, DrMatouke Matouke) evaluated the toxicity and bioaccumulation through a simple food chain of *Chlorella ellipsoides* (a freshwater alga) contaminated individually and with binary mixture of Titanium dioxide nanoparticles and lead. The alga was fed to Cyclopoids copepods (zooplankton) and the copepod in turn fed to *Clariasgariepinus* (fish) fries. Our results indicated that Pb and TiO2 NPs individually and mixed can be transferred from alga to copepods via dietary pathway, and chronic exposure of nTiO2 and Pb2+ mixtures in the copepods caused antagonistic effects on the biomass and antioxidant activities of the alga, delay the growth, changes metabolism and proximate compositions of the fish (Matouke and Mustapha, 2018a; Matouke and Mustapha 2018b; Matouke and Mustapha 2019; Matouke and Mustapha 2020). These findings raise concern about the quality of fish species from our freshwaters contaminated with $nTiO_2$ and Pb^{2+} and the health risk on consumption of fish from such contaminated water bodies.

On-going researches

Mr. Vice Chancellor sir, as a Professor, one should not stop teaching, research, community services and publishing once he/she sits on a professorial chair, if not, the chair may be broken. But rather, he/she should conduct more researches to solve myriads of everyday and emerging problems facing humanity. By this time also, he/she should be able to attract grants and funds for researches and be a great mentor to young academics. It is on this premix that I want to highlight some of our (myself and my postgraduate students) on-going researches.

Plant extract as alternative to ovaprim

Ovaprim is an expensive synthetic hormone to induce breeding in fishes. We are looking at safe and cheap local plant extract(s) that can equally induce breeding in fishes.

Life history characteristics of Niger perch (*Latesniloticus*) for use in its culture

We are currently working on the biology and life history characteristics of an economically important fish species *Latesniloticus* for use in its aquaculture to increase protein consumption of the people and to alleviate poverty.

Limnology and fish assemblages of Omu-aran reservoir, Omu-aran, Kwara State

We are documenting the water quality, heavy metal, plankton and fisheries of this water supply reservoir which is the first research of this type on the reservoir.

Integrated assessment of riverscape use in a changing climate: Implication on health, ecology and sustainability of Oyun Lake, Offa- Kwara State

We are exploring anthropogenic impact and risk perception on riverscape use and climate change on biodiversity and pollution in Oyun Lake as well as assessing the effect of changing temperature on spawning phenology and fecundity of fish species in the Oyun Lake.

Assessment of health status of Osun River using cyto-genotoxic and reproductive impairment endpoints

We are evaluating pollution in Osun River using bioaccumulation of pollutants in fish species through cyto-genotoxicity of micronucleus induction and reproductive impairment.

Photoperiodic manipulations to increase growth in edible frog culture

Once we have established that edible frog *Hoplobatrachusoccipitalis*could be cultured and photoperiodism can increase growth in fishes, we are trying to see whether photoperiodic manipulations could also increase growth of the species in culture.

Polyculture of *O. niloticus* and *C.gariepinus* under photoperiodic manipulations

This is the first research of its kind worldwide which aims at finding the best photoperiod for optimal growth and survival of the two species under polyculture system.

Siltation and sedimentation studies of Unilorin and Moro lakes

The research is to assess siltation and sedimentation in the two lakes and their effects on water quantity and quality, fauna assemblages and other functions of the lakes in order to curb/manage the situation in the lakes for their effective and sustainable functioning.

Cryopreservation of African catfish (*Clariasgariepinus*) milt

This research is to investigate the best cryoprotectants, cryoprotectant concentrations and extenders for the preservation of African catfish *Clariasgariepinus* milt, which will make available all the year round supply of fish seed for propagation, reduce wastage of the semen, unnecessary transport, stress and sacrifice of the male brood stock.

Fish anaesthetics

The research focused on the use of different locally available plants that are safe, cheap, and effective which can induce fish anaesthesia and recovery within few minutes.

Effects of turbidity on aquaculture of Tilapia and Catfish

The study is to evaluate turbidity (a serious water quality problem in ponds) on the growth and survival of the two species in aquaculture with the aim of solving the problem.

I sincerely hope and pray that our on-going researches will be successful and will contribute to science and development as well as help in eradicating poverty from our society.

Future research plans

Mr. Vice Chancellor sir, in order to continue my scholarship and pedagogy and sit comfortably on my professorial chair in the University, I wish to undertake the following researches among various others in the nearest future:

1. Production of biofuel from planktonic algae and water hyacinth (*Eichhorniacrassipes*)
2. Optimization of the growth of Nile Tilapia and African catfish throughcombination of genetic and photoperiodic manipulations.
3. Aquaponics – combined culture of fish (aquaculture) and vegetables (hydroponics or soil-less condition) in a single system
4. Generation of bioelectricity from the African electric catfish *Malapteruruselectricus*
5. Use of nanotechnology in fish preservation
6. Limnological monitoring of lakes using physico-chemical and biotic factors
7. Assessment of heavy metals in the tissues and organs of fish species from Apodu reservoir, Oyun Lake at University of

Ilorin, Oyun Lake at Offa, Nigeria, Agba Lake in Ilorin, Omu-aran Lake in Omu-aran, Kwara State.

8. Determination of electrical voltage discharge (EVD) of tropical African fish species
9. Determination of greenhouse gas emissions from lakes and reservoirs in Nigeria
10. Application of GIS and Remote Sensing to enhance Fisheries and Aquaculture
11. Developing blood tests to detect metabolic stress in fishes to increase fish production.

I pray to Allah (SWT) to give me long life, courage and determination to accomplish these plans. To this also, I wish to implore the University, Government and NGOs to give research grants and funds to enable researchers carry out meaningful researches that have direct impact on the people so as to eradicate poverty in the society.

Community services

Mr. Vice Chancellor sir, one of the core mandates of a University is service to the immediate and extended communities around the University. My community service involves conservation of fish. I do a lot of campaigns and awareness on the dangers of fish species extinction arising from over exploitation of lake resources, obnoxious fishing practices and unsustainable use and abuse of these man-made lakes to fishermen, users and stakeholders of the lakes. I also launched conservation strategies such as capture-release method, protection of the breeding habitats of these fishes, control of non-native species and initiation of legislation through the local branch of the Fisheries Society of Nigeria to save the fish species identified as being threatened on these lakes. But, poverty has not made the strategies to work out as expected, as fishermen are interested in catching and selling these vulnerable, threatened and endangered fishes to feed their families as against conserving them against extinction (a case of different strokes for different folks). I am in the process of establishing an animal conservation society/club in the University to sensitise and engage students and staff on conservation of our precious biodiversity. Along with that will also be the establishment of aquatic bird watching club to promote ecotourism and environmental education.

Conclusion

Mr. Vice Chancellor sir, many of the researches I have conducted, on-going or plan to conduct in the future were/are goals oriented, in response to how poverty could be eradicated through man-made lakes, advance frontiers of knowledge and scholarships as well as contribute to human capital development. Much of the work has contributed to the understanding and solutions to lake ecosystem problems and eradication of poverty. The science of limnology has become increasingly vital for devising cost-effective strategies to ensure that man-made lakes not only can serve this generation, but also can be preserved for the benefit of generations to come. Improvements in the teaching and study of limnology will benefit the society and mankind through new research breakthroughs that will raise the profile of both aquatic ecosystems and the sciences necessary for understanding how to protect, utilize, manage and sustainably exploit the vast resources in these lakes. Limnology will continue to be instrumental in identifying the linkages among runoff, water quality, and man-made lakes functioning to develop solutions to the problems of point and nonpoint-source pollution from runoff, conservation and sustainable exploitation of the water and its vast resources. The best adaptive strategy in construction, operations and management of these lakes is based on a good predictive limnology.

One prominent feature of man-made lakes in Nigeria that is affecting their utmost performances and utilization is cultural eutophication and siltation. These lakes are more prone to eutrophication and siltation because of the intense exchange of nutrients, erosion of sediments and indiscriminate dumping of anthropogenic materials from the watershed into the lake. Eutrophication and siltation is expected to increase in the near future due to human development and global warming. The effects of eutrophication and siltation include loss of biodiversity and socio-economic functions of the lake which could jeopardize the lakes in eradicating poverty.

If man-made lakes are constructed and potable tap water supplied from it to every nook and crannies of Nigeria, long distance trek to get water will be eliminated, water-borne diseases will be greatly reduced and there will be no need to buy sachet (pure) water, bottled wateror jerry can water and the digging and drilling of wells and boreholes. It will also enable the country to meet Sustainable Development Goal 6 of providing clean water, sanitation and hygiene (WaSH). If there have been street tap waters everywhere in the country, the recent COVID-19 pandemic would not have spread so much as people would regularly and thoroughly wash their hands using the street taps. International standard practice states that nobody should travel more than 100 metres before accessing safe and potable drinking water, thus man-made lakes should be seen as human right to life.

Fish species in our lakes are becoming vulnerable, endangered or threatened with extinction, we must save them from decline and extinction in order to meet today and future needs of human protein.

Since most man-made lakes have now assumed multi-purpose usage, users' conflicts are a regular feature, since these lakes are seen as belonging to everybody. One practical management guide to resolve users' conflicts is to establish clear and important priorities for water usage based on the lake's water budget, storage capacity, morphometry and its operational control. Education and awareness of the reservoir limitations will also play significant roles in resolving users' conflicts. With these management techniques put in place, conflicts arising from the reservoir usage will be considerably minimized, as it is not possible to satisfy every ones need of the use of the reservoir or ban the use of the reservoir for a particular function. Effective governance of man-made lakes requires that the rights and obligations are clearly defined.

Climate change is affecting the lake water, its fish and fisheries, thus, having devastating impacts on lake functions, fish productions and livelihood which could increase the poverty level among the populace.

Fish welfare in artisanal fisheries and aquaculture should be taken into consideration as it benefits both farmers and consumers. Consumers are becoming aware of the quality of fish from water bodies and aquaculture arising from poor welfare of the fish from lakes and aquaculture. Good nutrition from fish is strongly connected to good fish welfare. It should be known that whatever is good in terms of welfare to humans should also be extended to fish, as an injury to man, is also an injury to fish.

Recommendations

For optimal performance and utilization of man-made lakes, actions which erode their functions such as eutophication and siltation which should be curbed, by siting farm lands and houses far away from the lake watershed. Lakes Best Management Practices (LBMP) involving soil erosion control, should be done, this will reduce nutrient and sediment loads by controlling timing, amount and type of fertilizers, in case total stoppage of the use of fertilizers on farmlands situated close to lakes is impossible or could create conflicts. Biomanipulation with the use of zooplankton and fish to graze on algal biomass (Mustapha 2010c) could be adopted in the lakes in case eutrophication has occurred.

To resolve users' conflicts on these lakes and prevent water war, I recommend that percentages should be allocated to various uses of the lake. For example, water for drinking and industrial supplies could be allocated 50 and 20 percent respectively, while irrigation, fishing, recreation and other uses could be allotted the remaining percentage of the daily water budget and lake usage. Limits to water utilizations should be monitored in water stressed regions. This will prevent privatisation of these lakes and its resources in the future especially in developing countries like Nigeria.

There should also be regulated water withdrawal and establishment of minimum flow levels (MFLs) in the lakes especially when used for irrigation in the dry season. The use of Integrated Water Resource Management (IWRM) could also be an appropriate water management tool for use and delivery of water resources.

Water treatment plants and desilting systems should be built immediately alongside man-made lakes constructed for domestic water supply, and potable tap water should be supplied to all homes, streets and public places with the populace encouraged to conserve the water. Vulnerable people and communities must be actively involved in the design, implementation and management of lake ecosystems. Capacity building among lake end users should be encouraged for sustainable water use and development in the community, while government should develop and scale up Water, Sanitation and Hygiene (WaSH) provisions to prevent and curb the spread of diseases and improve food security through connection of WaSH acts and policies with science and environment. Information and communications technology (ICT) should be deployed in WaSH to monitor varieties of hydrological and poverty eradicating functions of man-made lakes as well as accountability of WaSH acts, policies and decisions.

Capture and culture fisheries should be strengthened in the lakes through high level management, fish stocking and cage aquaculture. This could make up the 2.4 million tons of yearly fish deficit in Nigeria, thereby saving the country 1.8 billion dollars of foreign exchange used in fish importation.

Government should develop the lakes for inland waterways navigation to complement the highways. This will aid development of the communities along the waterways through provision of basic amenities and siting of industries. The cost of developing and maintaining waterways is 80% lower than that of highways.

Guided recreational activities such as sport fishing, angling, swimming, diving, boating, bird watching, sightseeing, picnicking, camping, etc. should be superimposed and strengthened on these lakes to generate employment, income, revenue and tourism.

Studies on climate change and global warming as it affects lake, fish and fisheries should be intensified. This could be done through limnological studies which shed light on how futuristic climate change and global warming could alter water supply and lake productivity, exacerbate water quality problems, disrupt fish and fisheries and affect the socio-economic functions of the lake. Adaptive strategies to increase resilience and mitigate impact of climate change on fish, fisheries and lake ecosystem should be put in place. This include cutting down green house gas emissions, adoption of renewable energy, continuous monitoring of lakes and biodiversity, integration of water and fisheries development into National Adaptation Strategy and Plan of Action on Climate Change for Nigeria (NASPA-CCN), capacity building for fisher folks, education and awareness among others. Due to the perceived effects of climate change on every sphere of our lives, the bill which established National Climate Change Commission should be signed into law immediately. Legal framework for the planning, development, regulation and management of man-made lakes in Nigeria should be strengthened in order to deliver their functions sustainably.

Conservation efforts and strategies should be adopted to fight further loss of fish biodiversity in our lake ecosystems, so as to preserve fish genetic diversity, maintain lake functions and sustain fish resources to meet today and future needs.

Although acid rain and acid deposition has not been well documented in Nigeria, there is no doubt that the phenomenon is present and on-going. Researches should be geared towards more understanding of the event and its effects on water bodies and their biota.

Collaborative researches involving all water-related sciences, social sciences and engineering should be undertaken in our universities and research institutes for sustainable exploitation and management of man-made lakes water and their resources.

Environmental Impact Assessment of any proposed man-made lake should be carried out. This will reduce cost and time of the project, reduce damage to environment and disruption to the communities, improves the lake performance and acceptance. Pre- and most especially continuous post impoundment studies should be carried out before and after the construction of lakes to document and monitor episodic changes in the limnology and biodiversity of the lake. This can be used for a better predictive and adaptive management strategies on the lakes since most of these lakes have now assume multiple uses.

Limnology should be given priority and strengthened in the curriculum; research grants/funding should be made available, while limnologists should be employed in public water works, hydropower plants, and other water-related agencies to manage the lakes, reservoirs and impoundments. Limnological research institutes should be established to conduct multi-disciplinary researches on the numerous man-made lakes in Nigeria, collection of long-term data, training of limnologists and developing fundamental understanding of inland water ecosystems. Limnologists in Nigeria (though very few) should establish their own professional society, organise conferences and float journal(s) dedicated solely to limnology. This will enable public understanding of the discipline and disseminate research findings. Certification of the program should also be considered to ensure a minimum level of competence among would be and practicing limnologists.

Improvement in fish welfare in fisheries and aquaculture should be taken seriously as it will increase profits, productivity and acceptability of the fish and curb zoonotic diseases stemming from fish. Fishes that are less stressed are healthier, grow better and have better meat quality.

Man-made lakes and its biodiversities should be conserved just like wildlife. These lakes should be delineated and categorised as protected water bodies. Thus, National Lake Service and National Lakes Commission should be established in the country to regularly inspect, survey, protect, maintain and manage our lakes for safety, hazardous conditions, susceptibility to failure, record keeping amongst other functions.

Just like any other man-made structures, man-made lakes also undergo wears and tears. They should be removed or demolished as a result of aging, blockage, cracks, seepage, obsoleteness, inadequate management and faulty design.

The University of Ilorin should make more judicious use of her lake for teaching, research, community service, tourism, recreation and revenue generations. This could be achieved by proper limnological management of the lake and its vast resources.

Finally, we should all know that lakes do not need man; it is man that needs lakes, that's why he is building them. But man himself changes the lakes and eventually the lakes will change him. Therefore, man should be benevolent to these lakes by protecting, preserving, conserving and managing them and their vast resources to enable him reap the dividends of the lakes in providing livelihood and sustenance for today and the future needs and in eradicating man-made poverty.

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