

**THE 3Bs OF LIFE: THE BLACK, BRACKISH AND
BLUE WATERS: AN ECOLOGICAL SCENARIO
MISUNDERSTOOD**

BY

FRANCIS EMILE ASUQUO JP

BSc (HONs), MSc (Ibadan), PhD (Calabar)

ICZM (Venice), MARPOL (Bremerhaven)

**PhD MARINE CHEMISTRY, TOXICOLOGY & POLLUTION
PROFESSOR OF CHEMICAL OCEANOGRAPHY**

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DEDICATION

With love and utmost humility, I dedicate this work to my dear wife Dr (Mrs.) Ekaete Francis Asuquo , my children Radgr. Caleb Asuquo, Dr. Enoch Asuquo, QueenAnn Asuquo, Bar. Peace Asuquo, Engr. Divine Asuquo, Tarrynot Asuquo and my parents Teacher Emile Edet Asuquo and Madam Christiana Mayen Asuquo, who longed to see this day, but have gone on to be with the Lord.

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MY PROFILE

CITATION OF PROFESSOR FRANCIS EMILE ASUQUO

Dear Vice Chancellor, Sir! It has fallen my lot to present to you one of Africa's shining stars in the field of marine sciences and oceanography. I first came in contact with this academic *per excellence* in 2006 at a conference organized by the International Society of Environmental Geotechnology tagged ICIDEN-Abuja 2006. Since then, my passion to work with him developed greatly, and when I was admitted to pursue my Doctorate degree in Environmental Chemistry, I contacted him to be one of my supervisors, which he gladly accepted. I am proud to say that he is my mentor, his astuteness and diligence in mentorship resulted in being awarded the prestigious Fulbright Visiting Fellowship to the Department of Atmospheric, Space and Oceanic Sciences, University of Wisconsin, Madison, USA in 2008. His supervision of my thesis saw me through as one of the best Ph.D graduating student in 2010. Therefore, I feel humble to present this great and renowned scholar to you as today's inaugural lecturer.

Professor Francis Emile Asuquo (Ph.D) was born on 2nd October, 1959 at Ikot Udo Uruan in Akwa Ibom State, Nigeria. He attended the Holy Trinity Secondary School, Mbiakong, Uruan between 1972 and 1976, where he obtained a remarkable Division 1 academic distinction in West African School Certificate Examination. In 1976, he gained admission to read Chemistry at the University of Calabar, Calabar, where he obtained a Bachelor of Science degree with Second Class Honours (Upper Division) in 1980. Francis Asuquo proceeded for further studies at the Nigeria's premier university, the University of Ibadan from October 1985 to September 1986, where he earned a Master of Science degree in Organic Analytical Chemistry. His unquenchable desire for knowledge took him to the Institut für Meeresforschung, Bremerhaven, Germany in 1985, where he obtained a Diploma Certificate in Marine Pollution. Upon return to Nigeria, Professor Francis Asuquo registered for his Ph.D in 1992 at the University of Calabar, Calabar, and obtained his Ph.D degree in Marine Environmental Chemistry in 1994. He obtained other professional qualifications in his core area of research interest, clinching a Diploma Certificate of the University of Venice, Italy in Integrated Coastal Zone Management in 1993, a Diploma Certificate of the Centre National des Sciences et Technologies Nucleaires (CNSTN), Tunisia in Marine Nutrient Chemistry in 2010, and a Diploma Certificate of the Oceanic Platform of the Canary Islands (PLOCAN), Spain in Ocean Gliders Technology in 2017. He had a postdoctoral

training in Ghana at the University of Ghana, Legon, Ghana, in 1996, under the World Bank Postdoctoral Fellowship.

Professor Asuquo started his academic career as a Chemistry Tutor at the defunct School of Arts and Science, Uyo, between 1981 and 1983. He joined the University of Calabar, Calabar as a Junior Research Fellow in the Marine Chemistry programme, Physical Oceanography Department in 1983, and rose through the ranks, being promoted a Senior Research Fellow in 1996, and Full Professor of Marine Environmental Chemistry on October 1, 2006. He is the first Professor of Marine Environmental Chemistry in Nigeria and West Africa, a brilliant, hardworking, respectable, and distinguished alumnus of the University of Calabar. He is a full-blooded Malabite.

Professor Francis Asuquo has an exceptional career in this University, having served three times as Head, Physical Oceanography Department in 1996, 2002, and 2009. In 2007, he was appointed as the Acting Director, Institute of Oceanography, University of Calabar, Calabar. Following his successes through excellent and impeccable leadership, he was appointed as Director, Institute of Oceanography, University of Calabar, Nigeria in 2013, where he served till 2015. In 2015, he was elected the pioneer Dean, Faculty of Oceanography, University of Calabar, Calabar. His remarkable leadership feats earned him an appointment as Chair, External Linkages, Research and Publications Committee, Graduate School, and elected Chair, Committee of Deans, University of Calabar, Nigeria, in 2015 and 2016, respectively. Presently, he is serving as UNICAL Desk Officer / Coordinator, U6 Consortium of African Universities of this university.

Mr. Vice-Chancellor, Sir! Ladies and Gentlemen! Our distinguished lecturer's contributions to the University of Calabar, Nigerian Universities, and the wider world have been very outstanding. He has served as Visiting Professor, Sabbatical Professor and External Assessor for both postgraduate and undergraduate programmes in many universities including University of New England, Australia; University of Ghana, Legon, Ghana; Akwa Ibom State University of Science and Technology, Ikot Akpadem, Akwa Ibom State; Michael Okpara University, Umudike, and Covenant University, Ota, Ogun State. The scope of this citation does not allow for satisfactory representation of the immense contributions of Professor Asuquo in the development of the current state of knowledge of marine sciences in Africa. He has over thirty-

six (36) years of working experience to his credit as a lecturer, researcher and administrator. He has supervised six (6) Ph.D theses (Five (5) in Nigeria and One (1) in Australia), fifty-two (52) M.Sc. dissertations, fifty (50) postgraduate diploma dissertations, and over one hundred and eighty (180) B.Sc. projects. He has authored and co-authored eighty-two (82) scientific publications in refereed scholarly journals. He has attended conferences, workshops, seminars and other scientific meetings in Nigeria, Italy, Spain, Sweden, Tunisia, USA, France, South Africa, Germany, Ghana, UK, Portugal, and Cape Verde. He has a total of forty-four (44) conference papers.

In recognition of his academic expertise and administrative prowess, Professor Asuquo has had over thirty (30) years' experience as an environmental consultant to the Government of Nigeria and International Organisations. He was the National Consultant, WACAF 11 (West & Central Africa 11) Project on Marine Pollution Monitoring (Tar Balls on Nigerian Beaches); IAEA Consultant on Coastal Systems Vulnerability to Pollution: Mangroves ecology; and UNIDO Consultant on Guinea Current Large Marine Ecosystem. He has won many prestigious research fellowships and scholarship that took him to countries including Germany, Italy, Ghana, and Tunisia. He is a member of many professional bodies including Commonwealth Association for the Education and Training of Adults (CAETA), Nigeria Water and Sanitation Association (NIWASA), International Oceanographic Society (USA), Chemical Society of Nigeria (CSN), Nigerian Environmental Society (NES), African Monsoon Multidisciplinary Analyses (AMMA-Africa), Society of Environmental Toxicology and Chemistry (SETAC) Europe/Africa, American Chemical Society (ACS), and AtlantOS Project working Group.

He has served as a Resource person and Reviewer of many technical reports for the Federal Ministry of Environment, Abuja, Nigeria from 1999 till date, and has participated in more than 45 Environmental consultancies and Community Services including climate change and vulnerability assessments. In 2016, he was a Resource person at the 2nd Akwa Ibom State Climate Change and Clean Energy. He has served as a Reviewer and Panelist for Developing a Strategic Master Plan for University of Calabar, 2005 – 2015, and Panelist and Reviewer of University of Ghana Reader's for the Department of Marine and Fisheries Sciences in 2016. He has served as Editor-in-Chief, Tropical Journal of Environmental Research. Professor Asuquo is a peer reviewer for many learned national and international journals including African journal of

Environmental Pollution and Health, Global Journal of Environmental Sciences, Tropical Journal of Environmental Research, Asian Journal of Environment and Ecology, Journal of Oceanography and Marine Science, Environmental Monitoring and Assessment and many others. In 1987, he was recognized and awarded the title of “*Itiat nwed Uruan*” by the Uruan Community in the University of Calabar.

His record shows that he specializes in the pioneering role as pioneer student of UNICAL (1976), pioneer staff of the Institute of Oceanography (1983), pioneer Dean, Faculty of Oceanography (2015), pioneer Chairman, Committee of Deans from the Faculty of Oceanography, pioneer Desk Officer, U6 Consortium (2016) and first Nigerian oceanographer to deploy ocean gliders in the Atlantic Ocean (2017).

Mr. Vice-Chancellor, Sir! Ladies and Gentlemen! I consider it a singular honour and a privilege to present to us one of Africa’s outstanding and perhaps the most versatile, the most erudite marine, brackish and freshwater researcher cum scholar, an inspirational and dutiful teacher, a seasoned administrator par excellence, a thoroughly bred gentleman whose life philosophy is respect, diligence, humility, accessibility, and spirituality. He is an irrepressible advocate for the blue, black, and brackish enlightenment, conservation and sustainability. He is a responsible husband, father and grandfather. He is happily married to his darling wife, Dr. Ekaete Francis Asuquo, and the union is blessed with six (6) children and three (3) grandchildren.

The Vice-Chancellor, distinguished Ladies and Gentlemen, may I present Professor Francis Emile Asuquo to you as the 78th Inaugural lecturer of the University of Calabar, Nigeria.

Thank you.

Prof. Nsikak Udom Benson
Covenant University, Ota, Ogun State

PREAMBLE

*‘Tell me not in mournful numbers,
Life is but and empty dream!
For the soul is dead that slumbers,
And things are not what they seem.*

*LIFE is REAL, LIFE is EARNEST!
And the grave is not its goal,
Dust thou art, to dust returnest,
Was not spoken of the soul.....’*

These two paragraphs are Extracts from Longman Psalm of Life.

Longman here emphasizes the fact that LIFE is real and must be lived. You don't have to live as 'man die go'. There is a life to live and you should make life meaningful. Life has got to be contested for and maintained. For the grave is not the goal of life. This reminds us of the 2 forms of life: Celestial life and terrestrial life. The celestial life is Godly life or heavenly life, that we have no control. But for the terrestrial or earthly life, mankind, that is you and me, have contributions to make for its productivity and sustainability. The human heart is a perfect system, just like your wrist watch, it ticks on time and works normal. When the heart regulates well, it is often said that you are hale and hearty. But when there is a distortion in the heart, its rhythm changes and the heart automatically malfunctions. **And such is the water or aquatic environment.** Naturally, the aquatic ecosystem is a broad-based best necessity that has been positioned to cater for the survival, cultural and social welfare of mankind and other earthly lives. Just as the heart malfunctions due to some imbalance, the water ecological system has been distorted due to HUMAN ACTIVITIES. There is need to RESTORE OUR WATER ECOLOGICAL BALANCE. In Oceanography, we often declare: WATER ..LIFE, WATER .. LIFE. In order words, **WATER IS LIFE OR WATER GIVES LIFE.** This proverbial retort portrays the importance and relevance of water as a life-giving resource to all living forms. It reminds us of our role as scientists (oceanographers), and how delicate our profession is, and the need to approach every investigation or research responsibly with the aim of **providing reliable and adequate data and information** concerning the state, status and quality or worth of the aquatic ecological system. Water is life and therefore needs to be protected.

Our focus today is on the 3Bs of LIFE (WATER) and how it has been misunderstood. During the course of this lecture, I will x-ray water and ocean science as a science of life, conceptualize its localized forms as the 3Bs and most importantly, clarify how the 3Bs of life have been misconstrued.

*“Water, water, water everywhere
Yes from nature it was pure and free
Water was not meant for a dumping ground but to sustain life
Industrial development and human production
The indiscriminate disposal of plastic waste on land, sewages and bays
Have rendered the oceans unusable”*

CHAPTER ONE

1.0 INTRODUCTION

1.1 Role of early sea voyages or scientists

The expression WATER IS LIFE is a household word among oceanographers and limnologists. The simple-minded man finds it hard to comprehend why water is associated with life or why life should be linked to water. Investigation into water (ocean) sphere (biosphere) began about 5000BC when early scientists from Greeks, Egyptians, Portuguese, Phoenicians and others began their inquiries into the eastern Mediterranean near the Nile river.



Plate 1: Map showing Ferdinand Magellan's Circumnavigation of the world (courtesy Wikipedia, Ferdinand Magellan)

They went on sea voyages around the entire Mediterranean and into the Red Sea and the Indian Ocean, traversing around Africa, they reached England by sailing along the western European coast. Driven by zeal between 1492 – 1785, other sea explorationists such as Christopher Columbus , Vasco da Gama , Ferdinand Magellan, James Cook and Benjamin Franklin commenced their voyages and discovered the sea route to India, Africa and the Americas. They developed the magnetic compass, the marine chronometer to determine longitude and built ships and submarines that circumnavigated the world. Of great significance is Ferdinand Magellan's voyage from Spain in 1519 into the Atlantic Ocean (Plate 1). They went south wards crossing through the Straits of Magellan (named after him) at South America in October 1520. They continued to sail north wards into the Pacific Ocean and reached the Philippines, where he was killed in April 15, 1521. But the journey continued past Australia down to the Cape of Good Hope (present Cape Town, South Africa) into the Atlantic Ocean and back to Spain by September 8, 1522 with a crew of 28 sailors. They made great sacrifices to ascertain how water moves, their link or connection between the coastal nations and the processes that sets the ocean in motion, daily and seasonally (tidal incursions). Between 1872 and 1876, the H.M.S. Challenger (British three-masted warship) travelled around the world on a scientific expedition,

taking sediment samples, water samples, making soundings and collecting many biological specimens.

The early history of oceanography is about people, not just oceans and test tubes as presented below.

EARLY MILESTONES IN OCEANOGRAPHY

1000	Leif Ericson crosses the Atlantic Ocean to Canada
1492	Christopher Columbus crosses the Atlantic to West Indies
1500	Pedro Alvares Cabral discovers Brazil
1513	Juan Ponce de Leon describes the Florida current
1515	Peter Matyr discusses the origin of the Gulf Stream
1519 – 1522	Ferdinand magellalan circumnavigates the earth and attempts the deep sea soundings in the Pacific Ocean
1569	Gerardos Mercator develops a projection of the world representing North-South and East-West by straight lines, presently used in navigational charts
1802	Nathaniel Bowditch published his new American Practical Navigator. This book has been revised many times and remains a standard work on navigation to this day.
1818	John Ross dredges animals from nearly 2,000 metres while exploring Baffin Bay for a passage to the Pacific Ocean
1835	Gaspard Gustave de Coriolis publishes a classic paper on the effects of the earth's rotation on fluids in motion. Today, this discovery is known as the Coriolis force.
1843	Alexander Dallas Bache becomes superintendent of the US Coast Survey (later called the US Coast and Geodetic Survey) and expanded work on physics of the ocean and the nature of sediments and bottom-dwelling life.
1865	Johann George Forchhammer analyzed samples of seawater from a variety of locations and discovered that the ratios between the major ions or constituents are nearby constant from ocean to ocean

(McCormick & Thiruvathukal, 1976).

1.2 The Beginning of Ocean Science (Oceanography)

Oceanography is the science of investigating water and its environment, the physics, chemistry, biology, geology, living and non-living forms and their interaction with each other. Modern oceanography began as a field of science about 130 years ago, in the late **19th century**, after Americans, British and Europeans launched some expeditions into the Atlantic and Pacific Oceans to explore ocean currents, ocean life and the seafloor at few kilometers off their coastlines. Today ocean science is internationally recognized and has developed into a multidisciplinary science covering Physical Oceanography, Chemical Oceanography, Biological

Oceanography, Geological Oceanography, Mariculture and Fisheries Oceanography and presently a new aspect called Observational Oceanography has been added. Today in developed countries like Malaysia, Japan, USA, Phillipines, China to mention a few, their national economy and GDP is based solely on ocean resources, as emphasis has shifted from Green Economy towards exploitation of ocean resources, commonly referred to as the Blue economy. The ocean is viewed as ‘gold mine’ for energy development, transportation, mineral extraction, tourism, recreation as well as fisheries needs of coastal countries and for exports.

Dear Vice Chancellor, today is ocean day and it has fallen my lot to lay the foundation for other colleagues (mariners) that are on board the ship and will soon land on the shore. My lecture is focused on ‘The 3Bs of life. What are the 3Bs and how are they related to life? This is a trivial situation that must be approached systematically for a clear understanding of the subject matter. The question is what is life or the meaning of life? "What is life all about?" or "What is the purpose of existence?" How is water related to life? These questions are often asked by different people at different times, and there have been a large number of proposed answers to these questions. Different people from different cultures believe different things for answers to these questions. The search for the meaning of life has produced much scientific, theological, metaphysical and philosophical speculation throughout history.

The meaning of life as we perceive it today emanates from philosophical and religious contemplation of, and scientific inquiries about existence, social ties, consciousness, and happiness. Many other issues are also involved, such as symbolic meaning, ontology, value, purpose, ethics, good and evil, free will, the existence of one or multiple gods, conceptions of God, the soul, and the afterlife. Scientific contributions focus primarily on describing related empirical facts about the universe, exploring the context and parameters concerning the "how" of life.

The Ancient Greek philosophical perspectives on the meaning of life are numerous such as Platonism, Aristotelianism, Cynicism, Cyrenaicism, Socraticism, Epicureanism and Stoicism. They all thought about life and came out with their isms (Plate 2).



Plate 2: Plato and Aristotle in *The School of Athens* pondering about LIFE. Plato is pointing heavenwards to the sky, and Aristotle is waving to the world, certainly mixed ideas.(Courtesy, Wikipedia, School of Athens)

Stoicism established the school of thought that living according to reason and virtue is to be in harmony with the universe's divine order, and a recognition of the universal logos. Therefore the scientist approached life through scientific enquiry but a religious person prays to understand the issues of life.

Whether you pray, meditate or investigate, life must be understood for honor to be given to whom honor is due.

Until humans fully comprehend the essence and significance of living or life, it will be difficult to appreciate and respect the value of water as a life giving resource.

Do you know that your body requires 60% of water to survive and babies in the womb are surrounded by water (amniotic fluid) for them to live?

Do you that new born babies need about 80% of water in their bodies, that is why exclusive breast feeding is made compulsory for nursing mothers as breast milk contains a lot of water (88%).



Plate 3: Processes of water transformation between the three states of matter

Do you know that water as matter, exists in the 3 states: Solid (ice and snow), liquid (fluid) and gas (vapour and steam) (Plate 3)?

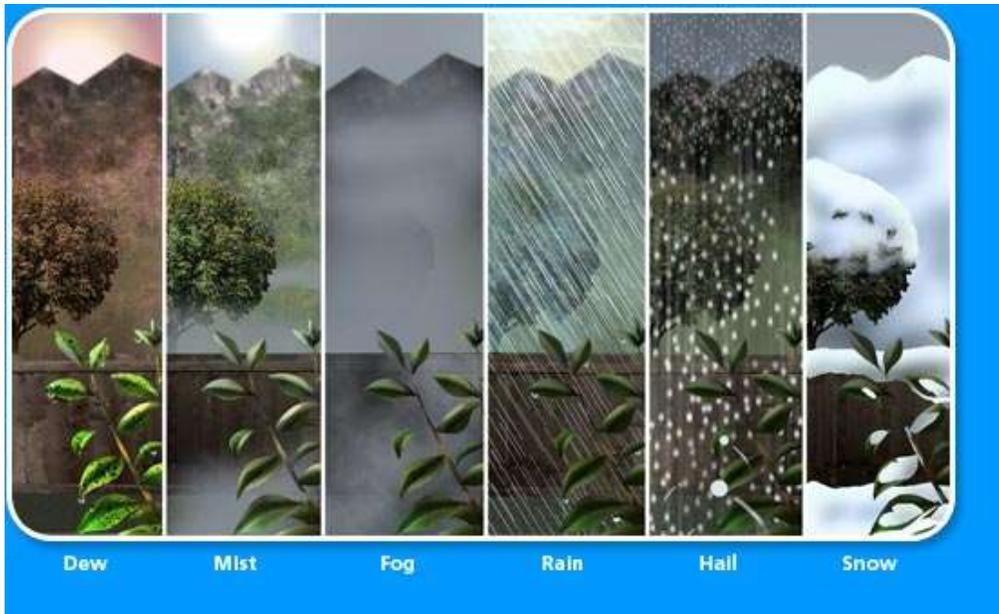


Plate 4: Different forms of water on the earth

Do you know that water drops onto the earth in 6 forms: dew, mist, fog, rain, hail and snow (Plate 4)?

Do you know that liquid *water* requires a small temperature range (not high temperature) and a pressurized atmosphere to remain liquid?

Do you know that liquid *water* is not abundant in the solar system, but is a prerogative of the Earth?

Do you know that with the drastic climate change scenario, your body requires much fluid (water) to be taken daily for you to function effectively without easily getting tired?

Africa, most particularly Nigeria is yet to realize the full potentials that water possesses.

WHO's classification scheme of countries by population using improved water sources in 2015 identified most countries in Africa, including Nigeria to belong to the low class, 50% (depicted by yellow color) (Plate 5). This non-recognition of the importance and benefits of water is reflected in the way issues concerning water, its programmes and resource utilization is handled by various academic institutions and Governments in Nigeria. But I must commend the initiative of our previous Vice Chancellors and the present administration in the University of Calabar for the bold step in establishing the Institute of Oceanography, some 30 years ago and presently a full fledge Faculty of Oceanography, the first of its kind in sub-Saharan Africa with the mandate of teaching and research in ocean sciences. Thank you Mr. Vice Chancellor for your support.

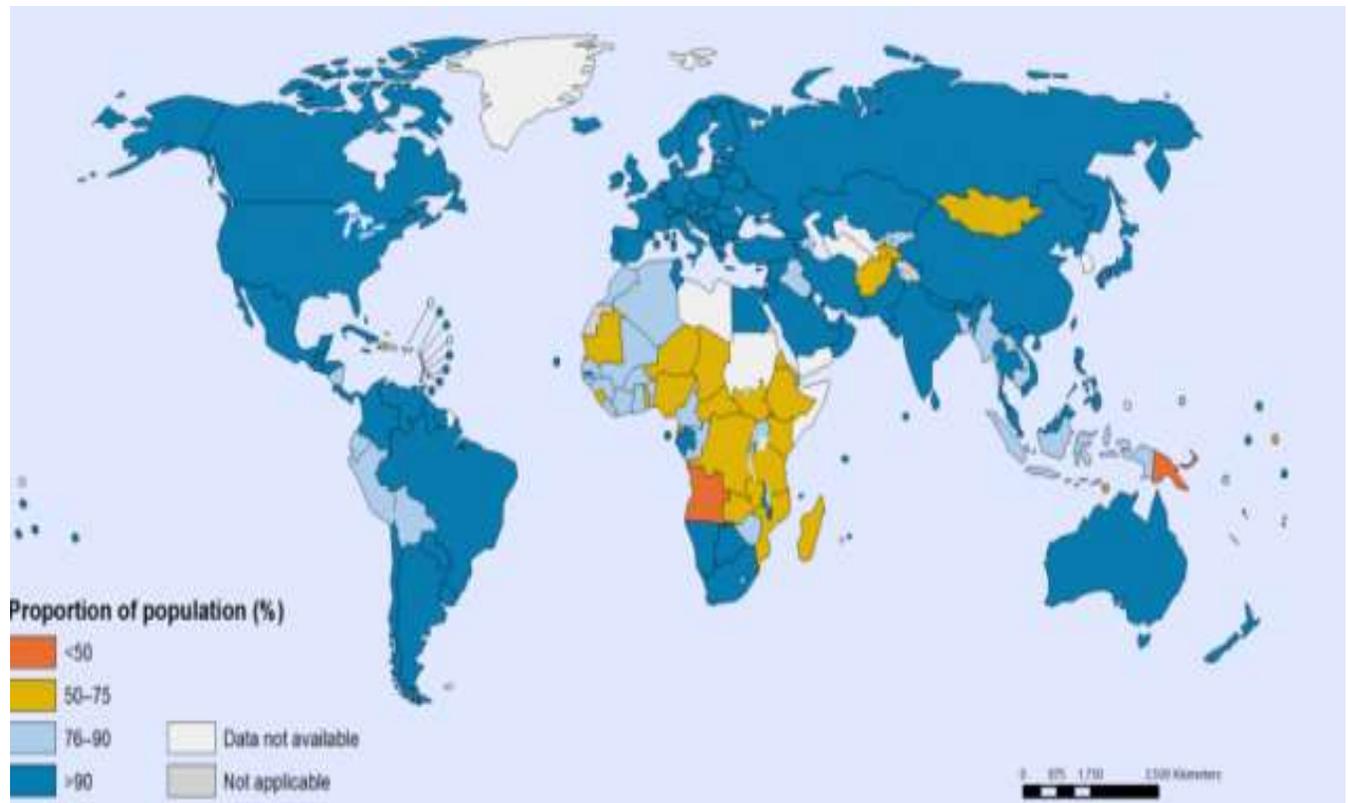


Plate 5: Proportion of population using improved water sources (%), (WHO, 2015)
 (Classification Scheme: Very Low, <50%, Low, 30 – 75%; Middle 76 – 90%; High >90%)

1.3 THE 3BS CONCEPT

Nature, in recognition of the paramount role water must play in nourishing and lubricating the earth, has supplied water to the earth in diverse ways and forms. He makes it abundant, and strategically places them to ensure that the earth operates as a functional ecosystem. What water does to the earth is what lubricating oils do to automobile engines.

The 3Bs refer to the **Black** or **fresh water** (streams, rivers, underground waters), **Brackish** or the **estuarine water** (estuary, deltas, lagoons) and the **Blue** water or **open ocean or sea water**.

Water in its tripartite existence: **Black** or **fresh water** (streams, rivers, underground waters), **Brackish** or the estuarine water (estuary, deltas, lagoons) and **Blue** water (open ocean or sea water) constitute the 3Bs of life which is synonymous to the 3 waters of life. This concept is hereby ascribed as Life’s Tripod Balance (LTB) as it is the pivot where every living thing spins (Fig.1).

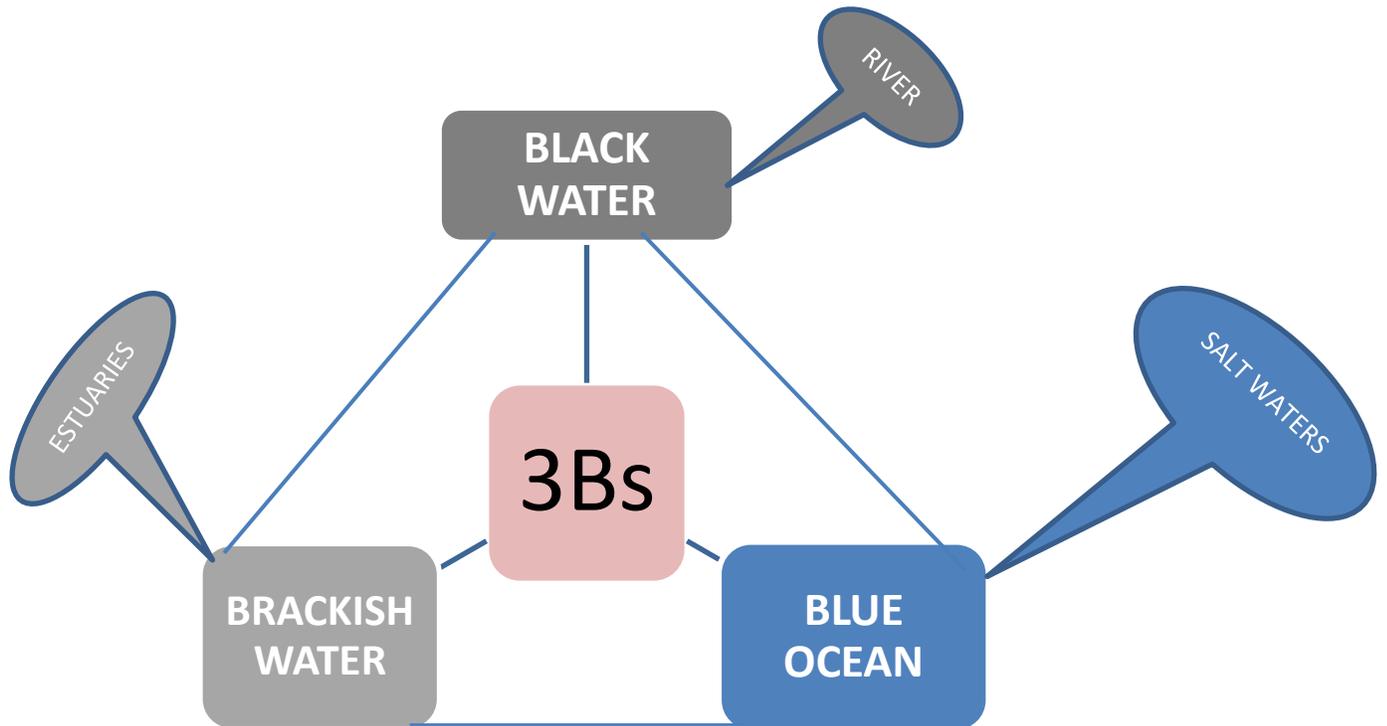


Fig.1: Life's tripod balance or The tripod of life

These 3 types of water occupy their strategic positions in nature and exercise their functions maximally until perturbations are injected by man.

My worry is that mankind that is expected to complement this endeavor and cherish it, is yet to fully appreciate and acknowledge the existence of water (the 3Bs) and what it will gain from this natural resource by preserving it.

My Vice Chancellor, Sir, water needs to be protected and valued at all times to ensure its functionality and sustainability.

1.4 FROM CHEMISTRY TO LIFE (WATER)

According to Richard Feynman, Excerpts from Lectures in Physics :

"If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generations of creatures, what statement would contain the most information in the fewest words? I believe it is the *atomic hypothesis* (or the *atomic fact*, or whatever you wish to call it) that *all things are made of atoms - little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.*"

A closer look at the above sentence, indicates that there is an enormous amount of information about the our world, beginning with the atoms.

Percentage Composition of gases in the atmosphere

The dry air or the atmosphere above is composed of atoms and molecules of not less than 16 gases in different percentage compositions (Table 1), (Mackenzie & Mackenzie, 1995).

Table 1: Percentage Composition of gases in the atmosphere

Constituents	Chemical symbol	Mole percent
Nitrogen	N ₂	78.084
Oxygen	O ₂	21.0
Argon	Ar	0.934
Carbon dioxide	CO ₂	0.0350
Neon	Ne	0.001818
Helium	He	0.000524
Methane	CH ₄	0.00017
Krypton	Kr	0.000114
Hydrogen	H ₂	0.000053
Nitrous oxide	N ₂ O	0.000031
Xenon	Xe	0.0000087
Ozone*	O ₃	trace to 0.0008
Carbon monoxide	CO	trace to 0.000025
Sulfur dioxide	SO ₂	trace to 0.00001
Nitrogen dioxide	NO ₂	trace to 0.000002
Ammonia	NH ₃	trace to 0.0000003

* Low concentrations in troposphere; ozone maximum in the 30 to 40km regime of the equatorial region.

The most abundant being Nitrogen (N₂) with 78% composition and the least abundant represented by ammonia (NH₃) with 3.0×10^{-7} %. The air that we breathe is **Oxygen** (O₂) and it occupies 21% composition of all the gases in the atmosphere. **Hydrogen** (H₂) gas has about 0.000053 or 5.3×10^{-5} % composition. Elemental abundance of hydrogen very small compared to oxygen.

As simple as it is, these two gases combine in a ratio of 2: 1. Scientifically, we say 2 moles of H₂ combines with 1 mole of O₂ to form the water molecule:

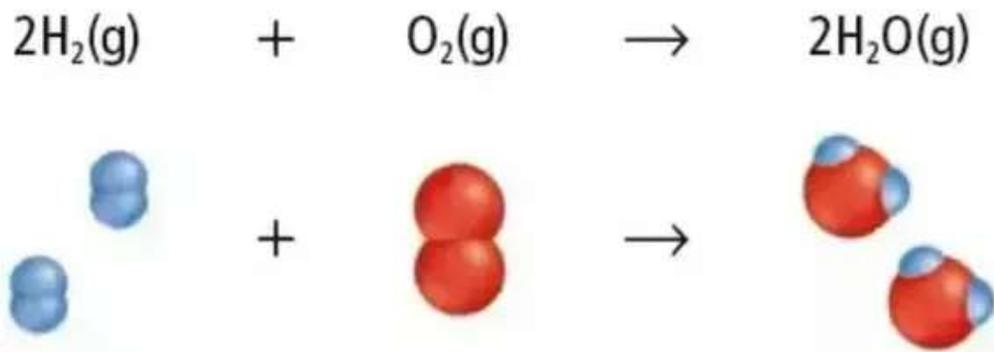


Plate 5: Atomistic representation of the formation of water

One (1) mole of hydrogen consists of 2 atoms of hydrogen, H:H, but to form water, we need 2 moles, that is 4 atoms of hydrogen, H:H:H:H. The 4 atoms are shared between the 2 atoms of oxygen as shown above (Plate 5).

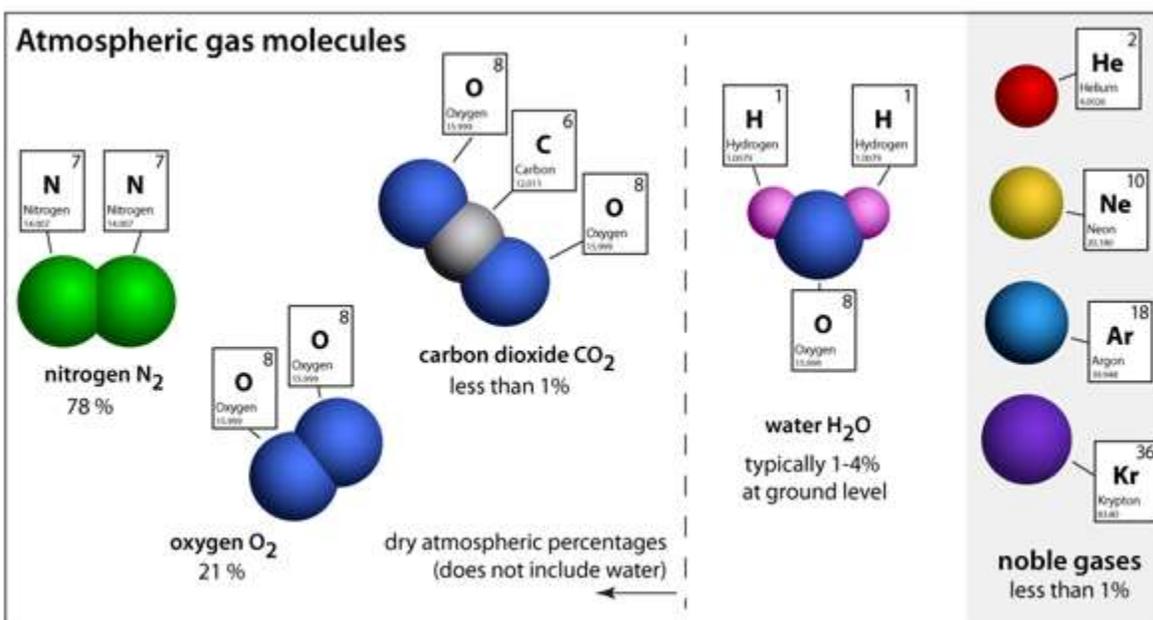


Plate 6: The molecular forms of Oxygen, Nitrogen, Water, Carbon dioxide and other atmospheric gases including inert gases (Note: *water exhibits and angular or V-shaped configuration whereas carbon dioxide and other gases are linear in shape*)

Water has a peculiar configuration. Though a water molecule (H_2O) consists of a single atom of oxygen bonded to two hydrogen atoms, it displays a nonlinear configuration or arrangement unlike carbon dioxide that is in straight line or linear form. **It is the non-linear arrangement (angular or V-shape configuration) of the oxygen and hydrogen atoms that gives water many unique molecular characteristics it possesses** (see Plate 6). At room temperature water

is a liquid, but there is also water in the air (on average the earth's air contains a few percent of water). Humidity is actually a measure of the amount of water that is in the air — on 'dry' days the humidity is low and there is very little water in the air.

Now we are getting to somewhere. How come about water in the wide and open sea.

In nature, liquid water exists as surface water (water in the streams, rivers, estuary and oceans), underground water (boreholes, aquifers) and atmospheric water (water vapor which could condense and fall as rain or snow). In water, hundreds of thousands of water molecules ($n\text{H}_2\text{O}$) associate together through a force of attraction called hydrogen bonding. **Ice, the solid form of water floats on water** because its density which is 0.9167 g/cm^3 is lower than that of water (0.9998 g/cm^3) at the same temperature. Liquid water is densest (sea water, 1.00 g/cm^3) due to the presence of dissolved salts and becomes less dense as the water molecules begin to form the hexagonal crystals of ice (on reaching the freezing point). This occurs because the force of attraction (hydrogen bonding), dominates at the lower temperature resulting in the conglomeration (gathering) of molecules. Density of ice increases slightly with decreasing temperature (0.9340 g/cm^3) but is still lower than that of water.

1.5 THE WORLD OF WATER

One of the first creations of God was water, because of its significance to life. WATER IS LIFE and nothing living can survive without water. God acknowledged the importance of this resource, and he gave a name to it - ‘’ (and I quote)..... ***and the gathering together of the waters he called SEAS (oceans)***” Genesis 1:10. Therefore, we can rightly say, the only programmes fully acknowledged and recognized by God, in order of importance, is firstly Oceanography (Genesis 1:10; in Exodus 17: 6 – Moses smote the rock and water came out) and secondly Medical Sciences (Numbers 21:8-9). All other academic programmes as good as they are, were designed and developed by man. Water is life.

You can survive temporarily without air, but when you are dehydrated, your end has come.

Total water Resources of the World

About $1,384,120,000 \text{ km}^3$ water is found in different forms in the hydrosphere (Table 2), with 98.0% being salt water and 2.0% being fresh water. Of the fresh water, only 1% is in liquid form on the surface (Rivers and fresh water lakes). In addition, the lower mantle of inner earth may hold as much as 5 times more water than all surface water combined (all oceans, all lakes, all rivers).

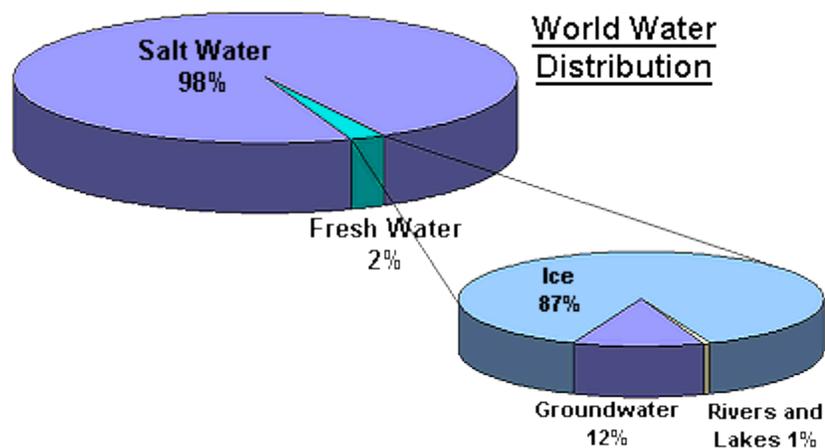


Plate 7: World water distribution by types

Table 2: Quantity of water in the Hydrosphere

Quantity of Water in Hydrosphere

<i>Water</i>	<i>Quantity (km³)</i>	<i>Quantity (in percentage)</i>
<i>Total Water (Pure and Saline)</i>		
Oceans	1,348,000,000	97.39
Snow caps, Icebergs, Glaciers	227,820,000	2.01
Groundwater and Soil Moisture	8,062,000	0.58
Lakes and Rivers	225,000	0.02
Atmosphere	13,000	0.001
<i>Total</i>	<i>1,384,120,000</i>	<i>100.00</i>
<i>Pure Water (2.6 % of total water)</i>		
Snow caps, Icebergs, Glaciers	27,818,246	77.23
Groundwater up to 0-0.8 km Depth	3,551,572	9.86
Groundwater up to 0.8-4 km Depth	4,448,470	12.35
Soil Moisture	61,1234	0.17
Fresh Water Lakes	126,070	0.35
Rivers	1,080	0.003
Aquatic Minerals of Earth	360	0.001
Atmosphere	14,408	0.003
Life	1,081	100.00
<i>Total</i>	<i>36,020,000</i>	

Distribution of river water

The total volume of water in rivers is estimated at 2,120 km³ (510 cubic miles), or 2% of the surface fresh water on Earth. Rivers and basins are often compared not according to their static volume, but to their flow of water, or surface runoff. The distribution of river runoff across the Earth's surface is very uneven (Table 3).

Table 3: The distribution of river runoff across the Earth's surface

Continent or region	River runoff (km ³ /year)	Percent of world total
North America	7,800	17.9
South America	12,000	27.6
Europe	2,900	6.7
Middle East and North Africa	140	0.3
Sub-Saharan Africa	4,000	9.2
Asia (excluding Middle East)	13,300	30.6
Australia	440	1.0
Oceania	6,500	14.9

The table shows that Africa has 4000 cubic km/ year of river runoff (about **9.5%**) of the total river runoff in the world.

A statistics of the ten poorest countries in terms of water resources per inhabitant are **Bahrain, Jordan, Kuwait, Libyan Arab Jamahirya, Maldives, Malta, Qatar, Saudi Arabia, United Arab Emirates** and **Yemen**. Nigeria is not there, neither is Africa, which indicates that we are blessed with water resources. In the large countries, water resources are also distributed unevenly in relation to the population.

Another look at water resources of the world reveal that more than a quarter of the world's population (about 2,1 billion people) lack access to clean water (WHO, 2017).

A recent report by WHO and UNICEF indicated the 10 Countries with the worst drinking Water Services. Parameters used in assessing these countries were: Accessibility of drinking water, availability when needed and levels of contamination of the water sources. The report indicated that 10 countries had the least safely managed water services world-wide. This include:

Uganda: Nearly 40 percent of people in Uganda need to travel for more than 30 minutes to access safe drinking water.

Ethiopia: There is a significant 43-point gap between safely water managed services in rural and urban water services in Ethiopia.

Nigeria: Is one of the fastest improving countries when it comes to water quality, but 15 percent of the people still drink unimproved water sources.

Cambodia: Is one of the 18 countries where at least 5% of the population depend on delivered water by UN services.

Nepal: The lack of proper sanitation facilities in Nepal leads to 30 % of the population practicing open defecation.

Ghana: More than half of the people in Ghana have limited sanitation services.

Bhutan: Only about a third of managed drinking water in Bhutan is free from contamination.

Pakistan: Pakistan is the country with the greatest gap in basic hygiene between the richest and the poorest.

Congo: In the rural parts of Congo only 21 % of the population has access to water nearby, which is nearly double what it was 5 years ago.

Mexico: Nearly three quarters of the people in Mexico drink packaged water and the country is a world leader in the consumption of bottled water per capita.

Nigeria is number 3 on the list of the countries with worst drinking water services. The present situation is not sacrosanct or irrevocable as I am one of those that propagate that Nigerian problem and challenges can be solved by Nigerians.

CHAPTER 2

2.0 THE STRATEGIC ROLE OF THE 3 WATERS OF LIFE

Man's corporate existence would have been impossible without the 3Bs. The strategic position of water in nature makes its usefulness indispensable for the accomplishment of all human purposes.

2.1 FRESH WATER SYSTEMS

The fresh water ecosystem exists as 3 types: **Black/grey/ white waters** representing streams, springs, wells and rivers. Fresh waters can be lotic (flowing) and lentic (still water) and are characterized by the nature of biotic (living organisms) and abiotic (non-living) components in the ecosystem.

Over 65 percent of the **fresh water on Earth** is found in icecaps and glaciers, and just about 29 percent is found in ground water. Only 1 percent of our **fresh water** is found in the surface water of lakes, rivers, and swamps. The total fresh water resources in the world are estimated in the order of 43 750 km³/year, distributed throughout the world according to the regional climates and physiographic structures.



Plate 8: Fresh water fall eg Agbokim falls, Obudu Cattle ranch water fall

At the continental level, America has the largest share of the world's total freshwater resources with 45 percent, followed by Asia with 28 percent, Europe with 15.5 percent and Africa with 9 percent.

% of Freshwater Resources of the world

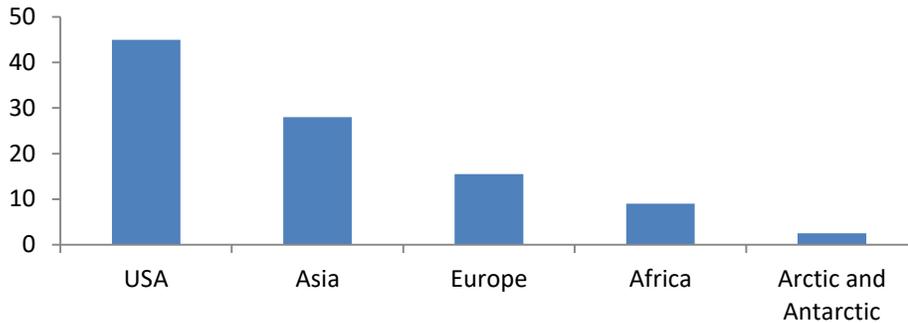


Fig. 2: Percentage (%) of Freshwater Resources of the world

2.1.1 The Chemical composition of freshwaters

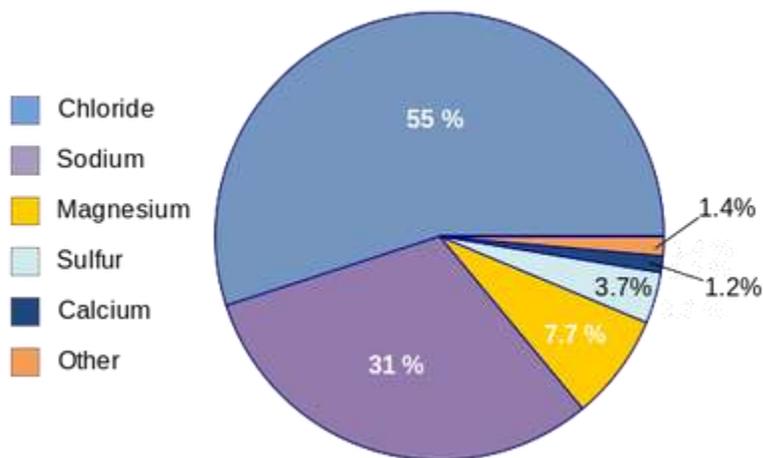


Fig. 3: The chemical of Freshwater resources

The fresh waters are characterized by distinct chemical composition which differentiates it from the other types of water. The fresh waters indicate waters of negligible salt content (< 1 parts per thousand or 1000mg/l) consisting of chlorine 55%, sodium 31%, magnesium 7.7%, sulphur 3.7%, calcium 1.2% and other elements constitute the minor components. Therefore fresh waters role is very unique and quite different from the one of brackish and blue waters.

2.1.2 Fishery composition of fresh waters

In nature, water for human consumption and domestic purposes (cooking, bathing, washing etc) are the **fresh waters**. But ecological studies reveal that fresh waters inhabit more than 100 species of fishes and organisms kept by nature to serve as food for mankind. Freshwater fishes

Freshwater contains complex microbial community consisting of primarily of planktonic and bacterial forms. The microbial biome especially the planktonic forms lay the foundation for the cyclic foodweb that sustains fresh water and marine life.



Freshwater frog



West African manatee freshwater mammal



Plate 9a,b,c,d: a) Freshwater fishes and game fish, b.) Freshwater microbial biomass, c) Freshwater frog, d) West African manatee or sea cow and e) freshwater snail

The freshwater frog, freshwater gastropod (snail) *Bithynia tentaculata* and the West African manatee (*Trichechus senegalensis*), also known as the West African manatee or sea cow are prevalent in fresh to brackish waters. These all serve as food and delicacies for the teeming coastal community worldwide if the waters are not contaminated or polluted.

The water we drink comes under the fresh water, but how safe is the water we consume. We'll look at that under water quality.

2.2 BRACKISH WATER SYSTEMS

The second **B** symbolizes the **Brackish** waters representing estuaries, saline lagoons, deltas and fjords. In Africa, we have the Nile delta, Niger delta, Volta estuary, Congo estuary, Lagos lagoon, Cross river estuary etc. as types of brackish water environments.

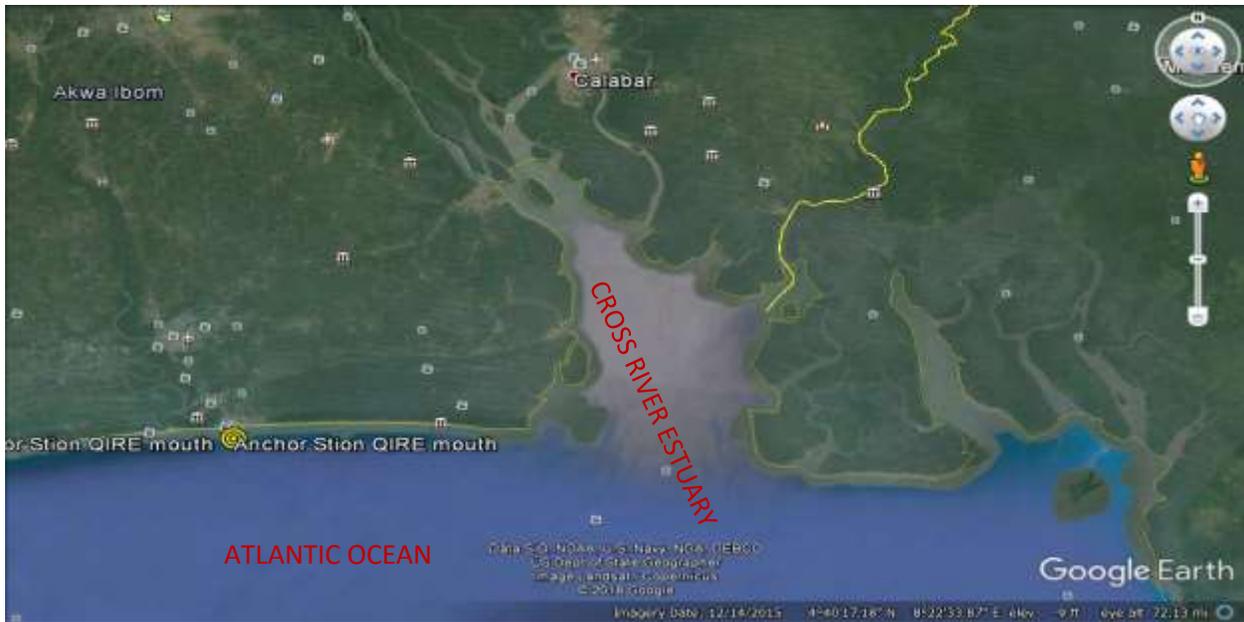


Plate 10: The google map of Cross river esyuary, Nigeria



Plate 11a,b: a.)The cross section of a typical estuary, b). Sea cruise to the Cross river estuary with Oceanography's research boat, Plankton Fischer.

Brackish refers to water that is saltier than fresh water, but not as salty as sea water. It is a product of mixing of seawater (ocean) with fresh water, as in estuaries, or it may occur naturally, as in brackish fossil aquifers.

Technically, brackish water contains between 0.5 and 30 grams of salt per litre , often expressed as 0.5 to 30 parts per thousand (ppt or ‰). Thus, brackish water covers a range of salinity regimes. It is a region of the aquatic environment that is very productive, has abundant micro-nutrients (green algae food) and serves as a breeding ground for most estuarine and marine fishes

A broader definition of **estuary** is "a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage" (Pritchard, 1967). This definition does not limit an estuary to a river mouth. The important characteristics of an estuary are that sea water mixes with fresh water, and there is an influence of the ocean waves and tide creating a dynamic relationship between the two waters.

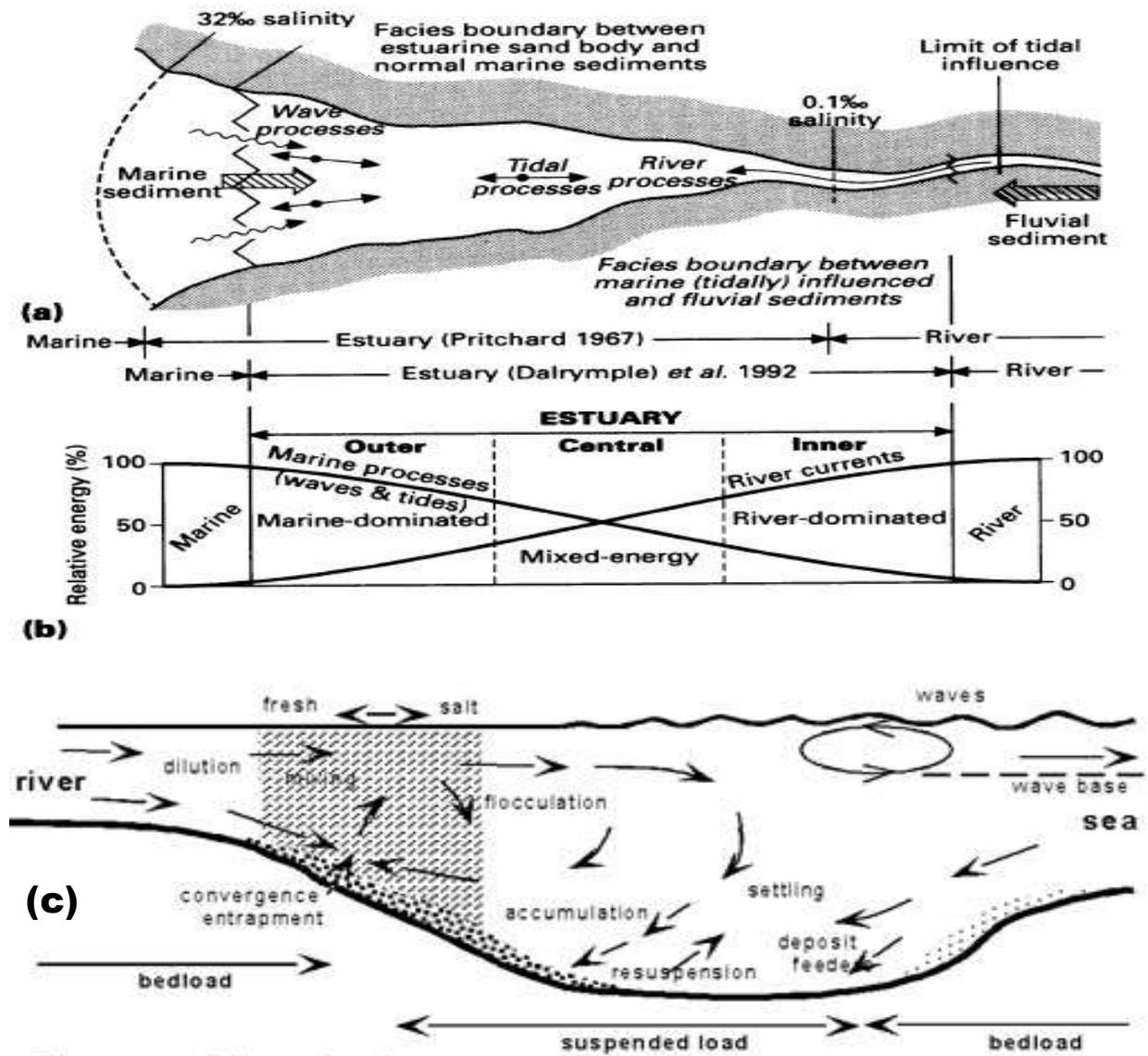


Fig. 4, b c: Schematic representation of a river flowing into the estuary before joining the sea (ocean). It portrays the estuary as a mixing zone for river and ocean waters.

2.2.1 Ecological Role of an Estuary

To most people, an estuary is a place where fresh water meets the sea. In its broader meaning, an estuary is that part of the mouth of a river in which the water level is greatly influenced by the ocean / sea. In Nigeria, there are more than 13 estuaries formed from the flowing of rivers into the Atlantic Ocean. In some countries such as the US and Canada, some estuaries have been set aside by the state and federal governments as a “state nature preserve” and “national estuarine research reserve.” In Nigeria, the Nigeria Conservation Foundation (NCF) in partnership with the AKS government have set aside the Stubb Creek and call it the Stubb Creek Forest Reserve, adjoining the Qua Iboe river estuary for the same purpose. Why should the government bother to preserve an estuary such as Qua Iboe river Stubb Creek?

There are many reasons for such action:

1. The estuaries of the world serve as breeding grounds for many important animals that live in deeper waters.
2. An estuary has a wide variety of habitats available for wildlife to use as nesting and feeding sites. Thus, estuaries harbor a lot of biodiversity.
3. The sediments and waters of an estuary are places where micronutrients are recycled and where the basic things needed for life are made available to a wide variety of aquatic organisms.
4. Estuaries serve as buffer zones to filter pollutants. Runoff from the land is cleansed before it enters a lake or ocean, and the effects of flooding and water level changes are minimized.
5. Estuaries are “endangered ecosystems.” Because of their quiet waters and nearness to lakes or oceans, estuaries are often attractive places for coastal developments such as home sites, jetties/ harbors and tourist developments. Few estuaries still exist in their natural conditions.

An estuary contains some areas that are almost always under water, some areas that are almost always dry land, and some areas between these two extremes. Each of these environments has a set of plants that can survive best under the given conditions. Each set of plants has a special role to play in the estuary and contributes to diversity of both plants and animals in the ecosystem.

Below is the world distribution of major estuaries, lakes and rivers (Fig. 5).

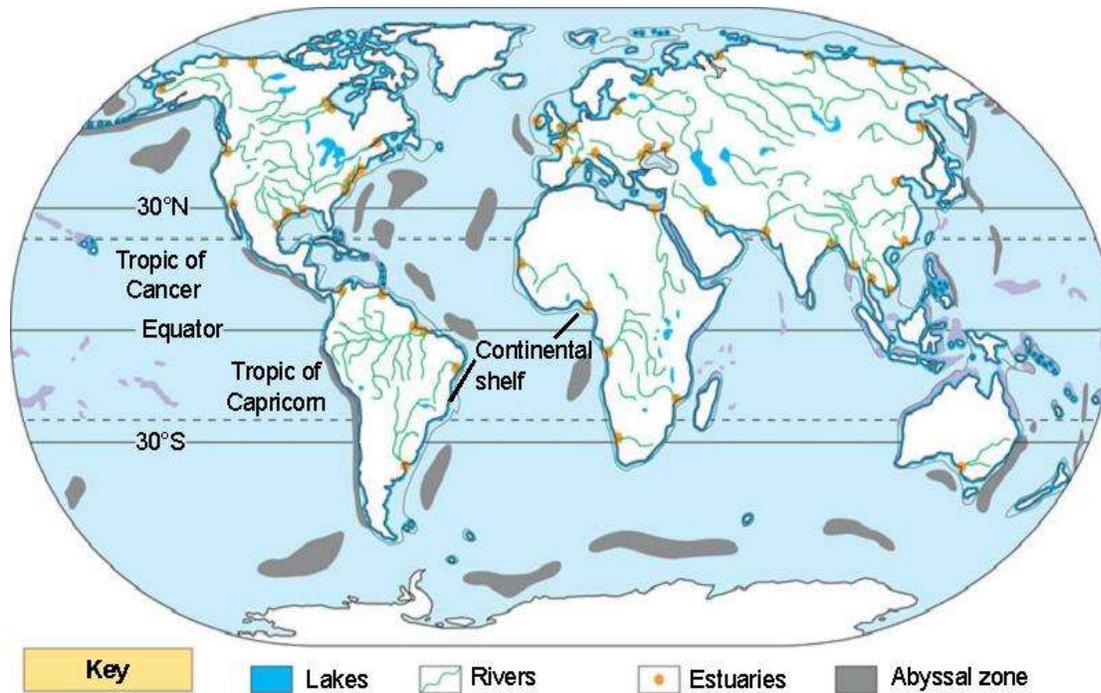


Fig.5: The world distribution of major estuaries, lakes and rivers. Estuaries/ deltas are in orange colors.

2.3 THE BLUE WATER SYSTEM (Open Ocean)

The third B are the **Blue** waters representing marine or seawater.



Plate 12: Waves a roaring in the open ocean

As one approaches a typical coastline, all that you are hearing are the breaking of waves in the shallow waters with a loud noise wa-a-a-a-ah, wa-a-a-a-ah, wa-a-a-a-ah. It is not an approaching

aircraft but the ocean rejoicing and bubble dancing. Saltwater is found in the ocean or enclosed sea.

The oceans surround our planet earth, covering the majority of earth's surface and control the water cycle that dominates our atmosphere and land. But more profound still, the story of our oceans envelops our home in a far larger context that reaches deep into the universe and places us in a rich family of ocean worlds that span our solar system and beyond. There are more than 326 million trillion gallons of water on earth. The earth's oceans contain about 96.5 percent of all the planet's water. Less than 3 percent of all water on earth is freshwater (usable for drinking). More than two-thirds of Earth's freshwater are locked up in ice caps and glaciers (Ocean World, 2013).

There is one Ocean, one world. However, oceanographers in their research generally recognize the existence of five **major oceans**: the Pacific, Atlantic, Indian, Arctic, and Southern oceans. Surrounding Africa are the North and South Atlantic Ocean on the west, the Southern ocean at the south, the Indian and Pacific oceans at the east and the Mediteranean sea on the north. This makes Africa a small island sandwiched between these major waters (Fig. 6).

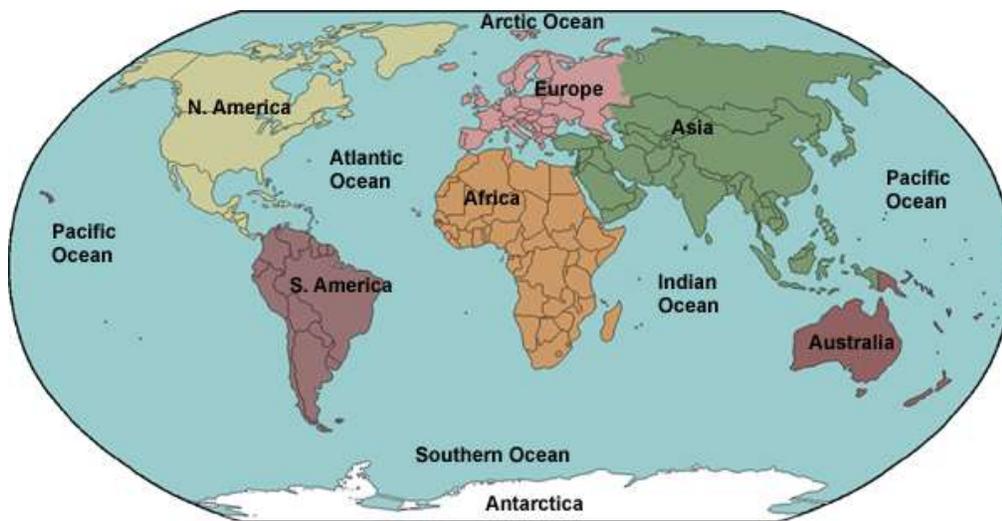


Fig.6: The worlds Ocean showing Africa and the Atlantic Ocean

2.3.1 OCEAN CHEMICAL COMPOSITION

Table 4: The chemical composition of the ocean compared with fresh water and brackish water

Type of Water	Dissolved salt content (mg/l)	Examples	Effects
Fresh water	< 1,000 mg/l	Rivers	Not noticeable
Brackish water	1,000 - 3,000 mg/l	Estuaries, deltas	Survival of euryhaline organisms
Moderately saline water	3,000 - 10,000 mg/l	Lagoons	Habitat for stenohaline organisms
Highly saline water	10,000 - 35,000 mg/l	Seawater, Open ocean	Habitat for stenohaline organisms
Enclosed seas	> 37,000 mg/l	Mediterranean Sea, Baffin Bay	Habitat for stenohaline organisms

2.3.2 THE POSITIVE IMPACTS OF OCEAN ON LIFE

- Ocean serves as a means of recreation and sporting events
- Ocean serves as transportation medium between coastal towns and international maritime linkages
- Ocean animals are a source of sea food to humans i.e. fisheries resources/ mariculture
- Sand extraction, solid mineral extraction (mineral ores)
- Ocean offshore for exploration and exploitation of petroleum (crude oil)
- Coastal ocean serves as sea ports, jetties, military bases, Naval and immigration posts, dockyards

The above 4 constitute the major components of ocean or blue economy.

- Ocean as sites for industrial layouts for manufacturing companies
- Ocean as a location for establishment of modern coastal cities etc

Since creation, this statuesque (fresh water, brackish and the oceans) has been maintained regardless the interplay of hydrodynamic forces during tidal incursions (flow in – flood and flow out – ebb) of water and the occurrence of catastrophic extreme events such as hurricanes and tsunamis.

The peculiarities between the 3Bs (waters of life) underscores the distinct and enormous roles they exhibit in maintaining water and biogeochemical cycles which regulates natural and all human processes. Therefore we see the **THREE B'S OF LIFE AS A NATURAL BLESSING TO HUMANITY.**

2.3.3 DISTINCT PECULIARITIES OF WATER

Water as potent Medicine

Water is a therapy for healthy living. WATER IS LIFE. Water is a part of our bodies and we simply cannot live without it. Many people fail to realize just how important water and appropriate hydration is for good health. When we fail to realize this, it can lead to an array of unpleasant consequences. Water as potent medicine has been investigated and results / findings are amazing and is an essential way to offer your body the refreshing it needs while also achieving many extra health benefits.

The Japanese Medical Society has reported that water therapy is a **100% cure** for disease like bronchitis, tuberculosis, arthritis, epilepsy, meningitis, diarrhea, sore throat and many other ailments. Research has proven that water therapy can cure most disease conditions very rapidly on its own, **with no other medical treatments.** Their report also indicated that, water therapy alleviates constipation within a single day, diabetes within one week, and hypertension and even cancer within a month (Biz, 2018).

Can Water Wash Away Disease? Yes, it can. In the Holy Bible, Elisha the man of God recommended water therapy to Naaman, the Captain of the host of the King of Syria who had leprosy. The man of God said, ‘Go and wash in River Jordan seven times, and thy flesh shall come again to thee, and thou shall be clean’ (2 Kings 5: 10, KJV). And this great man, whom the ‘Lord had given deliverance unto Syria’ many times was wroth and almost left complaining. But a kind-hearted fellow, one of his servants came and spoke softly to him and said to obey is better than gifts which the man of God has not even requested of you. He said only wash and be clean. Then it done on Naaman, ‘he went down and dipped himself seven times, and his flesh came again like unto the flesh of a little child’ and Naaman was healed instantly of leprosy.

My Vice Chancellor, it is not only in the biblical times that water washed away diseases and reinvigorates. Today, our medical practitioners (doctors and nurses) will give you an infusion of dextrose saline and/or normal saline when you are dehydrated. Water is life and has the cleansing and refreshing power. It is a healthy habit that you wash and be revived every time you feel tired, down or depressed. Water has healing power.

Research reports indicate that water has some magic powers (miraculous power). Drinking water early in the morning immediately upon waking up has amazing therapeutic effects for a multitude of health conditions. This therapy began with the ancient Ayurvedic medicine. The practice is called *Usha Paana Chikitsa* in Sanskrit, India which roughly interpreted means “early morning water treatment.”

About 17 years ago, a renowned clinician from Iran, Dr. Fereydoon Batmanghelidj in his book ‘**Your Body's Many Cries for Water**’, said that ‘*You Are Not Sick, You Are Thirsty! Don't treat thirst with medications*’. He discovered the healing powers of water and the link between dehydration and chronic illness. While serving a jail sentence in an Iranian prison, he used the only medicine available to him - *which was water* - to successfully treat 3,000 fellow prisoners who were suffering from stress-induced peptic ulcers. WATER IS LIFE. According to Dr. Batmanghelidj, *the body's biological thirst signals can be mistaken for signs and symptoms of other illnesses*. If we treat the root cause of these, which is **dehydration**, we can avoid costly and unnecessary medical interventions and enjoy long-term wellbeing.

Water as a therapy has many health benefits which include body rehydration , speeds up brain processing power, clears the colon, boosts metabolism, refreshes the skin, minimizes headache occurrence, stimulates your appetite for breakfast, stimulates bowel movement, rids the body of wastes, improves body immunity and avoids multiple disease conditions such as diabetes, kidney stones, asthma and angina among others. Presently water therapy as a hydrotherapy technique is practiced widely by the Japanese, Indians and the Chinese.

My Vice Chancellor, Sir, since clean water has all these paramount and magnificent benefits, I strongly advocate that we should DRINK AND PROTECT it rather than contaminate and destroy it.

There is a song, our advocacy song that goes like this:

Drink! Drink!! Drink! !! Drink!!!!

If you wanna LIVE

Drink! Drink!! Drink! !! Drink!!!!

If you wanna GROW

Drink! Drink!! Drink! !! Drink!!!!

If you wanna SUR-VI-I-I-I-I-IVE

DRINK!!!! ----2X

When I visit your office or home, and you give me a bottle of water – YOU ARE GIVING ME LIFE. You are telling me LIVE ON. A bottle of UNICAL water as a gift is better than a bottle of can malt. We drink to live and not live to drink. So if you want to live healthy and happily, drink clean fresh water regularly.

CHAPTER 3

3.0 OUR MODEST RESEARCH EFFORTS AND CONTRIBUTIONS TO SCIENCE & HUMANITY

3.1 Water Quality and Health

Over the past 3 decades, my research on water has focused on water quality, toxicology and pollution. Several hundreds of water, sediment and tissue samples have been collected and analyzed at home and abroad, and it is my delight to present some of my humble and outstanding research works to you.

Water clear and clean as it appears to the eyes, may not be PURE after all. Determination of quality of water is a priority to good health, not only for human consumption but also for every living thing, plants and animals.

In ascertaining good health, we carry out water analysis to determine the state of bottled water and other drinking water sources available for households' usage, commercial and for industrial purposes. The data and information generated are made available to individuals, commercial ventures and corporate organizations for a reliable and beneficial use of water as a natural resource, thus fulfilling its purpose (a blessing) in life. It is interesting to know that, in most countries of the world including Nigeria, such data are very useful in the development of Water Quality Standards and the formulation of Regulations for the efficient and sustainable use of water resources. In Nigeria, the Federal Ministry of Environment depends on us for the supply of quality environmental data that assist the Ministry in executing one of its mandates as a watch dog and a regulator of activities involving the utilization of water and disposal of waste materials in Nigeria. This Ministry has established the Nigerian Water quality standard and specifications for drinking water purposes and use by different categories of industries (FEPA, 1991;SON, 2007).

3.1.1 Water Quality of Drinking water sources in Nigeria

a. Water Quality of Bottle / Sachet Waters in the Nigerian Market:

Every bottle of water contains hundreds of dissolved chemical substances in concentrations that should be permissible for human consumption. In Nigeria we have analyzed and compare the water qualities Eva, Swan, Pime, UNICAL water, Global, Tropical, Nestle, Blue Rose and many others (Asuquo & Utre, 2011). These bottled waters are good for drinking purposes and we do hope the standard shall be maintained. Their mineral and chemical standards are all within the recommended and permissible limits of drinking water by SON, DPR, FMEnv and WHO. But regrettably, most bottle waters in Nigeria do not display their quality status on the bottle just like they display NAFDAC numbers. Water of good quality is determined by the amounts of some of the relevant parameters like pH, Sodium, Chlorine, Calcium, Sulphate and Carbonate, and these

should be displayed legibly, as it gives the consumer the assurance and confidence that the water is of good and acceptable. My work in collaboration with other colleagues has been centred on knowing the water quality of bottled waters available in the Nigerian market (Table 5).

Table 5: Observed water quality of some bottled waters in Nigeria (Asuquo & Utre, 2011).

Parameters	Premier	Swan	Eva	Pime	Global	Totagos	Tropical	WHO 1988 LIMIT
pH	7.08	7.28	7.24	7.27	6.65	6.68	7.25	6.5- 7.5
TDS mg/l	95.90	98.0	87.10	40.80	11.90	33.30	57.40	500
Conductivity $\mu\Omega/cm$	192.3	196.0	174.70	81.90	24.10	67.70	115.20	400
Chloride mg/l	69.10	70.50	62.50	29.30	8.52	24.30	40.90	-
Nitrate mg/l	2.271	0.513	0.105	0.04	0.133	4.19	2.402	20
Sulphate mg/l	9.67	9.86	8.789	4.12	1.194	3.41	5.80	200
Sodium mg/l	38.40	39.20	34.90	16.40	4.74	13.50	23.0	200
Calcium mg/l	11.60	11.80	1050	4.94	1.43	4.08	6.95	75
Alkalinity mg/l	15.0	20.0	20.0	15.0	15.0	20.0	15.0	-
Iron mg/l	0.103	ND	ND	0.302	0.012	0.05	0.033	0.30
Lead mg/l	ND	ND	ND	0.002	ND	ND	0.01	0.10
Zinc mg/l	0.001	ND	ND	0.004	0.001	ND	0.004	5.0
Manganese mg/l	0.03	0.001	ND	0.01	ND	ND	0.004	0.10
Cadmium mg/l	ND	ND	ND	ND	ND	ND	ND	0.10
Chromium mg/l	ND	ND	ND	ND	ND	ND	ND	0.10

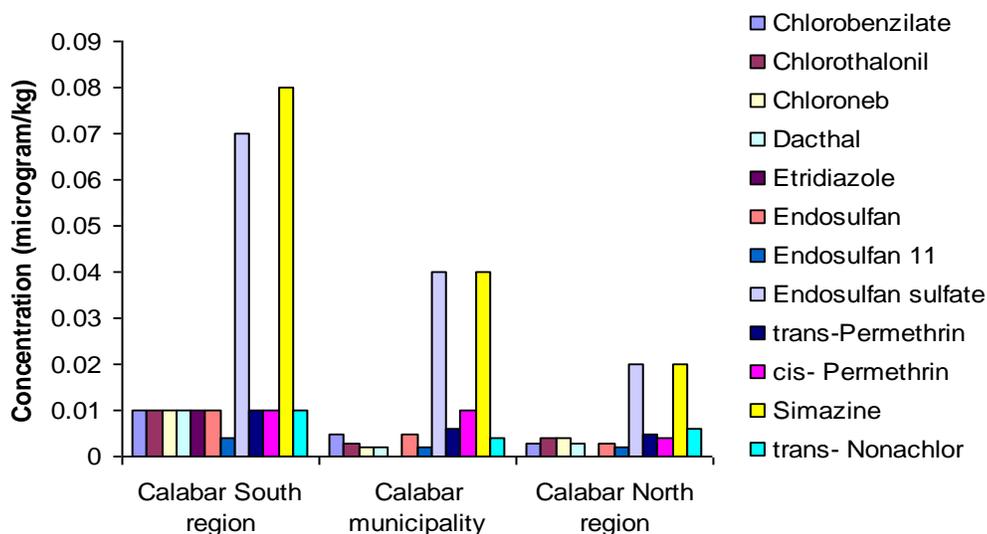
If I may ask, what is the pH of UNICAL water or Marian water? Is it safe to drink or not? The answer would have been unanimous if the values were clearly displayed on the bottles.

b. Water Quality of Boreholes , wells and streams in Nigeria

Presently in Calabar, just like most urban towns in Nigeria, the supply of potable water from Water Board for drinking and domestic purposes has been very erratic and highly epileptic. Almost every compound has a borehole, but how many of such borehole waters have been analyzed to determine their suitability for human consumption. It is a risk to consume water that has not been analyzed.

Water quality assessment of the some bore hole waters used as drinking water sources in Calabar municipality, South Eastern Nigeria, has shown that all the samples analyzed were feacally contaminated. These samples also contained other pathogenic organisms such as *Vibrio cholera*, *Salomnella typhi* and *Shigella dysenteria* in relative proportions. Results indicate that some of the samples had distinct colours (>50pt Co units), high acidity (pH 4.0 -5.50) and high coliform counts (3 or more E. coli counts /100 ml) when compared with recommended limits. This suggests that consumption of water with high acidity (low pH) may lead to an increased gastric juice content of the stomach thereby predisposing victims to ulcer cases. Treatments of the boreholes were strongly recommended (Asuquo & Asuquo, 1999).

Investigations were carried from February to May 2009 to ascertain the potability of selected borehole waters in Calabar, Nigeria, which is fast becoming a centre for commerce, industry and tourism (Fig.7). The area of study consisted of three egalitarian regions namely Calabar South (bordering the Republic of Cameroon), Calabar Municipality (middle) and Calabar North (at the Tinapa area). Potability and acceptability depended on the quality of the borehole waters complying with the Nigeria Federal Ministry of Environment and WHO Guidelines (2009). While the levels of physicochemical factors and secondary contaminants were all within permissible limits, remarkable contamination occurred with respect to Alachlor $0.2 \pm 0.01 \mu\text{g/l}$, Atrazine $0.1 \pm 0.001 \mu\text{g/l}$, Endosulfan sulfate $0.07 \pm 0.05 \mu\text{g/l}$, g.chlordane $0.1 \pm 0.02 \mu\text{g/l}$, Heptachlor epoxide $0.08 \pm 0.02 \mu\text{g/l}$, Methoxychlor $0.2 \pm 0.003 \mu\text{g/l}$ and Simazine $0.08 \pm 0.032 \mu\text{g/l}$ especially in samples obtained from Calabar South. The levels of these contaminants slightly exceeded the permissible limits of WHO/USEPA standards for potable waters and could lead to eye, liver, cardiovascular or nervous system problems. The health implications of these and the need to develop Urban Clean Water and Safety Policy (UCWSP) was recommended for Nigeria and developing countries (Asuquo *et al.*, 2011).



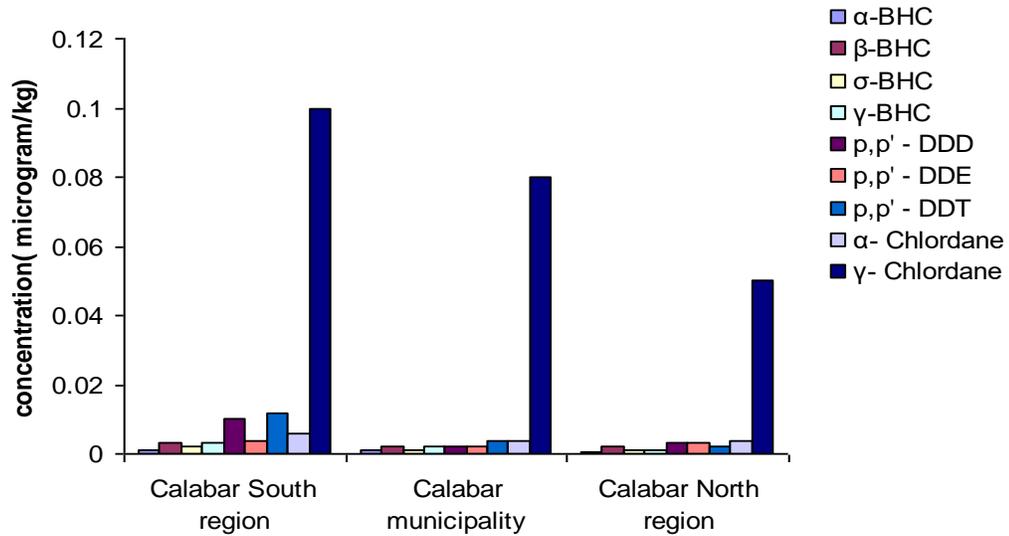


Fig.7 : Levels of organochlorines (pesticides) in borehole waters from Calabar, Nigeria, 2009.

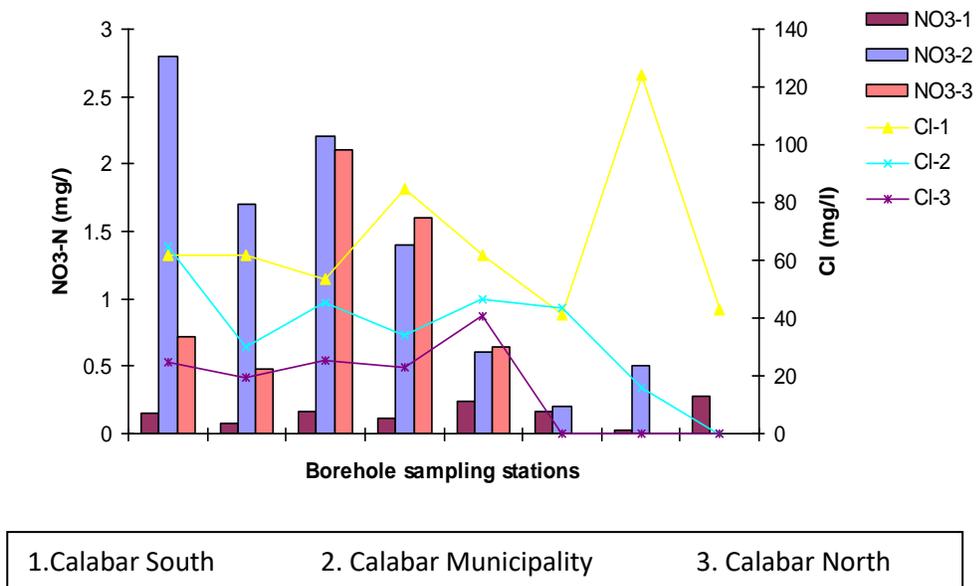


Fig.8 : Levels of nitrates and chlorides in borehole waters from Calabar, Nigeria, 2009.

3.1.2 Water Quality of Nigerian Rivers and Lagoons

Nigeria is one of the coastal countries situated in the tropical zone of Africa. The country has several rivers that provide water irrigation, fishing, drinking and transportation services. In comparing the quality of waters from Nigerian rivers, estuary and the oceans, our studies have shown that there is a clear distinction between the 3Bs as it was designed by nature. From a pristine background, most surface waters in Nigeria are gradually undergoing deterioration due to human activities. My research works, in collaboration with others have assessed the Calabar

river, Cross river and its estuary, the Great Kwa and Qua Iboe rivers , the Imo river, the Lagos lagoon and the Niger delta.

Studies on the water quality of Calabar river reveal a pristine environment with concentrations of physico-chemical factors being within acceptable limits for coastal waters. Water quality parameters namely temperature, pH, dissolved oxygen, nitrites, nitrates, ammonium ion, phosphates, dissolved silicon, suspended solids and salinity were measured monthly from surface and bottom water samples taken at a sampling station on the Calabar river. pH ranged from 6.2-7 and saline water intrusion (salinity range <0.1 - 7.13ppt) was minimal especially in the early months of the year. The concentration of dissolved nutrients showed slight monthly variation: nitrites 0.02 - 2.0 $\mu\text{mol/l}$; nitrates 0.2 -12.1 $\mu\text{mol/l}$; ammonium ion 0-7.4 $\mu\text{mol/l}$; and dissolved silicon 29-146 $\mu\text{mol/l}$. The level of dissolved oxygen (4.55 -6.75mg/l) and pH appeared to have no adverse effect on the biota. The dissolved oxygen percent saturation values were very close to saturation. The river was characterized by low but variable total suspended solids (Asuquo, 1989).

Most often information is also gathered with respect to the bottom profile of the rivers (Fig. 9). These are very useful information when considering the rate of river discharge, flushing characteristics of the river, real depth for navigational purposes depth and the bottom profiles of the river.

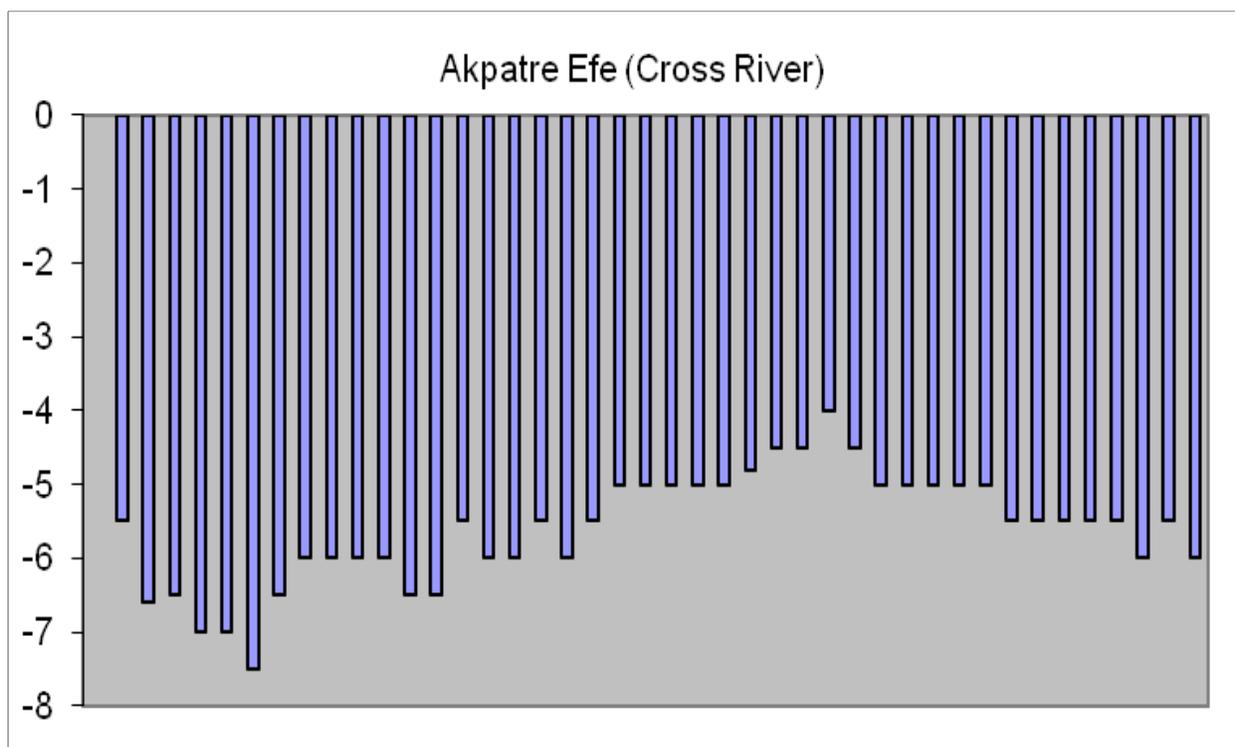
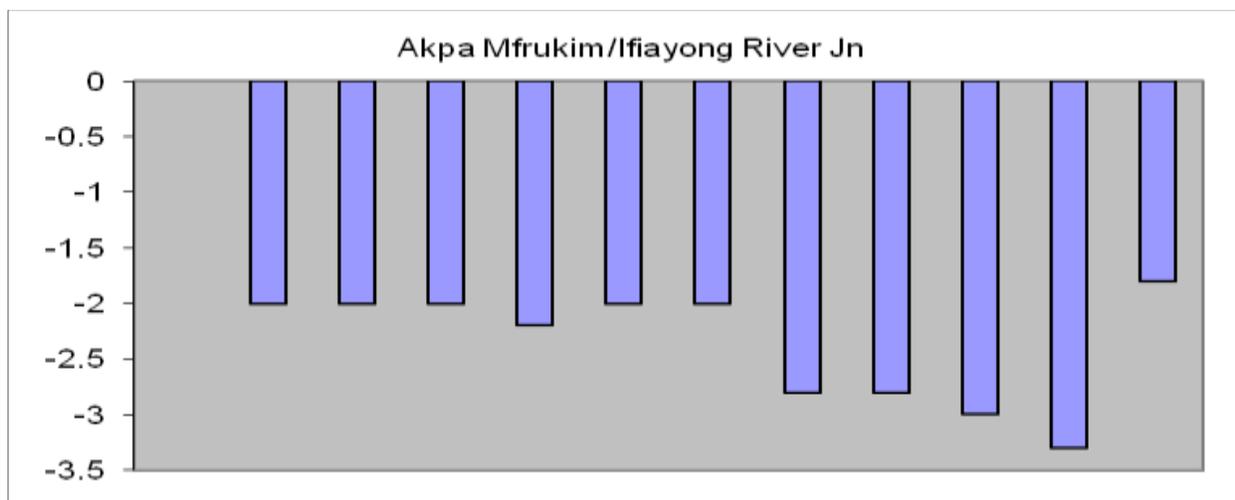


Fig.9: Bathymetric profiles of sections of the Cross river off Calabar river mouth, 2011.

Investigations into the variations in water quality characteristics, hydrocarbon levels and Fe contents of the Calabar river a major tributary of the Cross River, Nigeria was conducted between October 1994 and March 1996. The study showed that the river was relatively fresh (salinity 0.56ppm) from upstream indicating a remarkable diminution in salinity when compared to previous measurement. The river has high total hydrocarbon (THC) levels (22.0 - 558mg/i, mean 27.3 ± 3.9 mg/l) depicting anthropogenic additions and low Fe content (0.5 - 2.0mg/l, mean 1.5 ± 0.42 mg/l). THC was above the limit (10mg/l) and Fe below the limit (20mg/l)

recommended for nearshore waters (FEPA, 1988). Generally, all the measured water quality parameters were higher at flood tide than ebb tide temperature suggesting that tidal regimes are the dominating factor inducing changes in the river water quality. A statistical analysis using coefficient of determination r^2 gave no relationship between THC levels and current speed ($r^2 = 0.05$ for station 1 and $r^2 = 0.03$ for station). The potential sources of pollution such as occasional spills, residual oils from ships during the discharges of petroleum production at the jetties and the discharges from motorized boats commuting between Creek Town, Calabar and Oron were identified as point sources of pollution. Pollutant toxicity to fish, bioaccumulation and surface water contamination were observed (Asuquo, 1999).

3.1.3 Water Quality in Fish Pond Culture

The significance of the inter-relationship between pH, alkalinity, hardness and conductivity in fresh water ponds was studied using Water Quality Ratios (WQR) and pair-wise correlation analysis. While the relationship between alkalinity: hardness $r = 0.96$, $p > 0.025$, $n = 840$ and alkalinity; conductivity ($r = 0.50$, $p > 0.05$, $n = 84$), gave good correlations, the relationship of pH with alkalinity, hardness and conductivity was poor and insignificant ($p > 0.001$). Moderately high WQR (2.9) was obtained only for alkalinity/hardness relationships. The elevated alkalinity/hardness ratios are indicative of sufficient quantities of carbon dioxide which are required for plankton development. High ratios also suggest alkalinity and hardness as the principal factors contributing to the ionic stability of the system. The low WQRs and the consistently highly significant linear relationships ($0.05 > p > 0.001$) between pH and the order variables predicted a well buffered system favourable for pond fish production, Table 6 (Asuquo, 1998).

Table 6 : Comparison of the Water Quality of Ibeno Coastal water with Calabar river and University of Calabar Fish Farm waters.

Parameters	Ibeno Seawater mg/l	Calabar river (mg/l)	University of Calabar Fish Farm (mg/l)
Na	10,500	18	20
Cl	19,000	23	28
SO ₄	2,700	48	42
Ca	410	35	37

Mg	390	110	120
HCO ₃	142	109	116
pH	8.5	6.6	6.8

3.1.4 Water Quality of Ibeno Atlantic Coastline

Seasonal changes in the water Quality of Ibeno coastline suggest a nearshore environment slightly impacted by human activities. The levels and concentrations of physicochemical parameters, nutrient and total hydrocarbon in surface and interstitial water along Ibeno Atlantic coastline in dry and wet seasons were studied. The results show that the water was moderately acidic to alkaline in nature having a mean pH of 5.65 -8.35 during the period. The coastline was acidic in the dry season and alkaline in the wet season. The amount of dissolved oxygen measured showed concentrations in the ranges of 3.04-5.9mg/l in the dry and 0.98-41mg/l for the wet season., BOD₅ values were low during (he both seasons (1.1-1.4mg/l for dry and 0.4~30mg/l for wet season respectively). The variations in water temperature (24.7 – 29.3°C) were within the normal ranges for tropical waters. The organoleptic parameters (turbidity and colour) were generally high, 2.4.8 - 252.6 FTU and 1521 - 433.9 Pt Co. unit for the dry season, nutrients (PO₄, NH₄, NO₃ and SiO₃) were observed to be higher in dry season than wet season. Marked total hydrocarbon (THC) levels were measured in interstitial water than surface water in both dry and wet seasons. Values varied from 1.30mg/l in the surface water (wet season) to 25.5mg/l in the interstitial waters (dry season). The observed THC values for interstitial waters were higher than Department of Petroleum Resources (DPR) recommended limit (20mg/l) for coastal waters (Bassey & Asuquo, 1999).

An assessment of flood-ebb tidal dynamics of the near shore waters of the south Central Atlantic Ocean in Nigeria suggest enhanced contamination of the coastal water arising from sequential discharge of heavy metals from point and non-point sources through the Cross river and Qua Iboe river estuaries into the coastal marine waters. Bulk analyses of 100 water samples for heavy metals using Flame AAS (PyeUnicam) Model 9200 from surface (0 – 5m) and subsurface (6-10m) of nearshore waters indicate serious contamination of the waters especially during ebb-flow regime (Figs. 10 & 11). High metal concentrations occurred at ebb tide with reduced impact at flood. Heavy metal trends followed the sequence for ebb: Pb>Fe>Zn>As>Cu>Al>Cd=Co=Sn=Hg and flood : Pb>Fe>Cu>As>Zn>Al>Cd=Co=Sn=Hg incursions. The mean concentrations for specific metals were Pb (12.02 ± 22.8 ppm), Fe (0.84± 0.69 ppm), Cu (0.18± 0.12 ppm), Zn (0.30± 0.68 ppm), As (0.26±0.22 ppm), Al (0.02± 0.02 ppm) while Cd, Co, Sn and Hg were all undetectable. Strong positive and significant (P< 0.01) correlations were obtained between Fe/Al (r =0.97,n=100), Fe/As (r =0.94, n=100) and Al/As (r =0.98, n=100) which suggest strong association between the metals emanating from similar sources possibly

from inputs of less saline water from fluvial discharges. The consequences of increased extraction and exploitation of marine minerals especially non-solid (fossil fuels) and non-metallic (sand and gravels) minerals are the re-suspension of precipitated minerals in the wetlands/marshlands and shallow estuarine zones. Inputs of domestic/industrial effluents from coastal residential and industrial sources have probably contributed to the heavy metal flux in the near shore waters. Net water movements enhanced by strong tidal currents may have caused the redistribution of dissolved and dispersed heavy metals within the water column in the estuarine zone. These findings are essential for proffering eco-solutions for the sustainable management of the coastal marine waters (Asuquo & Ita, 2013).

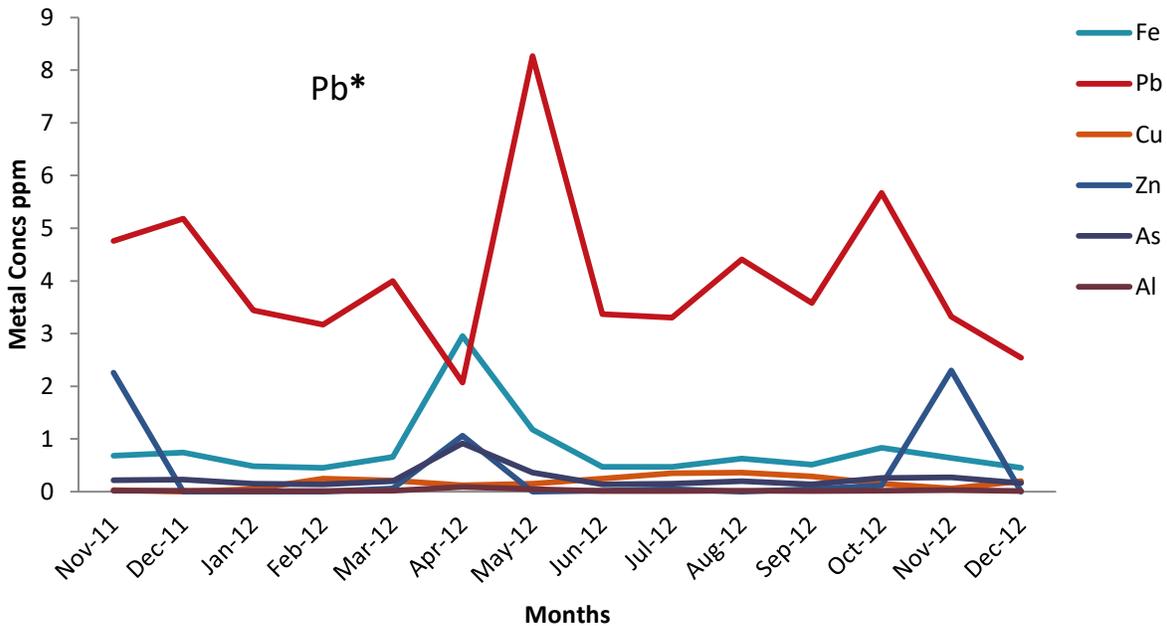


Fig. 10: Temporal Variation in the concentrations of heavy metals in South Equatorial Atlantic ocean (Note: Actual Pb* values above 4 = 10 x plotted value)

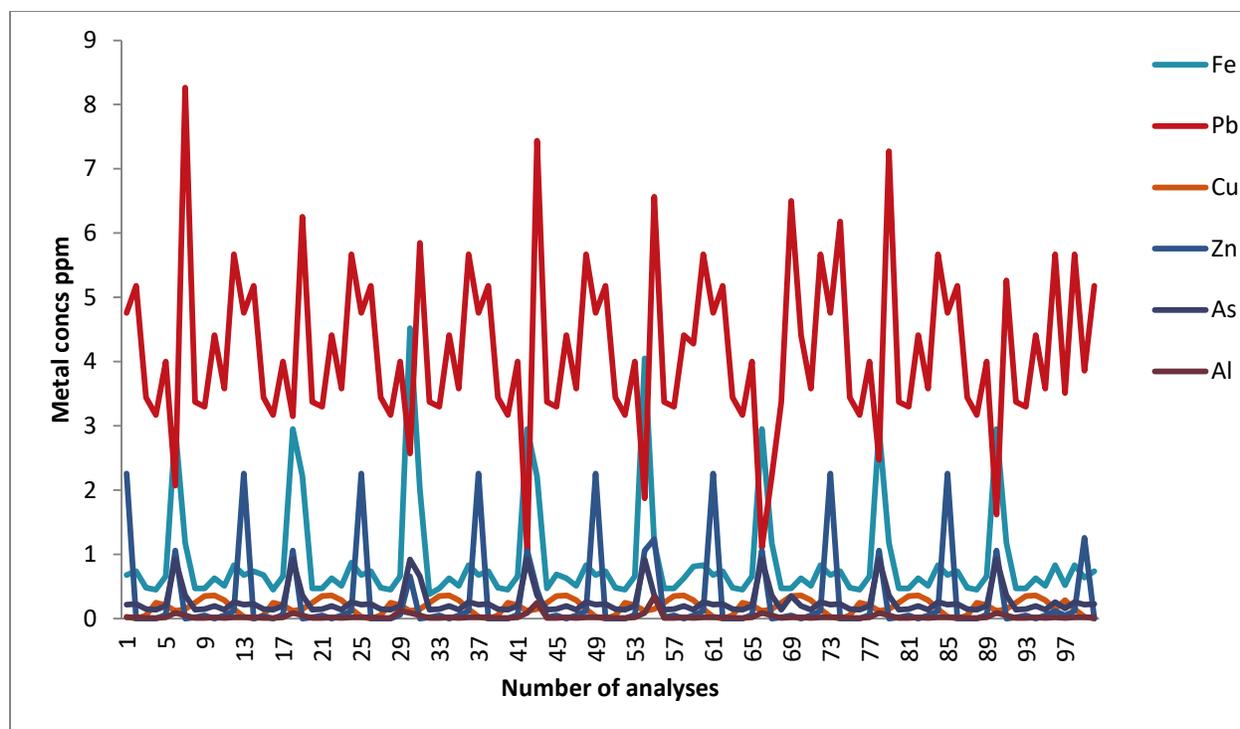


Fig. 11: Degree of abundance of specific heavy metals in the coastal waters of Gulf of Guinea

The bivalve, *Mactra nitida* is highly abundant along Ibeno shoreline, South East Nigeria. The organisms are largely consumed by the coastal dwellers as sea food and also serve as secondary source of income for the fishermen. The organisms range in sizes from 1.5-2.5 cm (small size) to 2.6-4.5 cm (adult size). Chemical analyses of the soft tissues for heavy metals and total dissolved petroleum hydrocarbons (TDPHs) showed reasonable signs of contamination (max, concentration 206.7 ± 25.1 pg/g for Fe and min. 1.9 ± 1.85 μ g/g for Cu). Maximum TDPH level observed was 275.4 ppm in the adult specie. There was a significant correlation between the two class sizes in relation to the metals concentration ($P < 0.05$, $r = 0.96$). However, Cu and Zn did not indicate early bioaccumulation in the small species when compared to the large ones. The mean concentrations of all metals analyzed were above WHO maximum permissible limits for fisheries and aquatic life indicating tissue contamination of the edible bivalve. The implications of these observations and the potential health hazard with regards to the high bioaccumulative potential of *Mactra nitida* were discussed (Asuquo *et al.*, 2005).

3.1.5 Water and Sediment Quality of Accra-Tema Coastline

Studies on the physicochemical parameters, major ions and the interrelationships between them in the surface waters of Accra-Tema coastline were made between August and October 1996. The mean values of physicochemical factors determined were $27.3 \pm 0.93^{\circ}\text{C}$, 32.85 ± 0.13 ‰, 7.9 ± 0.1 , 53.6 ± 0.30 mS/cm and 6.98 ± 0.8 mg/l for water temperature, salinity, pH, conductivity and dissolved oxygen respectively. The concentrations of major ionic species determined and the corresponding inter-ionic ratios were found to be higher than expected for a coastal environment except Mg/Cl (0.06698). The low ratio for Mg/Cl corresponds to the

decrease in Mg concentrations with increase in salinity of the coastline. A pair wise correlation analysis gave strong and highly significant r^2 values for the relationships: salinity/ DO, 0.92; Mg/Salinity, 0.94; pH/Mg, 0.77; temperature/Mg, 0.85 and temperature/Na, 0.85 at $P < 0.001$ and $n = 48$. The observed relationships were attributed to influx of saline water from the Goa lagoon (salinity 37.0 ppt), resulting in elevated concentrations of Na, Cl⁻ and SO₄²⁻ along the coastline which ultimately affected the ion pairing of the dissolved constituents (Asuquo & Akpabli, 2002).

Sediment samples at six different depths from four different beaches: Owene, Riviera, Sakumuno and Kpone along the Accra-Tema coastal area Ghana coastline were subjected to aggregate distribution and trace metal analyses for possible heavy metal pollution. Open digestion commonly employed in the laboratory and closed digestion with Teflon bomb were used and the metals in the sediments were determined by Atomic Absorption Spectrophotometer (AAS). Results indicated that sediments from the same beach taken at different depths follow the same particle size distribution pattern which is different from distribution patterns shown by the other beaches. Eastwards along the coast from Owene, particle size irrespective of depth moved from more coarse particles to very fine grains at Riviera, then to broader distribution of particles at Sakumono and to medium grains at Kpone. Digestion with the Teflon bomb was found to be more efficient and better than the open digestion method. Fine grains of sediments with particle sizes of 0.40mm and below were found to contain higher levels of the metals than the coarser sediments with particle size greater than 0.40mm. However, no direct relation between metal content and depth of sample has been found. All the sediments were found to contain on average, high amounts of metals especially manganese but the concentrations were all lower than the values obtained from previous studies (Akpabli *et al.*, 1998).

3.1.6 Water Pollution studies of Nigerian rivers: Cross river, Calabar, Great Kwa and Qua Iboe rivers, Nigeria

Fish quality deterioration

The muscle tissues of *Ethmalosa fimbriata* and *Chrysichthys nigrodigitatus* collected between the period March - August 1999 from the Cross river estuary, Nigeria, were assessed for possible anthropogenic impacts on these species. Levels of total hydrocarbons (THC > 6.0ppm) and Cu (> 2.6ppm) exceeded their WHO permissible limits (0.0001 and 0.02 ppm respectively) in the fish tissues (Table 7). Fe levels also exceeded the permissible limit (300 ppm) in more than 13.3% of *Chrysichthys nigrodigitatus* and 22.2% of *Ethmalosa fimbriata* collected during the period. **Lead was not detected in any of the fishes sampled.** Inter-location variation in mean concentrations of THC, Cu and Fe were minimal and insignificant ($P > 0.05$) except for *C. nigrodigitatus* sampled from Anantigha area ($P < 0.05$). Pollution pattern was in the order: Obufa Esuk (upstream) < Henshaw Town (midstream) < Anantigha (downstream), independent of weight and length of fish ($r < 0.3$, $P > 0.05$) but time -dependent ($P < 0.05$, ANOVA) especially in the accumulation of THC in *E. fimbriata* and Fe in *C. nigrodigitatus*. Linear relationship was found between Cu and Fe levels in *E. fimbriata* as described by the equation: $Y = 0.45 - 29.39 X$, ($r = 0.98$, $n = 18$, $P < 0.05$). *E. fimbriata* showed a higher affinity for Cu and Fe than *C. nigrodigitatus*. These results provide the baseline levels of these pollutants in the species investigated and also suggest that long term bioaccumulation of the toxins by these species is

potentially hazardous especially to coastal dwellers who consume them in large quantities yearly (Asuquo & Udoh, 2002).

Table 7: The mean concentrations of heavy metals and hydrocarbons in fishes and shell fishes from Cross river estuary, Nigeria

Fish Species	Cd	Pb	Zn	Fe	Mn	Cu	THC
<i>C. Nigrodigitatus</i>	0.8 ±1.8	3.0±4.1	30.8± 11.2	131± 75.2	17.3± 6.7	1.8± 2.7	17.3± 2.4
<i>Tympanotonus</i>	ND	ND	63.1± 16.1	243± 23.8	18.5±2.1	1.0± 1.7	12.17± 13.5
<i>E. Fimbriata</i>	0.55± 0.78	3.8±5.3	16.9± 3.6	99± 63.6	12.0±4,2	ND	42.2±32
<i>P. Elongatus</i>	0.18± 0,3	10±8.7	11.3±3.0	161± 86.7	10.5±6.4	3.0±5.2	39.8±27.1
<i>O. Niloticus</i>	0.55± 0.8	3.8±5.3	16.4±4.2	91.5± 31.8	ND	ND	55.1±9.4
<i>Portonus sp</i>	0.18± 0.3	7.5±0	35.6±3.3	109.5 ±82.7	53.0±22. 9	0.18±0. 3	39.4±37.7
WHO STD (1998)	1.0	0.5	50	300	100	0.02	25*

Enhanced concentrations of Fe, Zn, Mn, Pb, Cu, Cd and total hydrocarbons (THC) were determined in fish samples from the Cross river system, Nigeria. These have been associated with clinical defects (nausea, headache, hepatitis, body rashes) observed in coastal residents who are the major consumers of the fish species. Fish samples were collected from ten locations with varying degrees of exposure to human activities. Heavy metal concentrations in fish followed the sequence: Fe>Zn>Mn>**Pb**>Cu>Cd with the highest concentration of 243 µg/g (Fe) wet weight occurring in *Tympanotonus sp*. Fe levels were significantly (P< 0.001) higher than other metals analysed. The sequence in total hydrocarbon concentrations according to fish species was in the order of *O. nifoticus* (55.1µg/g) > *E. fimbriata* > *P. elongatus* > *Portonus sp* > *C. nigrodigitatus*

> *Tympanotonus* sp. Generally, the dermesal species showed a marked potential for tolerating high levels of heavy metals while the pelagic species showed preference for the accumulation of hydrocarbons. The degree of contamination depended on pollutant type, fish species, sampling location, trophic level and their mode of feeding. The persistent accumulation and tolerable potential of *Tympanotonus*, *Portonius* and *P. elongatus* suggest that they might be effectively utilized as self-integrating indicators for time-series monitoring of the rate of recovery of the impacted ecosystem by heavy metals. Possible sources of pollutants include leachates from municipal dumps, used crankcase oils from fluvial discharges (including mechanic workshops) and occasional oil spills (Asuquo *et al.*, 2004).

In 1999, Pb was not detected, but in 2004, Pb was detected in these fishes except in periwinkle indicating contamination of the river water.

3.1.7 Pollution of water and sediments by hydrocarbons and heavy metals

The impacts of polyaromatic hydrocarbons (PAHs) as contaminants on the near shore marine ecosystem arising from anthropogenic activities were reported. Σ PAHs concentrations observed in the surface sediments varied from 2.38 $\mu\text{g/g}$ at station 5 (upstream) to 5.177 $\mu\text{g/g}$ at station 1 (estuary). The highest levels were at stations 1 (estuary) and 3 (Esuk Atu). At the estuary, estuarine sedimentation of suspended sediments laden with PAH occurred while Station 3 was influenced by petroleum/oily waste generated from indiscriminate disposal of waste oil by artisan mechanic workshops. The PAH contents of the sediment increased with increased organic matter content in the silty-clay soils than the silt soils alone. A pair-wise correlation analyses showed that there was a significant ($P < 0.01$) variation in the PAH concentrations measured at each location implying that human-influenced factors played a significant role during the estuarine sedimentation of the particulate materials (Ogri *et al.*, 2006).

On January, 12 1998, a 24-inch crude oil pipeline linking Idoho offshore platform and the Exxon-Mobil Qua Iboe Terminal facility onshore, ruptured on the inner shelf of the Gulf of Guinea, S.E. Nigerian coast. The consequence was the release of over 40,000 bbl of Nigerian crude oil into the sea. More than 700km of the coastline including the mangrove swamps were oiled. Cleanup containment equipment and dispersant were immediately deployed in quick response to the spill. Movement of oil slick was westward along the direction of the prevailing winds, currents and waves and stranded large quantities of spilled oil ashore on Brass, Forcados, Escravos and Lagos lagoon coastal shores. Environmental impact studies to determine the acute effect of the spill commenced 24 hours after and the components studied included fisheries, benthos, chemistry, plankton, for both offshore and river/estuarine compartments of the aquatic environments. Mortality of aquatic bio-communities were not apparent after the spill, though planktonic organisms along spill track showed reduction in cell counts when compared with counts from the non-oiled zones. Benthic communities showed no significant population changes from unimpacted areas and mean population densities were generally low. The pelagic food fish and the shell fish species such as *Pseudotolithus elongatus* and *Callinectes amartum* caught in the area one week after the spill recorded high accumulation of petroleum hydrocarbon in their body muscles (Ewa-Oboho & Asuquo, 2006).

Mangrove surficial sediments, from the Great Kwa River, Nigeria were sampled and analysed to assess the degree of anthropogenic pollution by polycyclic aromatic hydrocarbons (PAHs). Five composite sediment samples were analysed by Gas Chromatography - FID after initial extraction and pretreatments. A significant ($p < 0.01$) trend occurred in the distribution of Σ PAHs (max 5.2 $\mu\text{g/g}$ dry sediment) which increased downstream with flouranthrene (2.65 $\mu\text{g/g}$ dry sediment weight) as the most abundant and acenaphthalene (0.33 $\mu\text{g/g}$ dry sediment weight) as the least abundant. Abnormal levels above biogenic background ($< 1.0 \mu\text{g/g}$ dry sediment weight) were found at storm outfalls where there was abundant deposition of silty-clay ($> 85\%$) sediment components. The marked variation of the ratio of individual PAHs between the stations and the high occurrence of naphthalene suggest strong inputs from petrogenic sources, possibly waste crankcase oils, offshore flaring, discharges from motorized boats used for maritime transportation and fishing along the mangrove creeks. Minor sources of PAHs are forest fires from deforestation activities such as farming, firewood and incineration of mangrove stems after extracting the matured ones used for building thatched houses. The potential impact of PAHs may include behavioral changes and bioaccumulation by substrates, environmental degradation and stress on mangrove ecosystem (Asuquo & Ogri, 2006).

The mean concentrations and distribution of ten heavy metals (Cr, Cd, Ni, V, Co, Pb, Zn, Fe, Mn, Cu) and hydrocarbon levels found in the coastal waters and sediments of the Cross River, Nigeria have been reported. The results indicate background levels to high contamination found in industrial areas. The most abundant metal was Fe, with a value of $9.79 \pm 0.14 \text{mg/l}$ in water and $2227.5 \pm 1062 \text{mg/l}$ in sediments. The study also showed that coastal water in the proximity of the South Atlantic contained higher concentration of metals than inland waters. The spatial distribution of metals in sediments followed a similar sequence with Cu/Cd being the least available metals and Fe the most dominated metal at the locations. Total hydrocarbon concentrations ranged from undetectable to 263.2 mg/l in water and 190 to 758.4 mg/l in sediments. The enhanced levels of Cr, Zn, Pb and THC in most locations monitored suggest contamination of the coastal waters by industrial and sewage inputs (Asuquo *et al.*, 1999).

3.1.8 Pollution of Fin Fish and sediments of Lagos Lagoon

Concentrations of Cd, Pb, Mn, Zn, and Cr were determined in sediment and finfish samples, collected in December, 2002 (dry season) from the Lagos lagoon and Forcados river, Nigeria. For the sediment samples, levels ranged from undetected to high levels in some locations. For the metals Cd, Pb, Mn, Zn, and Cr the mean concentrations in sediment were, 5.13 ± 0.74 , 78.76 ± 23.23 , 293.9 ± 198.55 , 50.23 ± 13.93 , $27.45 \pm 8.55 \mu\text{g g}^{-1}$ respectively, while in the fish samples the mean concentrations were 0.21, 1.78 ± 1.04 , 0.60 ± 0.24 , $2.62 \pm 0.77 \mu\text{g g}^{-1}$ respectively. Chromium was not detected in any of the fish samples. Pb exceeded the WHO limits in two fish samples. In contrast, all other metals exhibited low concentrations in the fish samples. The monitoring of selected elements in sea food was considered necessary, both to delineate any temporal change in trace metal levels in locally available organisms and to ensure that concentrations of Pb did not increase further. In this study the distribution and sources of the metals in sediment and fish from the different locations of the Lagos lagoon and Forcados river were discussed (Unyimadu *et al.*, 2004).

3.2 Urban waste Pollution in Calabar

A-10 month inventory of solid waste in Calabar city, Cross River State of Nigeria showed that domestic wastes constituted the largest source of solid waste produced (53.1 thousand tons/year) followed by commercial waste (10.2 thousand tons/year). The household or domestic waste comprised of organic matter such as peelings, soft stems, legumes, chaffs, plastics, grasses etc. and inorganic matter such as broken glasses, metal tins and scraps among others. The organic waste (only biodegradables) showed the highest occurrence in Calabar Central (Mayne Avenue/Atakpa, 76.5% and Ekpo Abasi, 85.7% respectively) while the lowest occurrence was obtained in Calabar North (Ikot Ekpo, 13.0%). The amount of domestic wastes changed with seasons being higher in the dry season than the wet season. A classification scheme, the 'ND/BD (non-degradable/biodegradable) ratio was developed and used as a pollution index. Based on the ratio, the Calabar Central (urban) was assigned a potentially impacted area (ND/BD>0.5) while the suburbs were less impacted (ND/BD>2.0) (Asuquo, 2000).

3.3 Rubber Effluents Pollution of Calabar river

Water quality investigations of the upper Calabar river were conducted between November 1997 and July 1998. The study revealed marked changes occurring in colour (96.3 ± 35.70 Pt Co units), NH_4 ($3.4 \pm 5.4\text{mg/l}$) and turbidity (15.7 ± 4.9 FTU) which were above WHO (1984) and FEPA (Federal Environmental Protection Agency, 1989) permissible limits for inland waters (15.0 Pt Co units, 0.5mg/l and 5.0 FTU respectively). These observations were attributed to effluents discharged into the river from a nearby rubber factory. The rubber effluents were characterized by high ionic content (conductivity, 3380 ± 1285.0 $\mu\text{S/cm}$), moderate acidity (pH 5.0 - 6.4) have marked total hardness ($2164.3\text{-}2372.7\text{mg/l}$ as CaCO_3), high NO_3 ($64.72 \pm 16.5\text{mg/l}$), high SO_4 ($1700 \pm 263.0\text{mg/l}$) and were totally devoid of dissolved oxygen (zero value). The effluents also impacted the surrounding sediments as high levels of Mn ($426.7 \pm 179.5\text{ppm}$), Fe ($790.8 \pm 136.6\text{ppm}$) and Cu ($4.5 \pm 0.9\text{ppm}$) were measured during the investigation. The effluents were more concentrated and toxic in the low production season, LPS (November-February) than the High Production Season, HPS (May - September), ascribed to the preferential sorption or higher uptake of drainage water by rubber trees for latex generation in the HPS. The poor quality of effluents contributed significantly ($P > 0.05$) to the pollution load of the river. Management procedures on the control of organic/inorganic pollution emanating from the factory were suggested (Asuquo, 2000).

3.4 Ecological Impact of dredging waste on the river

The effect of high turbidity on benthic-pelagic production at the mouth of the Cross river estuary (South eastern Nigeria) was investigated following the dredging of the river channel in 1998. Aliquots of water samples collected at various depths between 8.00hrs and 12.00hrs GMT, using a nansen water sampler, were fixed in a mixture of 0-5% Lugol's and 5% Bouin for image analysis of algae, faeces and protozoans, chlorophyll a concentration was measured fluorometrically using a Turner Design fluorimeter Model-10 Hol-Hansen *et al* 1965). Annual phytoplankton production in the estuary was higher ($25.0\text{gCm}^2 \text{yr}^{-1}$). The seasonal distribution of chlorophyll a correlated positively with that of primary production before ($r = 0.82, P < 0.001$) and after dredging ($r = 0.65, P < 0.001$). Values were higher in the rainy season than in the dry season. Reduction in Chlorophyll a concentration (primary production) shortly after dredging, could be attributed to the significant reduction in light penetration, the physical smothering of

benthic algae and disruption of benthic habitats. The patterns of seasonal copepod densities closely paralleled that of algal biomass. The efficiency of energy transfer from primary production to copepod production was lower after dredging (8%) than before dredging (15%). Copepod grazing rates were high and greater on larger phytoplankton species which had < 10 of algal carbon needed for secondary production. The role of detritus and coprophagy in secondary production in this estuary were critically discussed and the ecological implications explained (Ewa-Oboho *et al.*, 2006).

3.5 Marine Pollution studies of Nigerian Beaches by Tar balls

My research on marine pollution by pelagic oil residues commonly called tar balls has established that tar balls are ubiquitous along the South Atlantic coastline of West Africa. This work is one of the pioneer works reported on the occurrences of tar balls globally. Today tar balls and have been cited in many literatures as a result of my publications on tar balls abundance, source and distribution along the Nigeria coastline.

The Nigeria coastal waters and beaches have been subjected to the impact of organic and inorganic pollutants for some years now. Principally is the ubiquity of petroleum residues (tar balls) on the beaches. Concentrations of stranded tar balls were employed to assess the extent of beach pollution, temporal and spatial changes and the dynamics for tar distribution over a 4 year period (1985 to 1989, 1987 exclusive) along Ibeno-Okposo beach, Nigeria. Littoral observations showed that only wind and precipitation influenced the amount of tar on the beach. Based on findings, an empirical formula (oil spill formula) was proposed to estimate the total amount of oil in water after the occurrence of an accidental spill along the Nigeria coastline (Asuquo, 1997).

Tar ball concentrations were monitored between January 1988 to December, 1988. The monthly mean concentration of tar residues collected along Ibeno -Okposo beach showed that the highest amount of tar 1.39g/m was observed in January and the lowest 0.04g/m in October. This value was relatively low when compared to other regions of the world. The low value was attributed to the short beach front and the influence of dominating spilling breaker waves along the coastline (Asuquo, 1991).

The extent of accumulation and distribution of beach tars (weathered crude oil residues) along Ibeno segment of the Nigerian coast line was investigated between 1989 and 1990. The beach tars were monitored at monthly intervals over a distance of 35km per trip and quantified by gravimetry. A seasonal or temporal variation existed in the pattern of tar distributed. While the highest concentration of tar ($5.46\text{gm}^{-2}\text{ month}^{-1}$) was record in June 1989, the lowest accumulation ($0.02\text{gm}^{-2}\text{ month}^{-1}$) occurred in November 1989. These Observations showed that more tars were deposited in the wet season than the dry season. A pair wise correlation analysis gave good correlation between beach tar and wind speed ($r=0.78$, $p>0.05$), beach tar and total rainfall ($r = 0.55$, $P>0.050$) thereby identifying wind speed and precipitation as the principal environmental factors influencing the pattern of tar distribution along the coastline. The observed temporal trend and information is a reliable tool when executing environmental management plans for the protection of the beach against shoreline erosion and for beach development for recreation and tourism (Asuquo, 2000).

Oil related environmental degradation in the coastal regions of Nigeria have been a subject of intermittent civil disorder because of apparent and perceived negative impacts on the lives of the coastal dwellers. In this study, beach contamination by oil and non-oil materials, collectively called 'garbage' was reported. Data was collected fortnightly over a period of 7 months (Dec. 2000 -June 2001) along Ibeno-OKposo beach, which is one of the most popular beach resorts on the southeast coast of Nigeria. Results showed that the beaches' garbage was composed of hydrocarbon residues (tar balls) and plastics/ leather products, *Nypa fruticans* fragments, fishing materials, oyster shells and wood fragments. Concentration of tar balls ranged from 1 to 6 g/m². The non-hydrocarbon components were typically <20 g/m² and dominated by *Nypa fruticans* fragments (65%). Beach use was largely responsible for the plastic and other exotic wastes on the beach. The distribution of garbage on the beach is determined by a combination of climatic and hydrodynamic conditions. During the rainy season (April-October), surface run-off and river discharge as well as the wave energy are high and accumulation of garbage on the beach was low. The population of beach Users is noticeably low and tourism-related contribution to beach garbage budget is also low due to the unfavorable weather conditions for beach use. In the dry season (November- March) when wave conditions are mild, and beach tourism was intense, garbage concentration was high. Apart from garbage contribution by beach users, the high garbage concentration during the dry season was attributed to the net onshore transport of materials by waves. The study provided some baseline data for the modelling of environmental aesthetics of the Ibeno-Okposo beach with regards to tourism and recreation (Asuquo, 2002).

3.6 Trace metals in Tar Balls from Nigerian coastline

Tar ball samples collected from Ibeno/Okposo beach were analyzed to assess for the degree of metal enrichment by the tar. The metal concentrations found were, Pb (0.63 -1.7ppm), Ni (0.15 -0.66ppm), V (0.28 -69.44ppm), Fe, (0.30 -1.99ppm), Mn (0.06 -0.20ppm) and Cu (0.13 -0.0.39ppm), with distribution pattern following the sequence: V>Fe>Pb>Ni>Cu>Mn. In all cases V was the most abundant and Mn the least abundant metals. Very low enrichment was observed for all the metals. High correlation existed only for the relationships Pb: Mn (r= 0.70) and V: Mn (r= 0.82), while the other metals exhibited moderate and low correlations. The absence of strong correlation between the metals and the low levels of metal concentrations predict low anthropogenic influence from the tar balls analyzed (Asuquo, 1997).

Concentration of six metals (Pb, V, Ni, Fe, Mn and Cu) in Nigerian crude oils and beach tars (tar balls) were studied. The metal concentrations were generally higher in tar balls than in the crude oils. Vanadium was most abundant metal. Metals ratios especially V/Ni and V/Ni + V ratios for tentative source identification indicates that the beach tar originates from a reducing environment (high V/Ni) and less mature (high V/Ni) than the reference oil samples (Asuquo *et al.*, 1995).

3.7 Chemical Composition of crude oils and tar balls from Nigerian coastline: The source of tar balls on Nigerian beaches

Analysis of the chemical composition of tar balls revealed that floating tars found in the Nigerian coastal waters are of foreign origin even though Nigeria is rated as the 6th largest producer of petroleum among the oil producing exporting countries (OPEC) group.

Chemical compositions of representative beach tars collected monthly over a two year period (1989 -1991) at two locations (Badagry and Ibeno), 800km apart, on the Nigerian coastline and those of crude oil samples from offshore production wells characterized with the aim of identifying the potential source of the beach tars. The concentration ratios of Pristane/Phytane and nC₁₇/background of the beach tars were discernibly different from those of the oil samples. The tars were characterized by enhanced long chain n-alkane above nC₂₁, low Pristane/Phytane ratio (0.10-1.53), high V/Ni ratio (15-3000) and low Methylpenanthrene Index Ratio (0.72 -0.78). N-alkanes in more than 50% of the tar samples had a bimodal distribution, this being characteristic of tanker oil sludge. The observed compositional difference between the beach tars and crude oil samples suggests ballast waters (foreign origin) to be the most likely source of the beach tars (Asuquo *et al.*, 1996).

This study confirmed the findings from our previous study that tar balls found on Nigerian beaches were of different origin.

3.8 Water pollution studies of the Niger Delta region

Trace metals (Cd, Cr, Cu, Ni and Pb) concentrations in benthic sediments were analyzed through multi-step fractionation scheme to assess the levels and sources of contamination in estuarine, riverine and freshwater ecosystems in Niger Delta (Nigeria). The degree of contamination was assessed using the individual contamination factors (ICF) and global contamination factor (GCF). Multivariate statistical approaches including principal component analysis (PCA), cluster analysis and correlation test were employed to evaluate the interrelationships and associated sources of contamination. The spatial distribution of metal concentrations followed the pattern Pb>Cu>Cr>Cd>Ni. Ecological risk index by ICF showed significant potential mobility and bioavailability for Cu, Cr and Ni. The ICF contamination trend in the benthic sediments at all studied sites was Cu>Cr>Ni>Cd>Pb. The principal component and agglomerative clustering analyses indicate that trace metals contamination in the ecosystems were influenced by multiple pollution sources (Benson & Asuquo *et al.*, 2016).

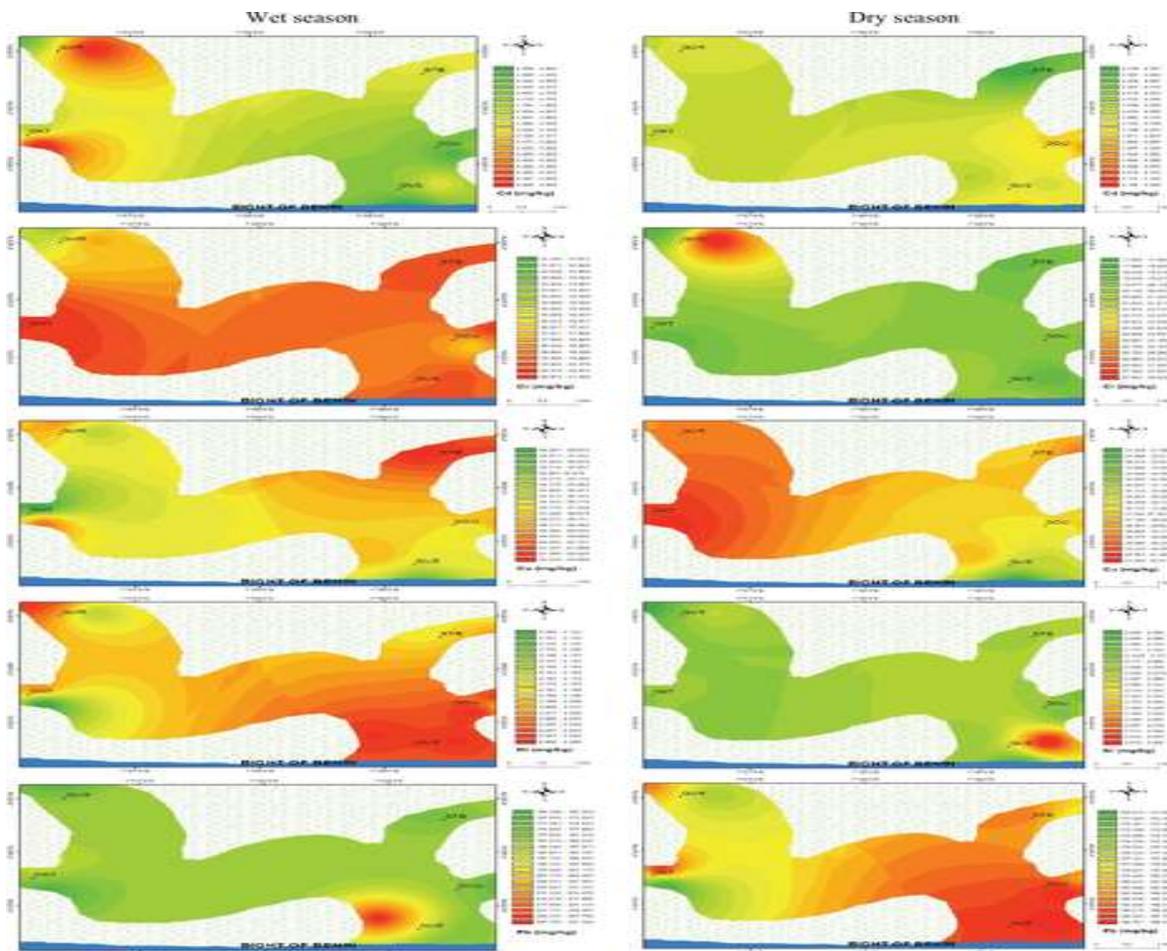


Fig. 12: Spatial distribution of trace metals in benthic sediments of mangrove ecosystems of Niger Delta during wet and dry seasons(Benson & Asuquo *et al.*, 2016).

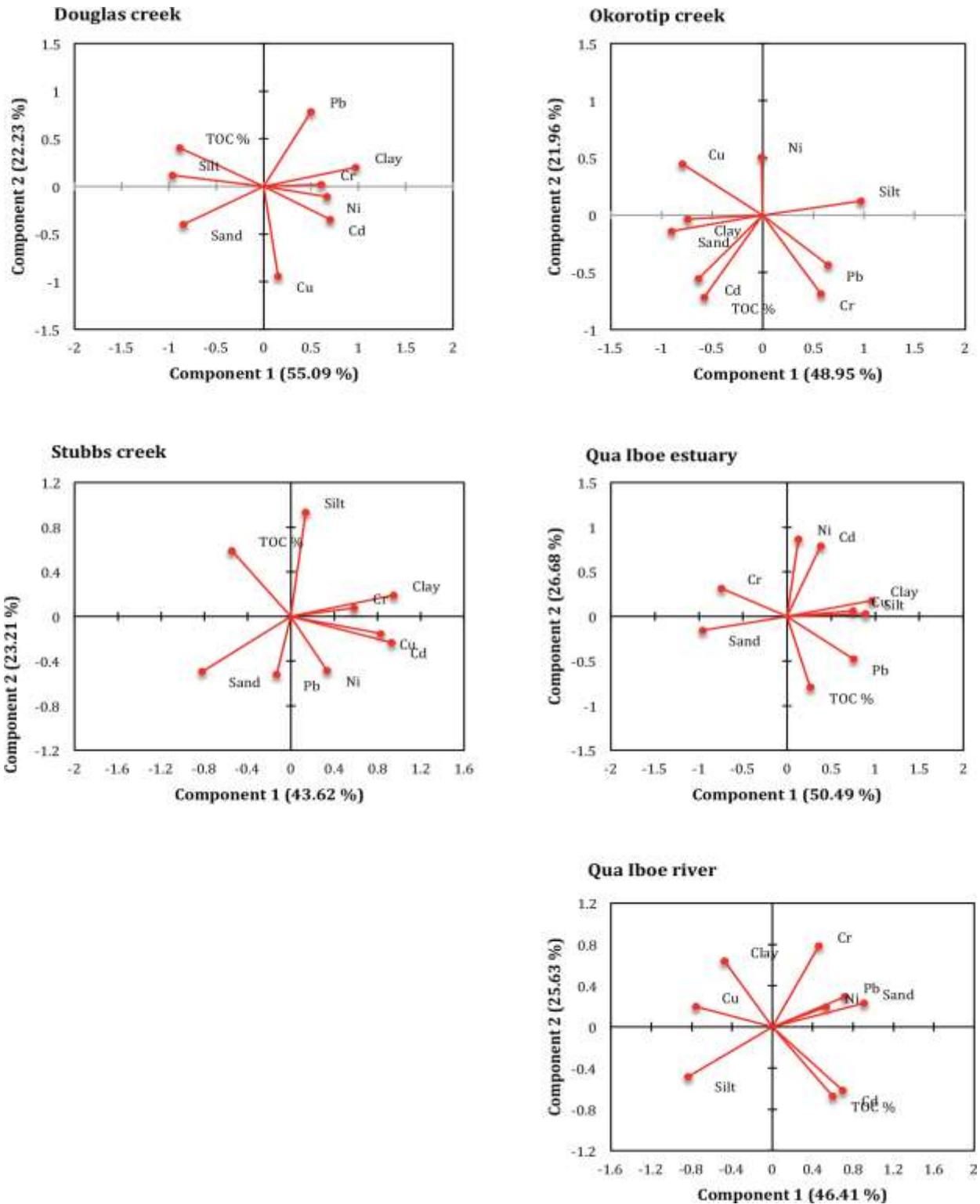


Fig. 13: The two principal components calculated by PCA reflecting the relationship of investigated trace metals and sedimentary variables (Benson & Asuquo *et al.*, 2016).

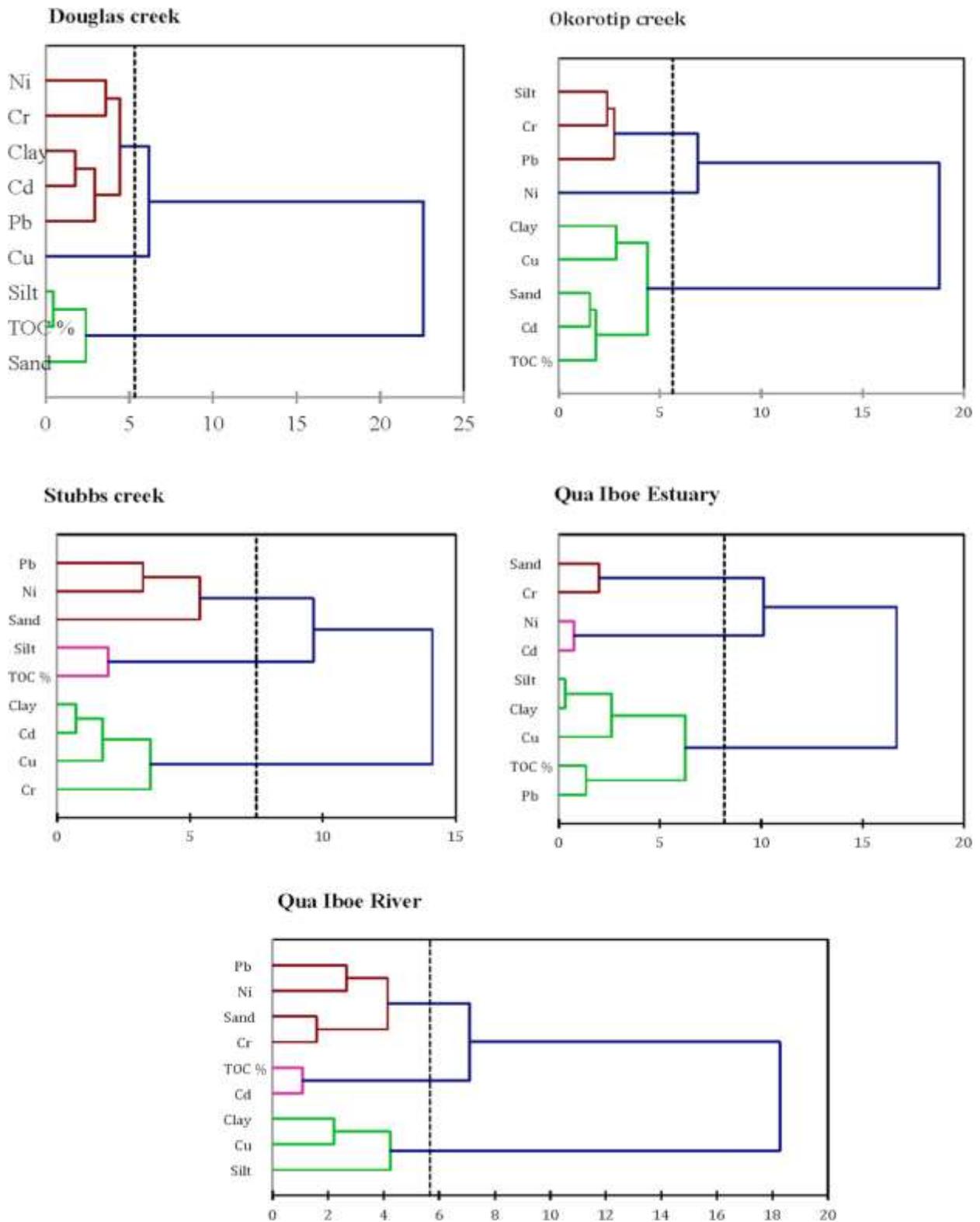


Fig.14: Hierarchical clustering analysis (Ward's Method) showing the relevant association among the parameters (Benson & Asuquo *et al.*, 2016).

3.9 Toxicity of Crude oil to Nigerian fresh water fishes

The water soluble fraction (WSF) of crude oil was tested against *Macrobrachium macrobrachion* and *Macrobrachium vollenhovenii*, at 2, 4, 6, 8 and 10 mg/L in glass aquaria stocked with ten animals for 96 h under observations for changes. Moribund swimming, restlessness, respiratory difficulties, depigmentation and mortalities were observed in the WSF exposure groups, but not in the controls. LC(50) values were estimated at 5 ± 1.76 and 4 ± 1.76 mg/L for *M. macrobrachion* and *M. vollenhovenii* respectively. There was no significant difference in mortalities between the two species ($p > 0.05$), leading to the conclusion that the WSF of crude oil in the Nigerian coastal waters may be equally toxic to *M. macrobrachion* and *M. vollenhovenii* (Ekanem, Asuquo *et al.*, 2017).

3.10 Toxicity of commercial bleach to Nigerian fresh water fishes

In Nigeria, bleach is a common household product used for cleaning, but its effect on humans and aquatic organisms is often underestimated. The harmful effects of bleach (Sodium hypochlorite solution) on hatchery-reared *Oreochromis niloticus* fingerlings obtained from University of Calabar fish farm was investigated in duplicates under laboratory conditions for 96 hours. From the range finding test, appropriate test concentrations (0, 5, 10, 15, 20 and 40 $\mu\text{g/l}$) were prepared for the toxicity tests. The experimental animals exhibited different percentage mortalities with toxicant concentrations. Peculiar manifestations, overturning and survival times were all concentration dependent, decreasing with increasing concentration of the toxicant. The study showed distressed behaviors of the fingerlings such as loss of equilibrium and erratic swimming, fading of skin colour, swimming on the back, gapping of mouth and rapid flapping of the operculum with eventual deaths. The 96 hours LC₅₀ for *O. niloticus* in both duplicates was 13.85 $\mu\text{g/l}$. This depicts that bleach is very toxic even at low concentrations and exerts severe stress on aquatic organisms that may result in ultimate mortality. Its presence in freshwater ecosystems can be used as a bio-indicator. Therefore, waste water containing bleach and related products should be carefully subjected to industrial waste treatment methods before final disposal into water bodies (Asuquo *et al.*, 2017).

3.11 Toxicity of rubber effluents to Nigerian fresh water fish species

The water soluble fraction (WSF) of *Hevea brasiliensis* was tested against *Clarias gariepinus*, at 0, 30, 40, 50, 60 and 70mg/l in glass aquaria stocked with ten animals for 96 hours under observation for changes. Moribund swimming, restlessness, respiratory difficulties, depigmentation and mortalities were observed in the WSF exposure groups, but not in the controls. LC₅₀ values were estimated at 50.12mg/l. There was no significant difference in mortalities between the replicate group ($P > 0.05$), leading to the conclusion that the WSF of *Hevea brasiliensis* had same toxic effects on both batches of the test organism (George, Asuquo *et al.*, 2013).

Toxicant conc. (mg/l)	Log values of concentration	%M	
		Batch A	Batch B
0	0	0	0
30	1.48	0	0
40	1.60	0	0
50	1.70	60	60
60	1.78	100	100
70	1.85	100	100

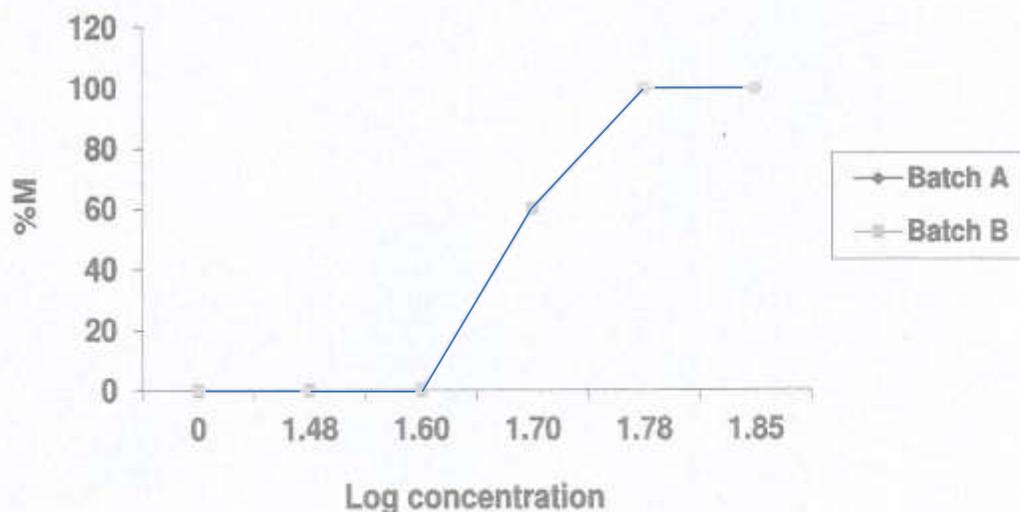


FIG. 1: Log-transformation of the toxicant on *C. gariepinus* for the determination of probit level of the toxicant at the end of experiment (96hrs)

Table 2: Means Water Parameter of Habitat Water Used for the Test.

Parameter	Min	Max	Mean	SD
Temperature ($^{\circ}$ C)	27.1	27.8	27.45	0.35
pH	5.16	7.50	6.33	1.17
Nitrite (mg/l)	0.1	0.1	0.1	0.0
Dissolve oxygen (mg/l)	1.2	6.6	3.9	2.7
Ammonia (mg/l)	0.0	0.0	0.0	0.0

3.12 Toxicity of crude oil to Nigerian vegetables

Field studies to ascertain the effects of crude oil spillage on agricultural crops and soil environments are few. A greenhouse experiment was carried out using zero % (control) 2%, 4% and 8% v/w levels of Qua Iboe crude oil treated soils to investigate the response of Okra (*Abelmoschus esculentus*) and fluted pumpkin (*Tolferia occidentalis*) to crude oil contamination. The results showed that redox potential, pH, temperature, electrical conductivity, organic carbon, total nitrogen and total hydrocarbon contents of the contaminated soils increased with increase in

crude oil concentrations. In contrast, available phosphorus, effective cation exchange capacity, exchangeable bases and acidity decreased with increase in crude oil concentrations. Okra and *Telferia* seeds showed a delayed germination in the 2% and 4% treated soils and total inhibition of germination in the 8% treated soils. The growth of Okra and *Telferia* seedlings decreased significantly ($P < 0.05$) with increase in crude oil concentrations. The amount of heavy metals and THC absorbed by Okra and *Telferia* shoots increased with increase in crude oil concentrations. However, Okra absorbed more Fe, Ni, and Cd while *Telferia* absorbed more Cu, Zn, and THC. The study recommended *Telferia* for a long term bioremediation of oil polluted sites after accidental spillage on land (Asuquo *et al.*, 2002).

3.13 Toxicity of a tropical weed *Justicia extensa* to fresh water fish species

The African Catfish *Clarias gariepinus* is the most widely cultured and eaten freshwater fish species in tropical Africa. The toxicity of *Justicia extensa* leaf extracts on fingerlings of *Clarias gariepinus* (mean body weight, 5.65 ± 1.63 g and total length, 9.64 ± 1.14 cm) was investigated in a static laboratory bioassay. The study revealed the acute and chronic nature of *J. extensa* toxicity after exposing the experimental animals to increasing concentrations of 0.4mg/l, 0.6mg/l, 0.8mg/l, 1.0mg/l and 1.2mg/l in a glass aquaria for 96 hours. Stress responses such as erratic swimming, respiratory distress, vertical erection, overturning, mucus secretion and gasping for air prior to death were observed. Cumulative mortality of exposed fish increased with increasing exposure time and concentration. The 96 hour LC_{50} and safe concentration for *Clarias gariepinus* fingerlings exposed to *Justicia extensa* were 0.73mg/l and 0.07mg/l respectively. The MLT_{50} at 1.0 and 1.2mg/l were 24.99 and 20.14 hours respectively. The low 96 hour LC_{50} value of 0.73mg/l recorded in this study suggests that *J. extensa* is very toxic which is responsible for its use by artisanal fishermen in the rural areas. The health implications that may arise due to the consumption of *J. extensa* contaminated fish by humans were evaluated (Asuquo & Ekpenyong, 2017).

CHAPTER 4

4.0 OUR MODEST CONTRIBUTION TO CLIMATE CHANGE

4.1 Climate change and seasonal variability in Calabar

The relationship between climate change and weather elements such as temperature, humidity and rainfall is of utmost importance especially, when considering the fact that slight perturbations in climate can cause incredible changes in these weather elements. Nigeria is located in the tropical humid region, influenced by the dry season (November – March) and wet season (April – October) each cycle. A critical evaluation of the interannual and interseasonal occurrences of temperature, humidity and rainfall patterns in Southeast, Nigeria between 2002 and 2011 indicated a shift in their frequency of occurrences from the month of September, with highest rainfall (736.1mm/mth in 2006) to June (335.4mm/mth in 2007). The periodic August break (previously a yearly phenomenon) is presently non-existence and is replaced by the occurrence of heavy rainfall in August 2002 (731.6mm/mth) and August 2011 (501.8mm/mth). Between 2007 – 2009, the month of June was the wettest period. Rainfall exhibited a unimodal configuration, temperature a bimodal pattern while humidity had highly fluctuating sequences with no predictable patterns. Prevailing SSTs due to warming of ocean surface generate rising vapors continuously which constitute the maritime air mass that circulates and dominates the tropical Central Atlantic atmosphere. This is responsible for the availability of water vapor in the ambient air almost all the year round which corroborates the high relative humidity (>80%) observed during the period. Reports of early precipitation abound in the months of January and February with dire consequences on agricultural activities contrary to expectations for the dry season months. These observations during the study period were indicative of the influences of climate change on the weather elements with expected impacts on agricultural activities, rural and urban water management schemes in Nigeria.

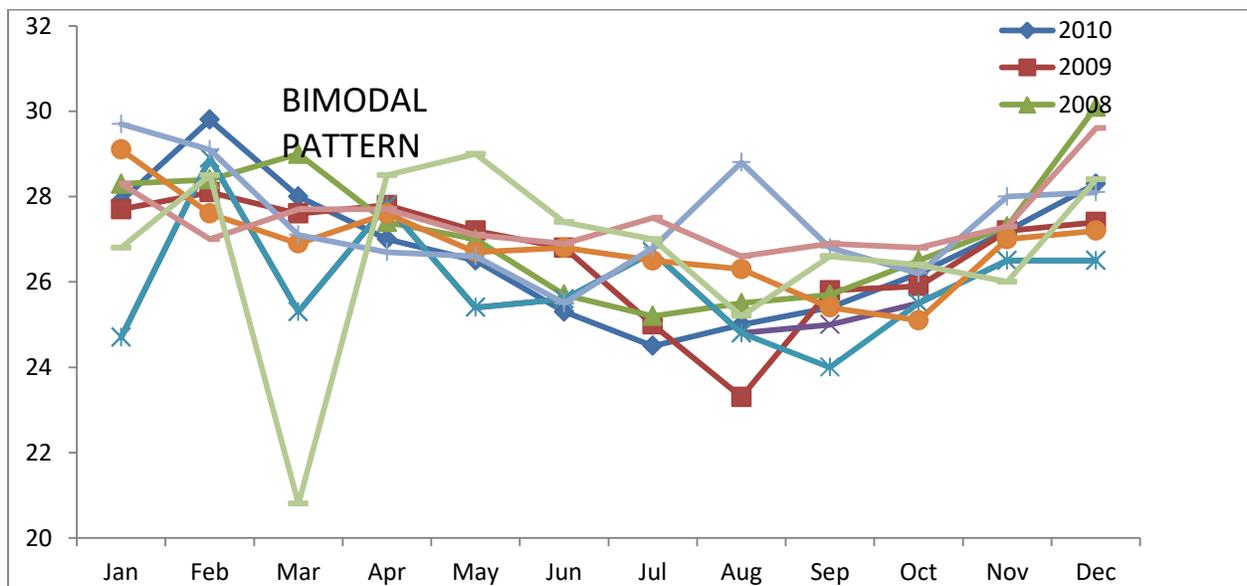


Fig. 13 : Seasonal temperature distribution in Calabar, 2002-2010

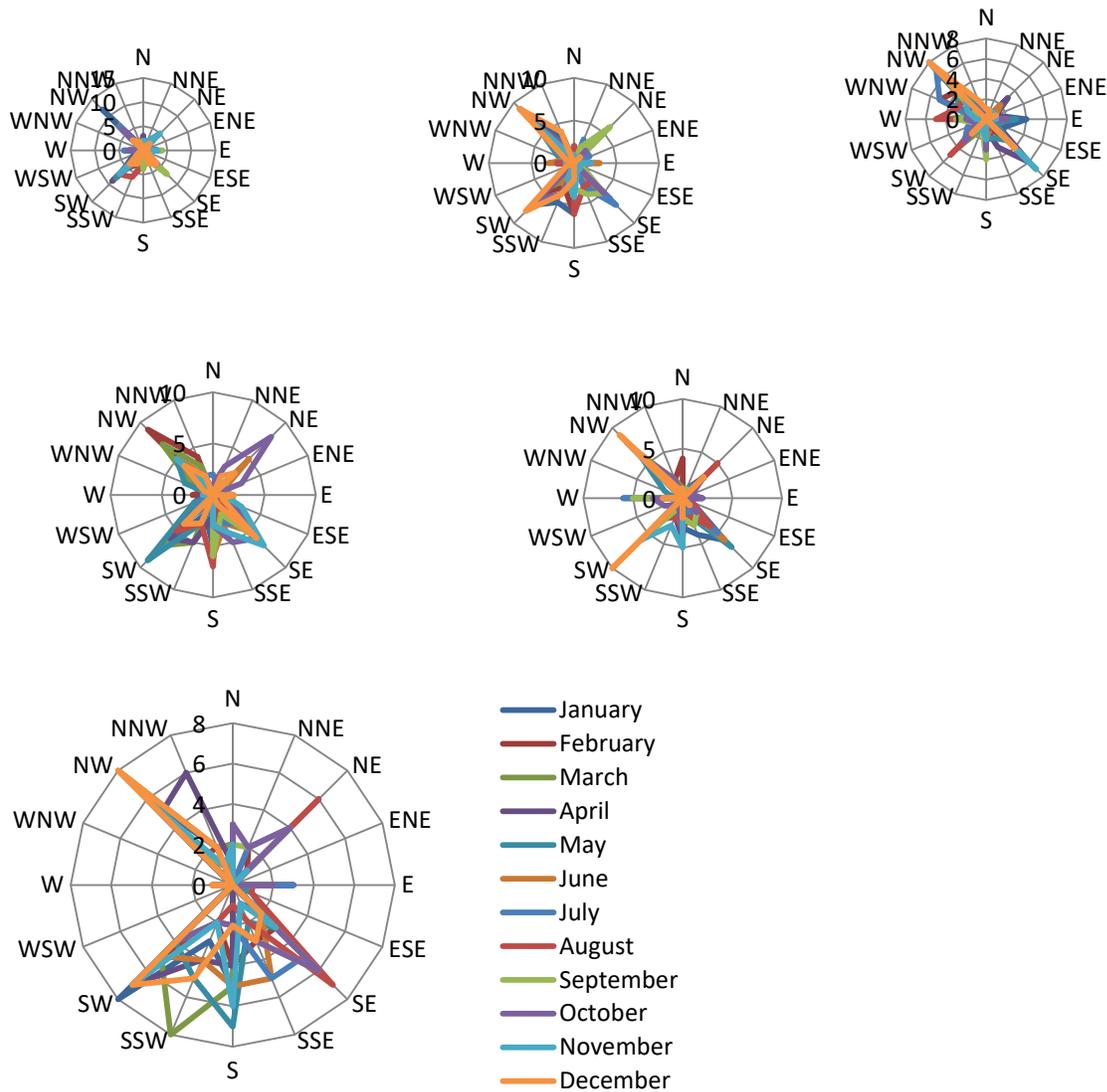


Fig.14 : Wind rose showing % frequency distribution of wind direction in Calabar 2002-2010

4.2 Climate change and the oceanic carbon cycle

The earth’s climate is greatly moderated by the world’s oceans. Our research publications have unraveled the variability’s, influences and consequences of carbon cycle biogeochemistry especially in the North Atlantic ocean. Numerical models have been employed in understanding and capturing spatiotemporal CO₂ trends, inter seasonal to decadal variability, and the characterization of thermal (pCO₂-T) and non-thermal (pCO₂-nonT) components of surface ocean pCO₂ and air-sea CO₂ flux variability. We employed the MIT Ocean General Circulation Model and available data from two sub polar North Atlantic observatories at 49°N, 16.5°W and 56.5°N, 52.6°W to capture in situ pCO₂ observations and deconvolute bio-physical controlling processes. The model suggests that the pCO₂ cycle is marked by a summertime minimum and

wintertime maximum. The physical-chemical and biological response pattern of the model is in good accordance with the observed $p\text{CO}_2$, $p\text{CO}_2\text{-T}$ and $p\text{CO}_2\text{-nonT}$ trends. Model outputs suggest that the CO_2 cycle is governed by contrasting effects of seasonal cooling and warming on one side and spring and summer net biology activities on the other side. It also predicts year-round under saturation, indicating that the region is a weak to moderate sink for CO_2 (Benson & Asuquo, 2016). This finding has been published also in a special edition on Climate change and oceanic carbon cycle edited by Isabel Ferrera (2017).

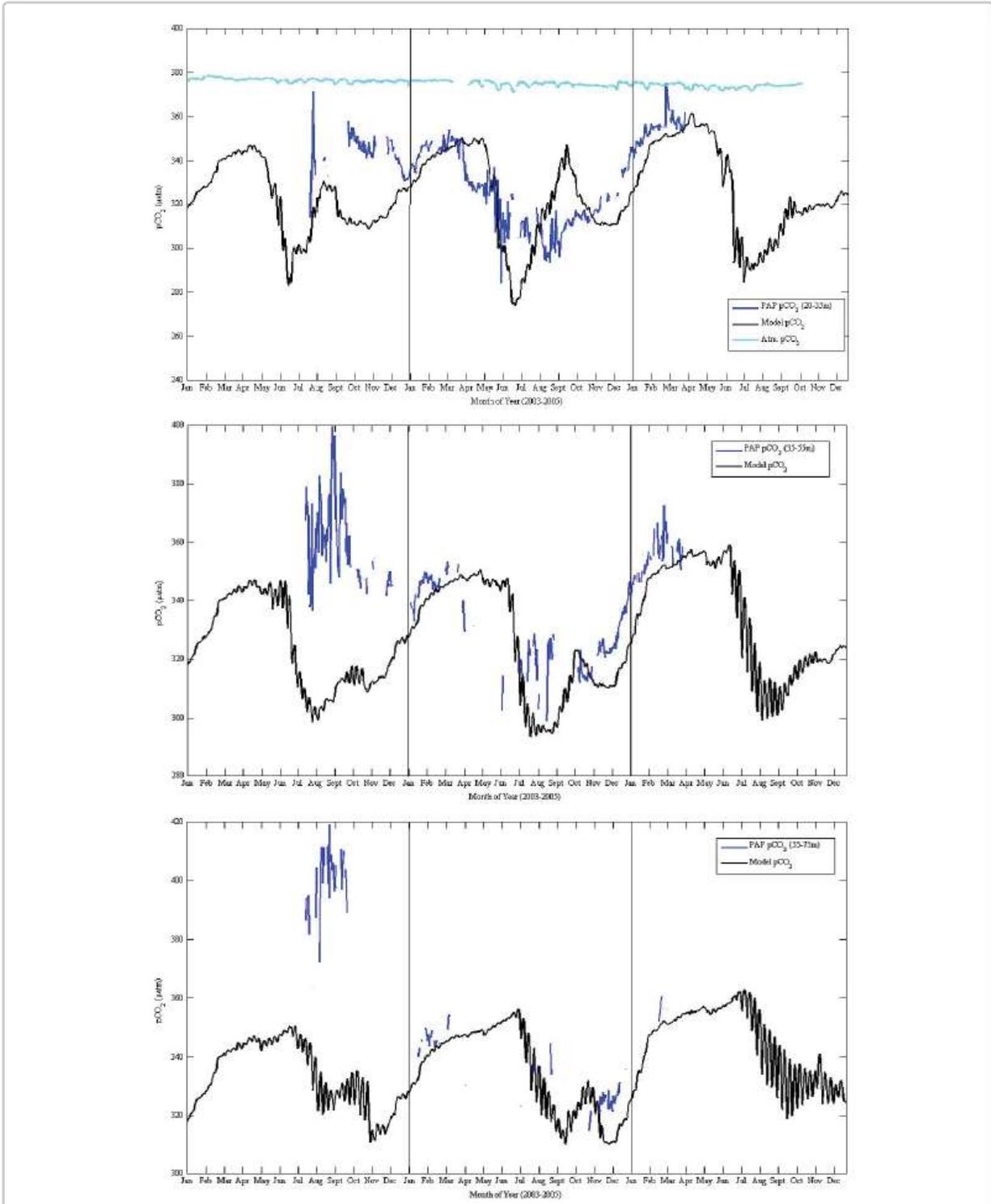


Fig. 15: Mixed layer comparison of model and measured $p\text{CO}_2$ at the NE Atlantic PAP site (Benson & Asuquo, 2016).

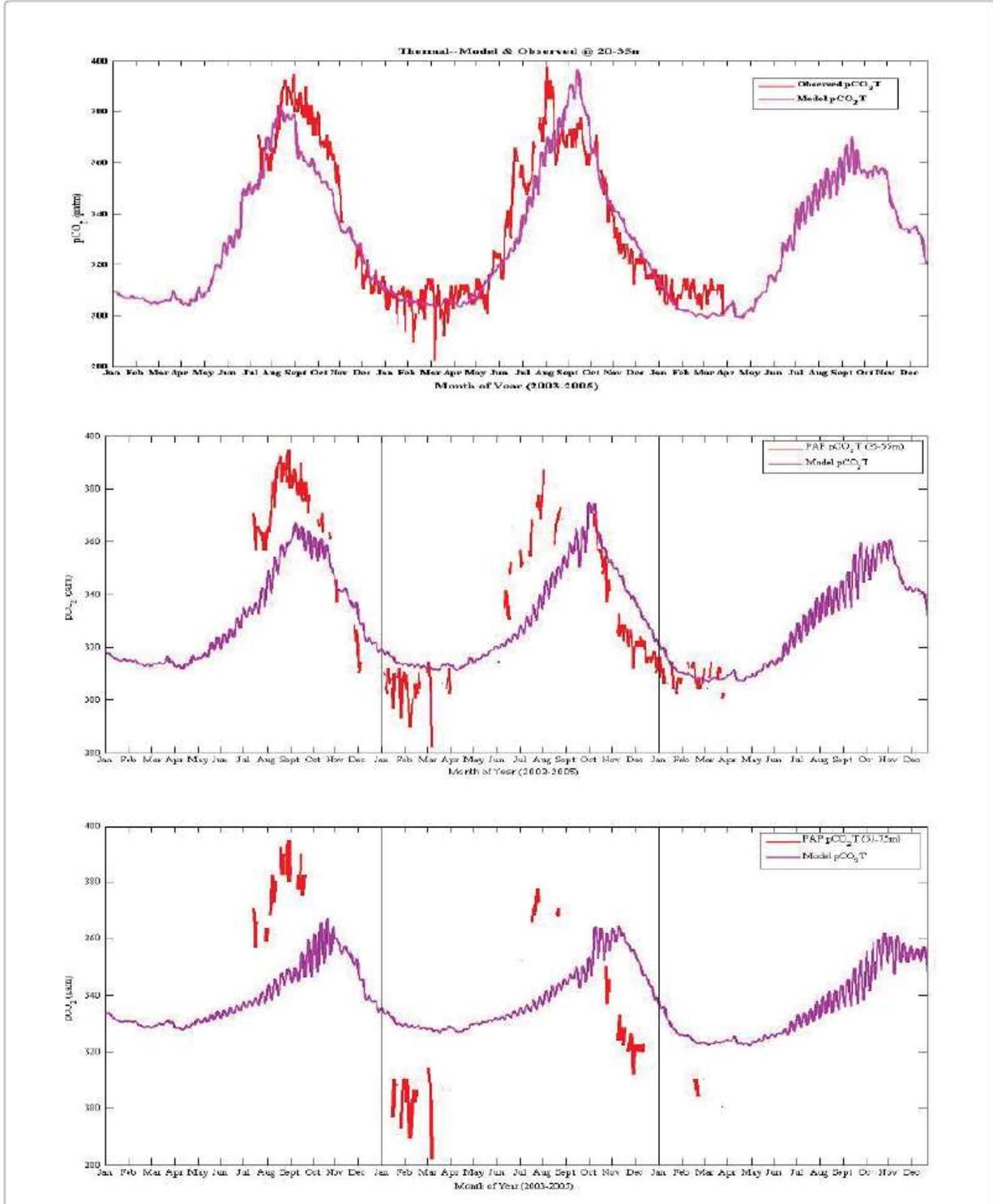


Fig. 16: Mixed layer comparison of observed pCO_2 -T and pCO_2 - non T at the PAP site (Benson & Asuquo, 2016)

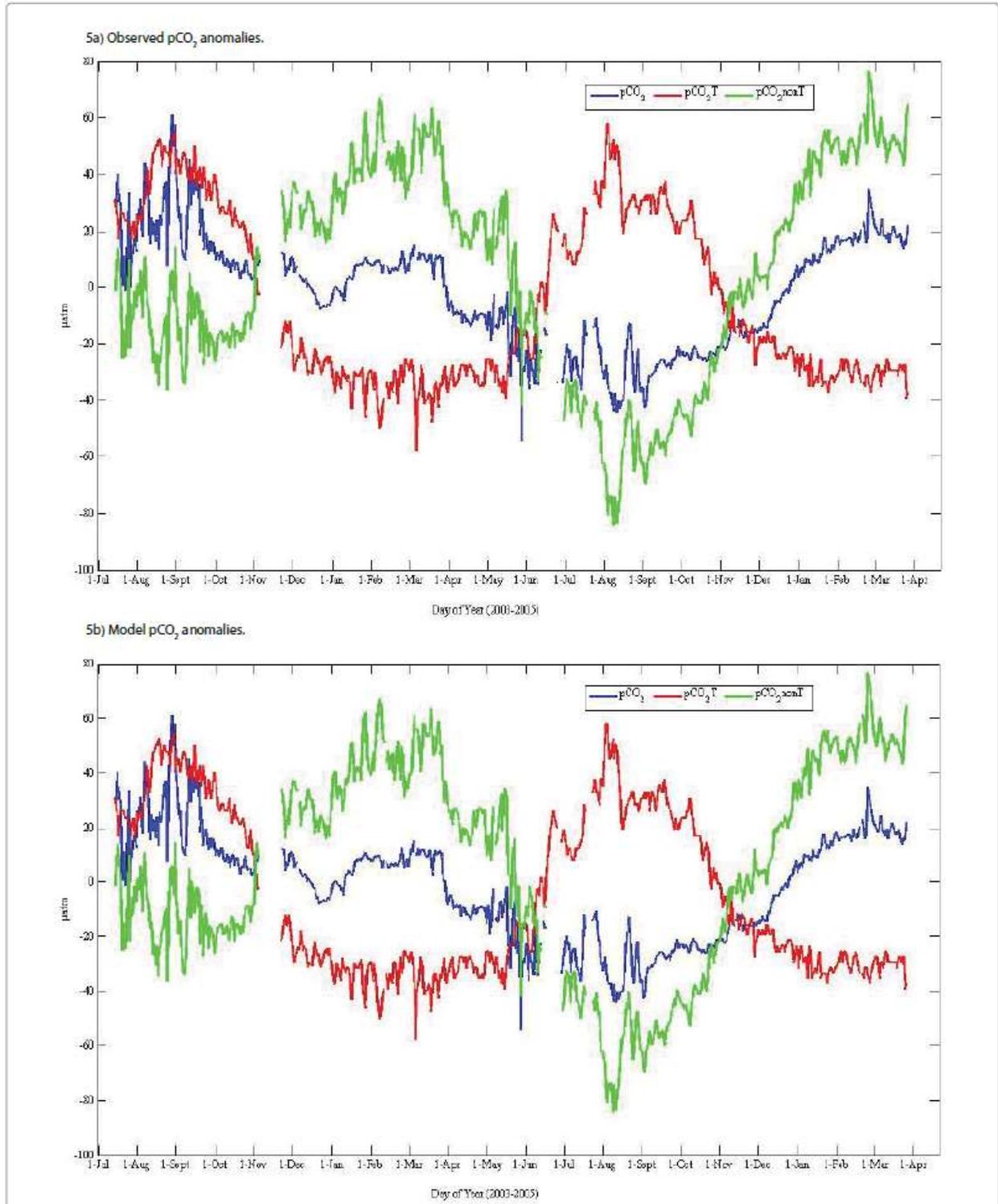
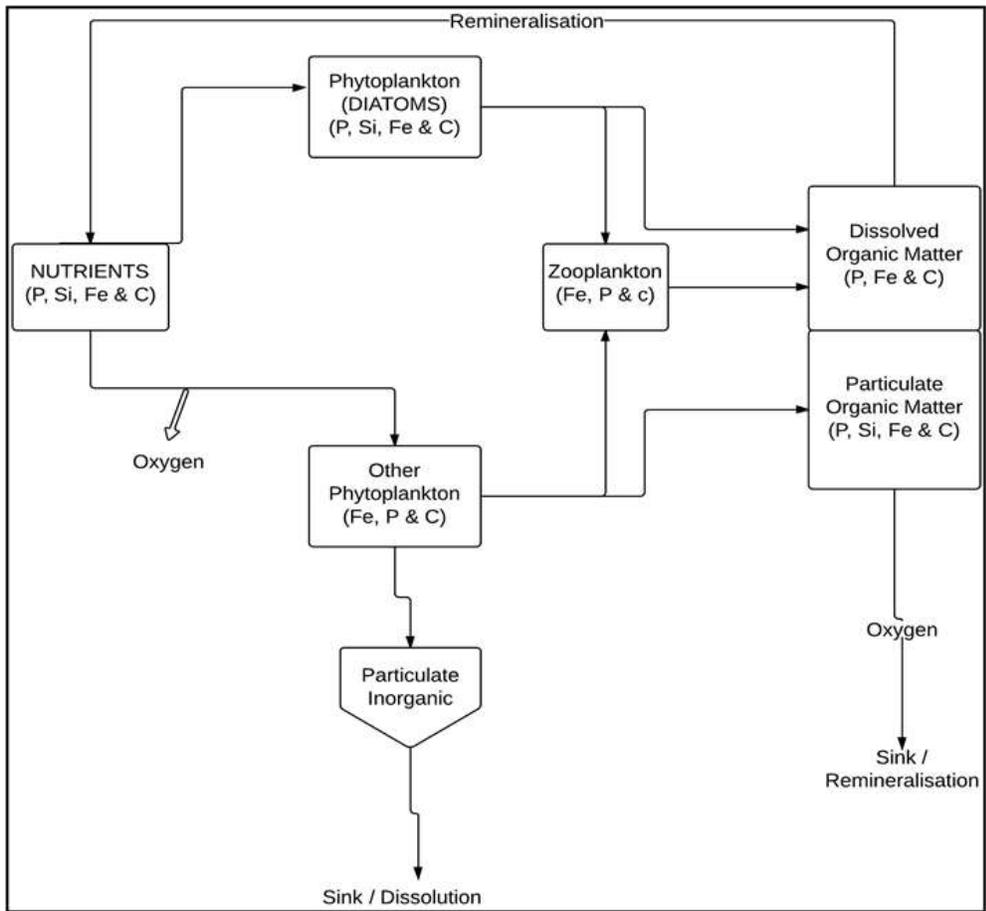


Fig.17 : Observed and model $p\text{CO}_2$, $p\text{CO}_2\text{-T}$ and $p\text{CO}_2\text{-non T}$ anomalies for PAP site (Benson & Asuquo, 2016).

A study of physical and biogeochemical variables using numerical model and mixed layer oceanographic data for 3 years in the Northwestern and Northeastern sites of the Atlantic Ocean presents some interesting phenomena. Model outputs indicated very good estimates showed considerable agreement in reproducing seasonal distributions of $p\text{CO}_2$, $p\text{CO}_2\text{-T}$, $p\text{CO}_2\text{-nonT}$, mixed layer temperature, and chlorophyll-a in both winter and summer, and therefore provide useful physical and theoretical understanding of their biogeochemistry. The model $p\text{CO}_2$ indicated a distinct temporal variability with seasonal changes coinciding with the change in sea surface temperature. It also provides an agreement that there is a strong seasonal cycle of mixed layer parameters filliped by nonthermal and physical factors. As an outgrowth of this work, the $p\text{CO}_2$ model outputs affirm the North Atlantic Ocean capacity as an important oceanographic sink for anthropogenic carbon dioxide (Benson,Asuquo *et al.*, 2015).



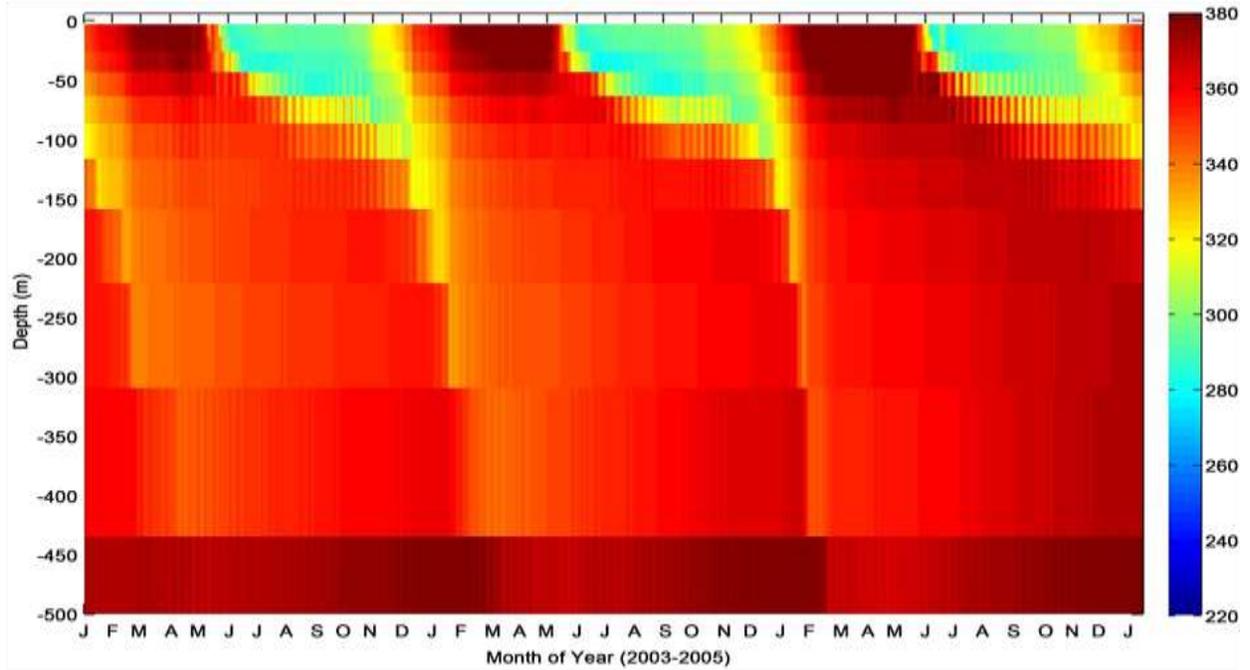


Fig. 18: Mixed layer depth profile of pCO₂ during period of consecutive deployments at the PAP site (Benson,Asuquo *et al.*, 2015).

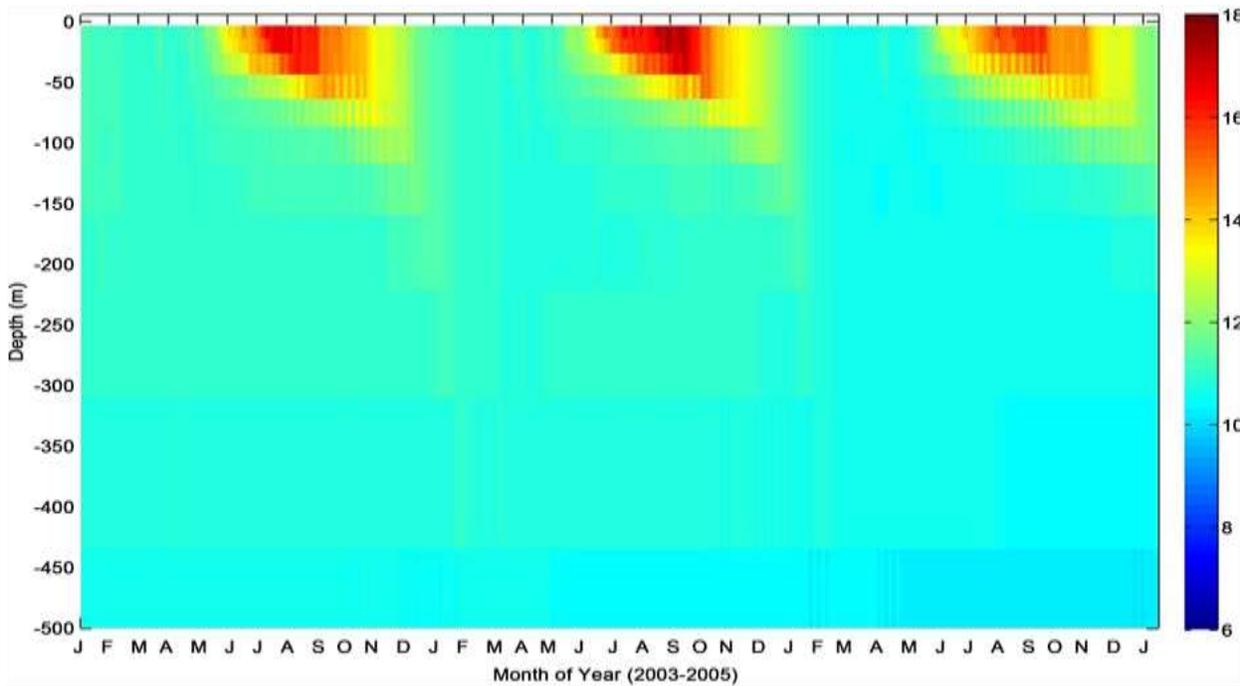


Fig.19: Mixed layer depth temperature profile corresponding to period of consecutive deployments at the PAP site (Benson,Asuquo *et al.*, 2015).

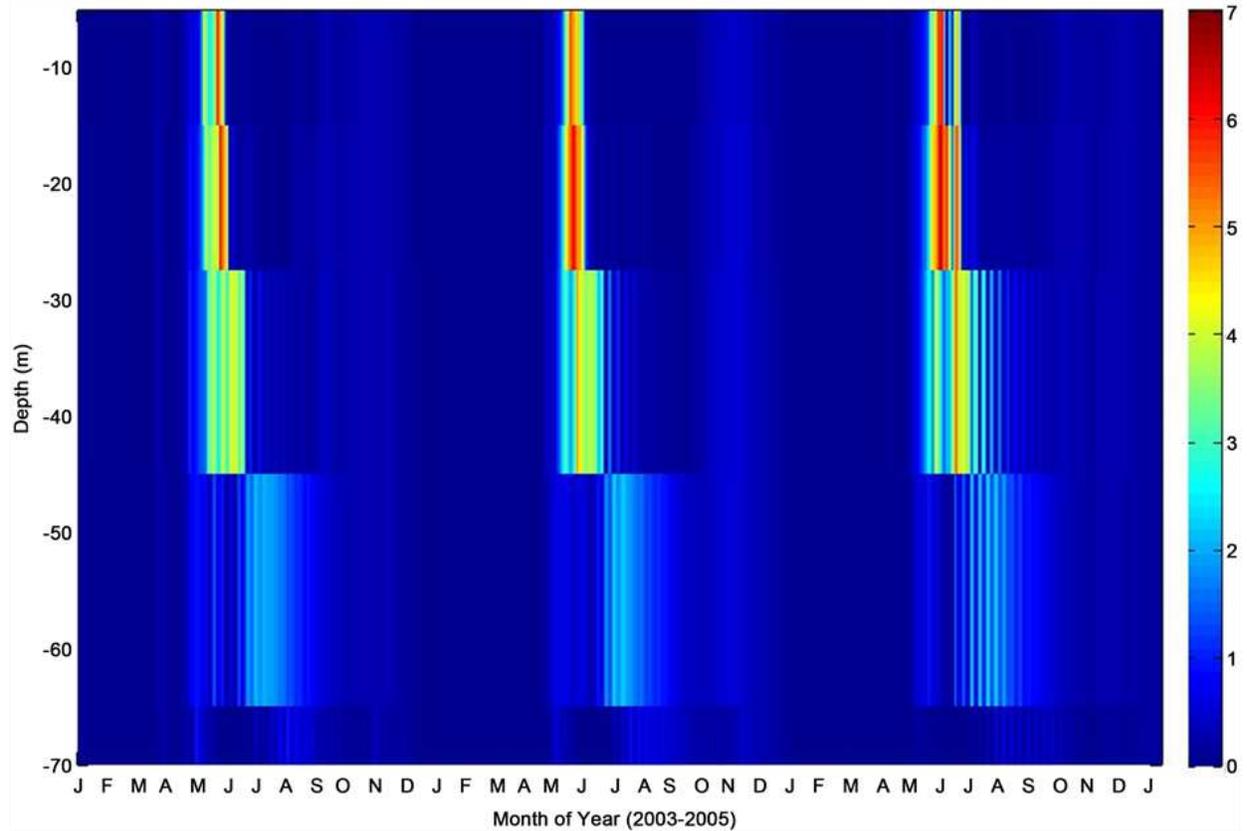


Fig. 20: Mixed layer depth chlorophyll-a profile corresponding to period of consecutive deployments at the PAP site (Benson,Asuquo *et al.*, 2015).

Observed partial pressure of carbon dioxide ($p\text{CO}_2$) and temperature data in surface and mixed layer seawater of the Northeast (49°N , 16.5°W) and Northwest (56.5°N , 52.6°W) Atlantic Ocean time series sites have been analyzed for seasonal variability and air-sea CO_2 fluxes. The NE PAP data showed an annual mean $p\text{CO}_2$ of 335.9 ± 89.6 matm (2003), 286.7 ± 103.5 matm (2004), and 335.9 ± 89.6 matm (2005). The annual data for NW KI deployments indicated annual $p\text{CO}_2$ average of 336.6 ± 14.3 and 359.1 ± 25.3 matm for 2004 and 2005 respectively. The oceanic $p\text{CO}_2$ distribution across the spatial gradients over a seasonal timescale is relatively homogeneous with marked seasonal variability. These data indicated consistently the undersaturation of oceanic surface water at the sites and thus a perennial carbon sink. Sea surface $p\text{CO}_2$ trend is marked by summertime minimum and wintertime maximum, while depicting anti-phase patterns with the observed temperature signals. Seasonal to annual CO_2 fluxes indicated a year-round CO_2 invasion of the NE and NW basins. Estimated net basin-scale CO_2 uptake fluxes of 2.96 ± 1.73 and 1.84 ± 1.3 $\text{mol m}^{-2} \text{CO}_2 \text{a}^{-1}$ were obtained for NE PAP (2nd - 4th) and NW K1 deployments, respectively (Benson, Asuquo *et al.*, 2014).

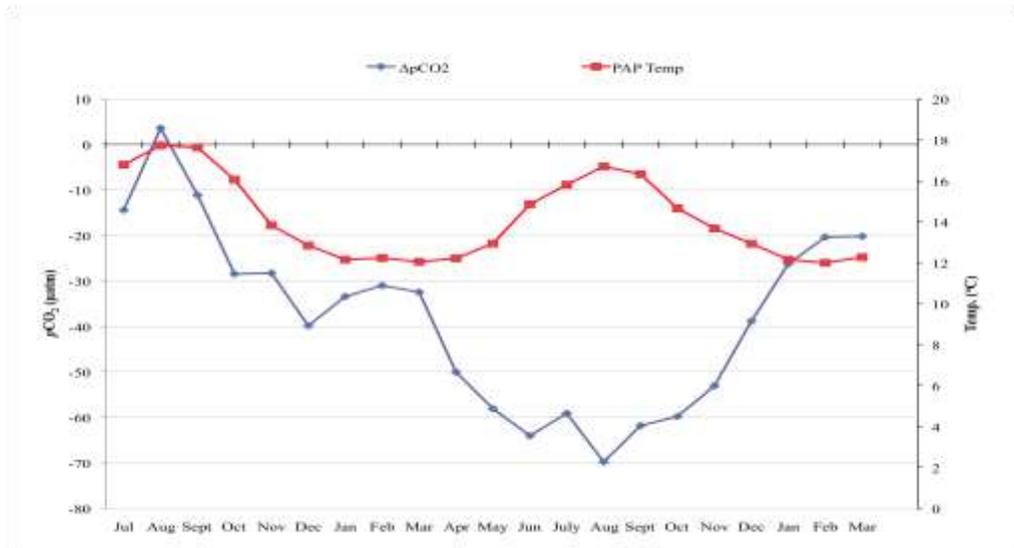


Fig.21: Monthly $\Delta p\text{CO}_2$ between July 2003 – March 2005 plotted as a function of SST at the PAP observatory (Benson, Asuquo *et al.*, 2014).

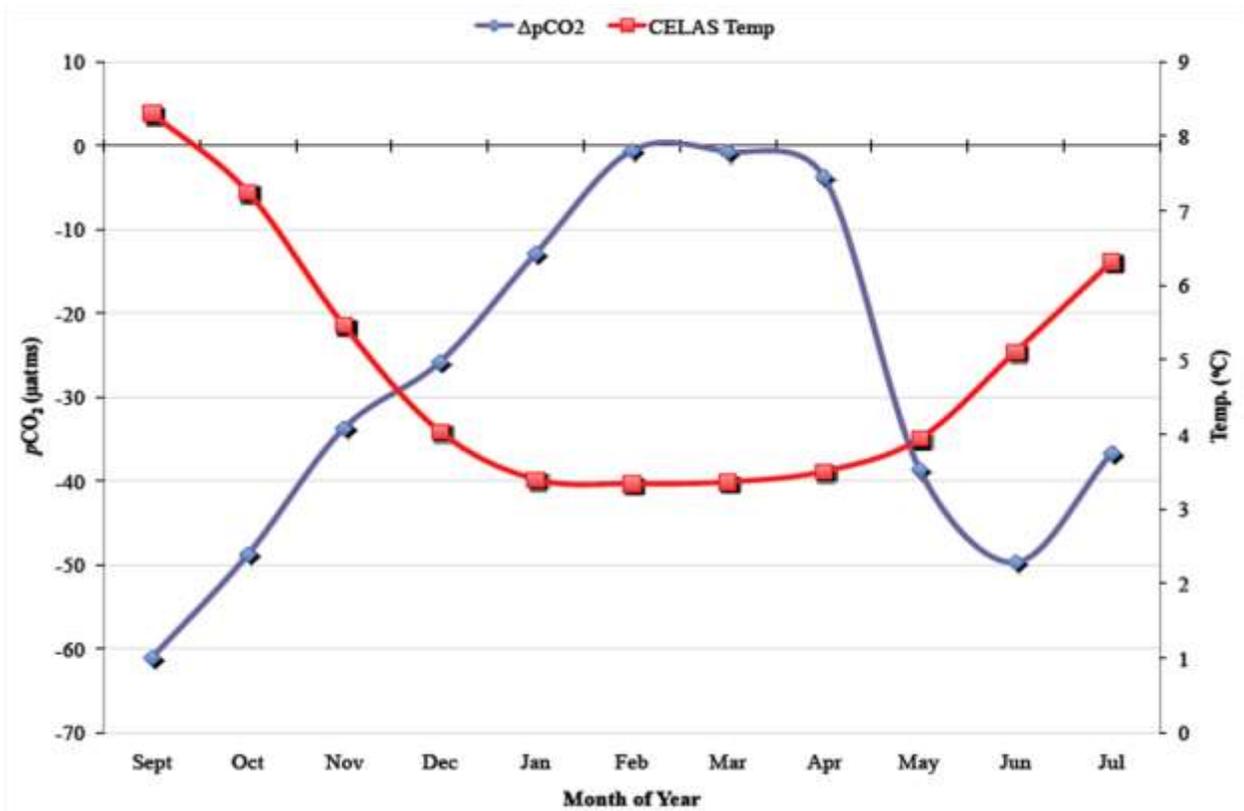


Fig.22 : Monthly $\Delta p\text{CO}_2$ between September 2004 – July 2005 plotted as a function of SST at the K1 CELAS site (Benson, Asuquo *et al.*, 2014).

CHAPTER FIVE

5.0 AN ECOLOGICAL SCENARIO MISUNDERSTOOD

Sometimes ago a conversation ensued between humanist and a young Christian girl. The freethinker asked the Christian little girl who was coming back from Sunday School, why did she waste her time in doing such a thing as that. She said because she believed that there is a God. And the man said, 'child you are so wrong to believe in such a thing as that'. And the little girl stoop down and picked up a little flower off the ground, pulled it from its petals and said, **Sir, can you tell me how this lives?** There it was. When the old man began to search his mind back, he could have said to the girl, well its growing in the earth... Then he thought the net question will be, Where did the earth come from? How did that seed get there?.....And on and on and on, it keeps reverberating until his mind rolled back and **he saw it**, in contrast to his believe. That caused him to walk away and drop his head and cry, and the man was gloriously converted to Christ at the age of 85 years. That was God in Simplicity, and he always uses simple things like **WATER** to achieve great things that sustain life.

5.1 Assimilative Capacity of the 3Bs (Waters) of LIFE

The Assimilative Capacity (also known as the receiving, absorptive or environmental Capacity) is defined as ability of the environment to accommodate a particular activity or rate of an activity, such as the discharge of contaminants, without unacceptable impact or effect. In order words, mankind believes that since WATER has such a large volume, covering 3/4s of the earth's surface, it must have accommodative capacity to receive large volumes of discharge per unit time, or quantity of dredgings dumped per unit time, or quantity of effluents added per unit time) without unacceptable impact. Oh, How misleading this has been. Man has always misunderstood nature and cannot comprehend the breadth and depth of most natural things.

Man thinks that this most lucrative and profound resource (water) can absorb, accumulate, assimilate and dissolve every substance dumped into it. But we fail to give a second thought, and answer some pertinent questions:

Why did God (nature) give to mankind the 3Bs (freshwater, brackish water and the ocean)? God could have decided to make it only One B (only fresh water or only estuary or only the blue ocean). If it was only fresh water where would the sea food and common salt come from? If it was only sea water (where would the drinking water come from? But God made it very beautiful, and placed the 3Bs in their places to fulfill the purpose of life sustainability.

Until we can find the answers to these pertinent and fundamental questions, our understanding of the ecological spectrum as designed by nature will still be oblique and obscure. Just think of it, what it would have been without freshwater. After a hard day's work, you need a cool bath, or when you are thirsty, your body needs sparkling fresh water. As you apply water depending on

your specific need, it refreshes, revitalizes, strengthens and makes you feel lively and young again. This agrees with our concept that WATER IS LIFE and Life is wealth.

5.2 THE CHANGING OCEAN

Naturally, water has the assimilative capacity for self-purification and it also has a carrying capacity. My several researches and publications have revealed that while many substances are indiscriminately dumped into water ways and the oceans dissolve them, many others do exist in the water column as suspended and floating particles. They float because water cannot assimilate, dissolve, break, consume, fragment, exterminate, disintegrate, dilute, or biodegrade them. When water has reached its carrying capacity or holding capacity or climax, the water becomes polluted due to the high concentrations of the dumped or added materials.



Plates 13 a, b: A). The discharge of waste water into nearby stream B). Picture of a polluted water body

Such additions and inputs have resulted in the deterioration of water quality. And what is the outcome, water borne diseases such as dysentery, diarrhea, typhoid, yellow fever (Asuquo and Asuquo, 1999), and consumption of contaminated sea food produces headache, nausea, (Asuquo *et al.*, 2004) and cancer (Asuquo & Udoh, 2002; Asuquo *et al.*, 2004) etc.

During my 36 years of research in the aquatic environment (rivers, estuary and ocean), we have assessed the effects and impacts of such uncontrolled and intentional discharges emanating from domestic, commercial and industrial sources into the nearby streams. These streams flow downstream into the rivers, and the rivers carry the contaminants into the estuaries and lagoons and the estuaries/ lagoons finally release the burden to the oceans. This transfer process is identical to a relay race where the starter (streams/ rivers) hands over the baton (contaminant) to the next in line and this continues until the same baton (contaminant) is handed over to the last athlete (oceans). The overall effect leads to **Marine Contamination or Marine Pollution**. The materials are contaminants when their concentrations are below the acceptable/ permissible limits and pollutants when the concentrations and amounts of the materials are above the permissible limits set by regulatory authorities.

The state of the world's ocean is well illustrated by United Nations Environment Programme who observed and I quote 'In 1989, man's *fingerprint* is found everywhere in the oceans. Chemical contamination and litter can be *observed* from the *poles* to the *tropics* and from beaches to abyssal depths (GESAMP 1990). This was in 1989, what do we think is the state of the ocean today after 29 years.

DEFINITION OF MARINE POLLUTION

Marine Pollution simply refers to: "The introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) which results in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities".

The centre of the problem is man ... introduction by man into the marine environment, substances that are toxic and harmful, because they believe the ocean will absorb them. How wrong humans are, a misconception of the nature of water... that is the ecological scenario misunderstood.

5.3 HEALTH OF THE OCEANS AND THE CHALLENGES OF MARINE POLLUTION

Chemicals dumped into the ocean directly or indirectly have severe impacts on the health of the ocean. Impacts of marine pollution are numerous but not limited to:

- Alteration in the water quality of coastal ocean
- Toxicity, death and destruction or complete extermination of vulnerable species such as ocean microbial communities, fry and juveniles of fish
- Litters on beaches and reduction in recreational and tourism values of beaches
- Bioaccumulation of heavy metals and hydrocarbons by fish

- Leads to increased pH of ocean waters
- Influences the CO₂ concentration and biogeochemical cycles in the ocean
- Influences the global climate change
- Changing sea levels have affected everyone on our planet, and marine scientists and meteorologists have been monitoring these trends for decades.
- As global temperatures increase, the ocean responds by expanding.
- Ocean levels are currently rising at the rate of 0.1mm per year.
- The Greenland ice sheet is melting at the rate of 287 billion tons a year, and the Antarctic ice sheet is losing 134 billion tons a year.

5.4 THE WAY FORWARD

Since every process of production generates waste, there should be efficient waste collection system instituted by national governments such that waste generated anywhere (from households, commercial centres, schools, markets, etc.) are retrieved and channeled to appropriate disposal sites for waste treatment, reduction and minimization. This approach is comparable to the use of the 4Rs, waste reduction, reuse, recycling and recovery in waste management.

Suggested and recommended remedies:

- There should be a proper management for the marine environment, giving attention to effective waste treatment technology and alternative means of disposal, such as the use of engineered landfills.
- The practice of effective management of river basins and water quality should be developed and encouraged by national governments.
- The Federal and State Governments should be willing to pay the price of towing the path of clean technologies and low carbon emission systems that are associated with low waste generation.
- The Federal Environmental Protection Agencies must ensure that no price or effort is judged to be too high, and that a factory cannot be built, except it has a well articulate plan or component for waste treatment and management.

The procedure described above will not only ensure clean and blue waters but life longevity for humans and aquatic life.

CHAPTER SIX

6.0 CONCLUSION

6.1 FUTURE RESEARCH AND WORKPLAN

Use of autonomous underwater vehicles (AUVs) or ocean gliders for monitoring essential ocean variables

The world's ocean has undergone gross contamination due to human or anthropogenic activities that have introduced particulate and dissolved materials into the ocean. The assessment of these substances for the past decades have been conducted using conventional oceanographic techniques that involved the spending of several man-hours at sea for collection of in situ data followed by laboratory procedural analysis. This approach is relatively cumbersome, wasted time and involved large sums of research fund expenditure. In recent times, ocean gliders have been developed that could monitor essential ocean variables with relative ease and comfort. An ocean glider is an autonomous, unmanned underwater vehicle used for ocean science. Since gliders require little or no human assistance while traveling, these little robots are uniquely suited for collecting data in remote locations, safely and at relatively low cost. Gliders are often equipped with a wide variety of sensors to monitor temperature, salinity, currents, and other ocean conditions. This information creates a more complete picture of what is happening in the ocean in a global perspective and provides data and information that are comparable anywhere in the world's ocean.



Plate 14 : Two types of ocean gliders; the sea glider and the Slocum glider on display in at National Oceanography Centre, Southampton, UK, 2016.



Plate 14 : Prof. Asuquo (centre) with other colleagues during the 7th EGO conference on autonomous ocean gliders at Southampton, UK.

In Southampton, UK, I presented a paper titled ‘Ocean gliders Applications as an alternative technology to conventional (analytical) techniques in the Bight of Bonny, Nigeria’. In recognition of my ingenuity and interest in the use of ocean gliders, I was invited to participate in the New Era of Blue Enlightenment Project: Building an Atlantic Community that took place from 12th – 14th July 2017 at Lisbon, Portugal. I presented a paper titled: AtlantOS Project In Nigeria: Developing a workable Plan for Atlantic Ocean Monitoring and Coastal Areas Sustainability in Nigeria, West Africa. This conference witnessed the signing of a trilateral agreement between South Africa, Brazil and the European Union for a joint execution of projects bordering the South Atlantic Ocean.

In November 2017, I was supported by the University of Calabar to participated in the 8th Glider School Training on Ocean Gliders Technology at Oceanic Platform of the Canary Islands (PLOCAN), Spain from 6 - 11th November 2017. This workshop laid the foundation for the University of Calabar to join world oceanographic institutions that are known to be using ocean gliders for ocean monitoring and assessment. I deployed a Slocum glider at the Canary Platform during the workshop, and was recognized as the First Nigerian Oceanography to deploy the ocean glider. See picture below:

Teledyne Webb Research is at Plataforma Oceánica de Canarias.
10 November 2017, Telde, Spain ·

Francis Asuquo, the first Nigerian to attend PLOCAN's Glider school, deploys the Slocum G2 Silbo as part of today's activities in the harbor.



Posted on Teledyne Webb page : <https://web.facebook.com/TeledyneWebbResearch/> 10th November 2017.

Presently an International research collaboration has been initiated between the Plataforma Oceánica de Canarias (PLOCAN), Spain and the University of Calabar, Nigeria for the deployment of ocean gliders in Calabar after the signing of a Memorandum of Understanding (MoU). Efforts are also being made to key into the H20-20 AlterEco Project on monitoring the rate of contaminants of our coastal areas funded by the UK Government through partnership with colleagues from National Oceanography Centre, Liverpool, UK and LOCEAN, Université Pierre *et* Marie Curie, Paris, France.

APPRECIATION AND ACKNOWLEDGEMENT

Our God is worthy of praise. I thank him for his faithfulness and for ordering my footsteps into the oceanography profession, through which he has worked with me and guided me every step of the way.

My inaugural lecture was scheduled for June this year, but in February, with a gap created in inaugural lecture schedule, Prof. B.I. Ita, Chairman, Committee of Deans requested if I could fill the gap. I accepted completely unaware of the enormity of the task ahead. However, I am familiar with the author of knowledge and wisdom, through whom are all things and by whom all things consist, he made a way for conceptualization of the topic and the voyage to the end. For this I say thank you Jesus.

I wish to thank my amiable Vice Chancellor and friend, Prof. Zana Akpagu, whom I have known for many years now, right from our days as malabites in the Malabor Republic. It is good having an Alumnus as the Vice Chancellor who understands both teething and ageing problems of this university. This is evident in our indefatigable Vice Chancellors' three agenda as his main objective; STUDENTS, STUDENTS, STUDENTS. This is to ensure that, no teething problem affects the university at 42 years and beyond. Thank you for coming on board at this time to sail this university to greater heights.

Oh, what can I say about my beloved wife who has missed my company from commencement of this write up, however, knowing that she truly loves me and was praying for me was consoling. She has been very supportive and patience relying for God's leadership to a successful end. Honey, thank you so much for your many contributions that has made this lecture a great success. My children have been a great encouragement as they rally around me, making sure that I have healthy breaks while concentrating to bring out his lecture. Caleb, Enoch, QueenAnn, Peace, Divine, Tarrynot and my niece, Pearl, and daughter-in-law, Eme-ita, I say thank you.

My journey in life has been strongly supported by the special care and love of my Pastor (Rev.) & Mrs. Eke U. Eke. This is a man of God that has impacted my life and has been used by God to censor as I navigate life journey, right from age sixteen. He conducted my wedding, preached my thanksgiving service as a Professor and continually admonish with the word of God which stabilizes and builds up my faith. I remain grateful, Pastor.

To my siblings and their families, Rev. & Mrs. Joseph Asuquo, Dr. (Mrs.) Mary Offong, Mr. & Mrs. Emmanuel Asuquo, Hon. Justice (rtd) & Mrs. Denis E. Okon, Mrs. Justina Emmanuel M. Matthew and Mr. & Mrs. Daniel Essien, I appreciate all of you for sustaining the legacy of love and unity left by our parents. I salute all my brethren at the Headstone Bride Tabernacle, Calabar for their prayers and love to me and my family at all times.

It is joy and refreshing to work in Oceanography. I appreciate my Dean, Faculty of Oceanography, Prof. Albert P. Ekanem and the Director, Institute of Oceanography Prof. Paul J. Udo for their support and encouragement when they heard of my inaugural lecture presentation. I express my thanks to Prof. U. K. Enyenihi, the first Director of Institute of Oceanography, who brought all of us on board in 1983. My gratitude also goes to the general Oceanography family especially our senior colleagues Prof. Austin I. Obiekezie, Prof. Efiom Edem Antia, Prof. Paul O. Ajah, Prof. Udemé Enin, Prof. Ekpo Eyo Antai, Prof. Sieghard Holzlohner, Prof. Ekom R. Akpan, Prof. Daniel AmaAbasi, Associate Prof. Francis Nwosu (SubDean) for being special friends to me. The efforts of Sony Eteng, Godwin Otego, Jude Udom, Victoria Emeka, Edak Efiom, Aniema Inyang-Etor, Antigha Ambo, Grace Olaleye, Dr. Philomena Asuquo, Lynda Uta Edet, Uncle Job Basse, Usen Umana, Emmanuel Basse, Patrick Ekene, Timothy Okon, Timothy Anyanwu and all others too numerous to mention are all appreciated.

My career began with a good foundation I had from the Chemistry Department, University of Calabar. I wish to appreciate my BSc supervisor, Prof. Miranda Dosunmu, my PhD supervisor, Prof. Francis Morah, my lecturers, Prof. U.J. Ekpe of blessed memory, Prof. U. J. Ibok, Dr. R. K. Sood (India), late Dr. N. T. Akinchan (India), Dr. Louis Obyo-Nelson, Prof. J.O. Ofem for teaching me to know that matter transformation is a continuous process resulting in the formation of new substances always.

My process of transformation began when I met Prof. O. Osibanjo, Professor of Analytical Chemistry, University of Ibadan. I am grateful to him for allowing me to use his laboratory for water analysis while working on the water pollution status of Awba Dam, Ibadan in 1986 during my MSc programme.

I thank Prof. Dr. J.C. Diunker and Prof. Dr. Manfred Ehrhardt of the Marine Chemistry Department, University of Kiel, Germany who allowed and assisted me to analyse tar ball and crude oil samples I took from Nigeria to Germany. It was a thrilling experience to use HPLC, GC, FT-IR and GC-MS in the analysis of the tar samples for the first time. My subsequent trip supported by the Germany-Nigerian Cooperation to the Institute of Marine Research, Bremerhaven, where I spent 3 months under the mentorship of Prof. Dr. W. Ernst on the analysis of organic micropollutants and hydrocarbons in water and sediments is greatly appreciated.

The support of UNIDO during my Diploma in Integrated Zone Management course in Venice and that of IAEA facilitated by Prof. Francis Sikoki, National Coordinator, IAEA TECHNICAL COOPERATION PROJECTS (RAF/7014,7015 & 7017) in Nigeria, on nutrient monitoring and analysis in Tunisia is hereby greatly acknowledged.

I wish to pay glowing tribute to my ocean elevators who has made my contact with the outside world possible; Prof. Sabrina Speich of the Department of Geosciences, Laboratory of Dynamic Meteorology (LMD), France and Prof. Johannes Kartstensen of the Ocean Circulation & Climate Dynamics Center (GEOMAR), Helmholtz Centre for Ocean Research, Kiel for their

unflinching support in ensuring that Nigeria *vis a vis* Africa is represented on issues concerning global oceanographic research.

I am grateful to the Chairman, COD, Prof. B. I. Ita for the confidence he has in me to deliver this lecture at short notice. I thank the Committee of Deans Secretariat, Mrs. Matilda Akpan and her team for all the support I received during the preparation for this lecture.

I will not fail to acknowledge my friends in the AtlantOS network, Dr. Matthew Palmer, Prof. Pierre Testor, Mr. Victor Turpin and Dr. Carlos Barrera of PLOCAN for their encouragement and support towards making the marine science project of procuring and deployment of ocean gliders in the Gulf of Guinea a reality.

To my inlaw and friend, Prof. Chidi Ibe, I do not forget your encouragement and advice, which has helped me a great deal as a researcher. To my brother and colleague in the oceanography family, Prof. Ita Ewa-Oboho of Akwa Ibom State University, Prof. Sylvester P. Antai, who mentored me on the essentials and strategies of conducting environmental consultancy, I say thank you all for being there for me when I call.

My inaugural friend and colleague, Prof. Nsikak Udom Benson, I am grateful to you for postponing your trip to the United States of America to be here to honour me, I say thank you.

My Vice Chancellor, time will fail me to begin to mention everyone that has impacted my life during the course of my journey as an oceanographer. I say thank you to all my invited guests from the University of Lagos, Nigerian Institute of Oceanography and Marine Research, University of Uyo, Akwa Ibom State University, University of Port Harcourt, Covenant University, University of Benin, Federal University of Agriculture, Umudike, University of Lagos, my relatives and kinsmen from Uruan, Uyo, and all Akwa Ibomites and Cross Riverians, I say thank you for all your support.

A very big thank you to all the members of my Inaugural Committee, comprising of colleagues and students from Oceanography and Department of Nursing, headed by Dr. Philomena Asuquo, you have all made me proud.

Thank you everyone for the effective role you have played, the sacrifices you have made, and travelling from far and near to make my outing a great success. May the Almighty God richly bless and reward you.

PROFESSOR FRANCIS EMILE ASUQUO & FAMILY

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LOCAL & INTERNATIONAL CONFERENCE PRESENTATIONS

1. **Asuquo, F.E ..** Benson,N.U.& Nsisiong, S.Daniel (2017). The influence and fluctuating trends of ocean variables in surface mixed layer of the south Atlantic Ocean, Nigeria. International Workshop on Marine & Atmospheric Sciences in West Africa 12 – 17 November 2017 , at the OSCM and the INDP in Mindelo , Cape Verde.
2. **Asuquo, F.E .** & Benson,N.U (2017). AtlantOS Project In Nigeria: Developing a workable Plan for Atlantic Ocean Monitoring and Coastal Areas Sustainability in Nigeria, West Africa. Building an Atlantic Community: Project and Ideas Meeting Place - 12 July 2017 and a New Era of Blue Enlightenment, July 13-14, 2017.
3. **Asuquo, F.E . (2016).** Ocean gliders Applications as an alternative technology to conventional (analytical) techniques in the Bight of Bonny, Nigeria. 7th EGO conference on autonomous ocean gliders and their applications Monday 26th September – Thursday 29th September 2016 at National Oceanography Centre, Southampton, UK.
4. **Asuquo, F.E.(2016).** Resource Person: 4th U6 Initiative for Development Conference holding in University of Cape Coast, Cape Coast, Ghana, Theme: “Addressing the Sustainable Development Goals (SDG) Through Collaborative and Transnational Research” from September 11th to 15th 2016.
5. **Asuquo, F.E . (2016).** Resource Person.1st Akwa Ibom State Climate Change and Clean Energy Summit. Theme: Charting a Roadmap for sustainable environment, from July 26 – 30, 2016 at Le Meridien Complex, Uyo, Akwa Ibom State, Nigeria.
6. **Asuquo, F.E . (2016).** Scientific Expert. 2nd AtlantOS Essential Ocean Variables Workshop from 30 June to 1 July 2016 at Steigenberger Conti Hansa, Kiel, Germany.
7. **Asuquo, F.E . (2016).** Scientific Expert.2nd Training Workshop on University-Industry Linkages for African Universities, University of Ilorin, Ilorin, Nigeria, 10 to 12th May, 2016.
8. **Asuquo, Francis Emile** and Akpan,Israel Edet (2015). Organochlorine pesticides and polychlorinated biphenyls in sediments of Calabar river, South eastern Nigeria. 7TH SETAC Africa Conference, 5-8 October 2015, Langebaan, South Africa. October 2015.
9. **Asuquo, F.E . (2015).** Resource Person.2nd Regional Steering/ Technical Committee Meeting: Monitoring for Environment and Security in Africa (MESA) Programme. Theme: Enhancing the use of Earth Observation Information to support Fisheries

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10. **Asuquo, Francis E. (2015).** Report on the status of the Centre of Excellence (CoEX) for Fisheries and Aquaculture, University of Calabar, Nigeria, Paper presented to TETFund on the Verification Visit to the Institute of Oceanography, University of Calabar, Calabar, Nigeria on 7th May, 2015.10pp.
11. **Asuquo, Francis Emile (2015).** Public Lecture on “From the Gray to the blue waters: The emerging scenario”. Presented at the Faculty of Applied Sciences Seminar, Applied Sciences Block, Cape Peninsula University of Technology, Cape Town South Africa on 29th April 2015.
12. **Asuquo, F.E . (2015).** Coordinator.Public Lecture on Application of Satellite remote sensing in data acquisition and management of the coastal zone by Odum, Princewill O. First Faculty of Marine Sciences Seminar, Faculty of Marine Sciences, University of Calabar, Calabar, Nigeria on 24th April, 2015.
13. **Asuquo, F.E . (2015).** Resource Person.Conference on Sensitization on the Implementation of the Nigerian maritime Administration & Safety Agency’s mandate on the coastal and inland (cabotage) Act 2003 in Nigeria, 20th March 2015 at Transcorp Hotel, Calabar, Nigeria.
14. International Conference on Oceanography, Institute of Oceanography, University of Calabar, Calabar, Nigeria, 12 – 14th November, 2013:
15. **Asuquo, Francis Emile** and Ita, Richard Eyo (2013). Assessment of flood-ebb tidal dynamics on heavy metal distribution in the nearshore waters of the Gulf of Guinea, Nigeria. Conference on 2iE’s Science Week, 10 -14th April 2013, Ouagadougou 01 - Burkina Faso.
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17. **Asuquo, F.E . (2011).** Resource Person.Workshop on the Review and Setting of Standards for the Establishment of the Faculty of Oceanography and Naval Architecture in Akwa Ibom State University held in Senate Chambers, Akwa Ibom State University, Ikot Akpaden, Mkpatt Enin LGA, Akwa Ibom State, June 19, 2011.
18. **Asuquo, F.E.(2011).** Resource Person.Workshop/Project Review Meeting on Longevity Assessment of Coastal Groundwater of Some Niger Delta Communities Organized by National Centre for marine Geosciences, Yenagoa in Calabar, Planet Guest House on 30th September, 2011.

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□ Tropical Ecology □ Marine Pollution Bulletin □ Indian Journal of Marine Sciences □ The Environmentalist □ Bulletin of Environmental Contamination and Toxicology □ Journal of Environmental Systems □ Journal of Oceanography and Marine Science □ European Journal of Experimental Biology □ Journal of Natural Sciences Research □ Environmental Monitoring and Assessment □ International Journal of Marine Science □ Open Journal of Marine Science □ Journal of Earth Science and Climate Change; and □ PLoS ONE