MAKERERE UNIVERSITY

EVOLUTION OF ENVIRONMENTAL SCIENCE:
THE SCIENCE OF INTEGRATION

Professorial Inagural Lecture

Prof. James Okot-Okumu
BSc., MSc., PGD-EST., PhD

OCTOBER 25th 2019

EVOLUTION OF ENVIRONMENTAL SCIENCE: THE SCIENCE OF INTEGRATION

Professor James Okot-Okumu – Professor of Environment and Natural Resources

Professorial Inaugural Lecture

By

Prof. James Okot-Okumu

BSc, MSc, PGD-EST, PhD

October 25th 2019

DEDICATION:

Dedicated to my family; my wife Judith Achen Okot and the children: Nigel Kinyera Okot, Jeff Howard Oryem, Michael Okumu, Mercy Eunice Akot, Trevor Ochola, Dorcus Daniela Atim, James Okot Junior, Beatrice Joy Aber.

I Love You All

ACKNOWLEDGEMENT

I will always be indebted to Dr. Peter Larway (RIP) a very dedicated Scottish Biochemist who was my first supervisor of an academic research at the University of Ghana, to all my lecturers at University of Ghana Legon who opened my way to the academia and my lecturers and research supervisors at IHE-Delft and RIVM-Bilthoeven Laboratory-The Netherlands who opened the door for me to Environmental Science. To my colleagues at Makerere University and other Government Institutions that I have worked with in Science capacity building, research and consultancies, I honestly appreciate the experience.

Finally I would like to thank all my family members who have been with me and provided support in my journey to this level of my academic achievement

ABSTRACT

Human social development and sophistication of production, search for livelihoods and the exponential population growth have destabilized natural balances with overwhelming and deleterious impacts on the environment (air, water, soil/land and life). Early awareness concerning environmental conservation was documented in the 1800s. However, the impacts of such concerns by prominent scientists and communities only became significant to governments especially in the USA and Europe in the 1960s. National Environmental Policies and Acts were enacted from the late 1960s and the requirements for Environmental Impact Assessment of large projects began to be enforced as legislation. The national concerns were translated into global agreed actions (e.g. Brundtland Report 1987 and Earth summit 1992) of environmental protection conventions and treaties. Consequentially environmental management concepts (e.g. CP. CE, IE, LCA, and SCP) and their implementation emerged especially during the 1980s. Together with these efforts Scientists, Economists and Social Scientists were carrying out research and studying better ways of natural resources utilisation, production and products consumption with minimum resources extraction and efficiency and effective services utilization with minimum wastes for sustainability.

It became apparent that the traditional sciences though excellent in their own domains, operated individually or sector wise and therefore did not provide for better understanding of environmental impacts for informed decision-making. Therefore the need for a new science to analyse and plan for this new era and concerns was realized and therefore **Environmental Science was born** spearheaded by Ecologists working together with other Scientists, Engineers and Social Scientists. Environmental Science emerged during the 20th century as a desirable and deliberate scientific discipline using a **holistic approach to environmental management (Conservation) for maximum social benefits.** It has a pivotal role in solving the earth's degradation problems by **identifying, analysing, assessing and mitigating environmental problems.**

This lecture, therefore, is about the evolution of environmental science, my career progression and highlights of my research and overall contributions to Environmental Science and natural resources management. The important role of the traditional science disciplines in the birth and growth of Environmental Science is presented. This is done systematically to illustrate how **natural science gave birth to the science of 'Ecology'** and how the concepts of **Ecology helped in shaping Environmental Science**. Efforts by earlier scientists and my own research will be used to demonstrate how **Environmental Scientists** can contribute effectively to the understanding of the environment and its interaction with humans.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

EQUATION

ACRONYMS

AU	African Union	NO_x	Nitrogen Oxides
BOD	Biochemical Oxygen Demand	NO_2	Nitrite
BSc	Bachelor of Science	NO_3	Nitrate
CH_4	Methane	O	Oxygen atom
CO	Carbon monoxide	O_2	Oxygen molecule
CO_2	Carbon dioxide	O_3	Ozone
CP	Cleaner Production	PhD	Doctor of Philosophy
CE	Circular Economy	$PM_{2.5}$	Particulate matter 2.5 micrometers or less in diameter
ΔE	Change in internal Energy	PM_{10}	Particulate matter 10 micrometers or less in diameter
ET	Evapotranspiration	*Q*	Heat gained or lost by a system
G	Gravitational force	P	Phosphorus
GHG	Greenhouse gas	PDCA	Plan, Do, Check, Act
H	Hydrogen	POPs	Persistent Organic Pollutants
HNO_3	Nitric acid	SCP	Sustainable Consumption and Production
H_2O	Water	SDGs	Sustainable Development Goals
H_2SO_4	Sulphuric Acid	SO_x	Sulphur Oxides
HM	Heavy Metal	SO_2	Sulphur dioxide
IE	Industrial Ecology	SO_3	Sulphur trioxide
IEM	Integrated Environmental Management	TOC	Total Organic Carbon
IHE	Institute of Hydraulic and Infrastructural Engineering	TSS	Total Suspended Solids
ISWM	Integrated Solid Waste management	UGX	Ugandan Shillings
LDC	Least Developed Countries	UPOPs	Unintentional Persistent Organic Pollutants
LP	Lean Production	UK	United Kingdom
MDGs	Millennium Development Goals	UN	United Nations
MSc	Masters of Science	UNDP	United Nations Development Programme
N	Nitrogen	UPK	Uganda Polytechnic Kyambogo
NDP	National Development Plan	USA	United States of America
NFA	National Footprints Accounts	*W*	Work done by or on a system
NH_3	Ammonia	WM	Waste Management
NH_4^+	Ammonium ion	WWF	World Wide Fund for Nature

Prof. James Okot-Okumu

PROFILE

I have PhD in Environmental Science and Natural Resources (Mak), MSc in Environmental Science and Technology (IHE- Delft, The Netherlands), PGD Environmental Science and Technology- Distinction (IHE- Delft, The Netherlands), BSc Hons - Biochemistry and Chemistry (University of Ghana, Legon), Certificate in Environmental Management in Industries (University of Tampere, Finland), Certificate in Basic Principles of Decentralisation (UMI, Kampala). I now have over 30 years of professional experience in Environmental Science that includes teaching, research and student supervision at Makerere University and working with Government Departments and the community.

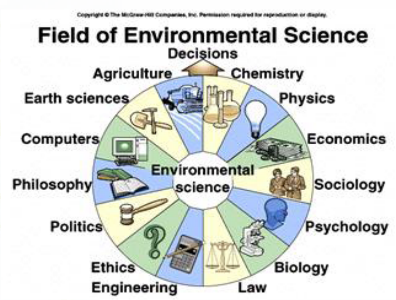
I was the Head of Department of Environmental Management at the School of Forestry, Environmental and Geographical Science, College of Agricultural and Environmental Sciences for 8 years (2011 -2019). My teaching and research interests include: **Water Resources Management, Cleaner Production, Waste Management and Pollution analysis, Environmental and Social Impact Assessment (ESIA) and Environmental Audit.** At Makerere University I chaired the Course restructuring committee for Environmental Science courses and the review committees on all courses at the Department of Environmental Management. My work experience also includes extensive consultancy in Environment and Natural Resources Management. My academic and professional expertise has enabled me to contribute to Uganda national development in various capacities such as Chairperson of the Technical Committee (UNBS/TC16/SC1) on Petroleum and Petrochemical Products, steering committee member Uganda Water Partnership- Ministry of Water and Environment, steering committee member Global Biodiversity Information Landscape- NEMA. I am a member of professional bodies including the **International Water Association (IWA), Nature Uganda, Uganda Association for Impact Assessment.** Previous assignments include Lecturing (Biochemistry and Chemistry) at the then Uganda Polytechnic Kyambogo and serving as **a Senior Environment Officer**, Government of Uganda.

CHAPTER 1:
INTRODUCTION

1.1 Environmental Science and Its Evolution

Environmental science *is an interdisciplinary academic field that integrates various professional disciplines in the sciences and others to the study and manage environment and find solutions to environmental problems.* . The science operates by combining information from many disciplines, such as biology, chemistry, physics, geology, geography, economics, sociology, demography, cultural anthropology, agriculture, engineering, law, ethics and politics, Fig. 1 (Begon et al., 2006, Raven et al 2010). The holistic nature of environmental science enables the integration of diverse talents from the different science and social science disciplines to obtain knowledge on the environment plan and implement sustainable options for social and economic development. Environmental science is generally guided by the ***concepts of Ecology.***

Figure 1: Field of Environmental Science and Related Disciplines



As Enger & Smith (1995) stated, ***environmental science uses ecosystem dynamics, concepts and principles to explain human interactions with the natural and man-made systems, human impacts on the systems and also seeks the best ways to address or solve problems in natural and man-made systems.*** Ecology (Greek, Oikos= house or place to live) literally means the study of 'home' (Odum, 1971). However a more elaborate definition of ecology would be ***'the study of the relations of organisms to one another and to their surrounding or environment'*** (Begon et al., 2006; Odum 1971; Raven et al, 2010).

(Source: wrtermpaperfgqu.bogensport-vas.com)

Kreb's (1971) definition of ecology emphasises the aspects of organism's distribution and abundance being determined by the interactions, which is more descriptive. The history of science indicates that scientists long ago were already interested in exploring new plant and animal species and new concepts in order to better understand the natural processes on planet earth (Enger & Smith, 1995; Raven et al., 2010; Odum, 1971). Some of the exploration results were rewarding as was in the areas of food security, medicine, minerals and other natural resources. These efforts were from scientists from disciplines of Botany, Zoology, Chemistry, Geology and Physics. The classical classification of scientists (e.g. Botanists, Zoologists, Chemists, Geologists, Physicists, and Astronomers) started long then and are still applied based on specific research interests. These specializations still focus their research efforts on the areas in which they specialize. Specializations in these science disciplines is good and **must be maintained because these were, are now and will continue to be the underpinning of science.** However as these specialized scientific fields developed the exploring mind of scientists expanded to start asking more ***questions especially on why species lived where they did and what affected them from their surroundings (environmental factors).*** This was the beginning of the formation of the field of ecology in the mid 1800s, (Fig 2) which looked at both biological and non-biological factors and their interplay in an ecosystem (*biological community of interacting organisms and their physical environment*) as illustrated in Fig 3.

Figure 2: The progression of Environmental Science

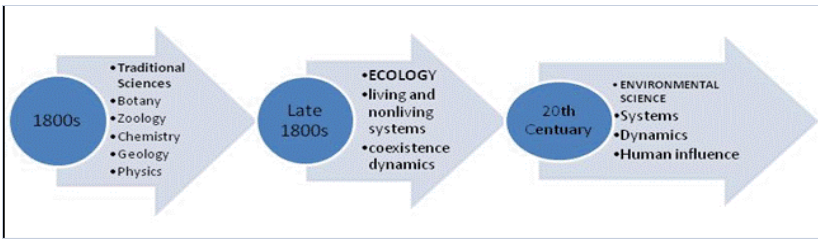
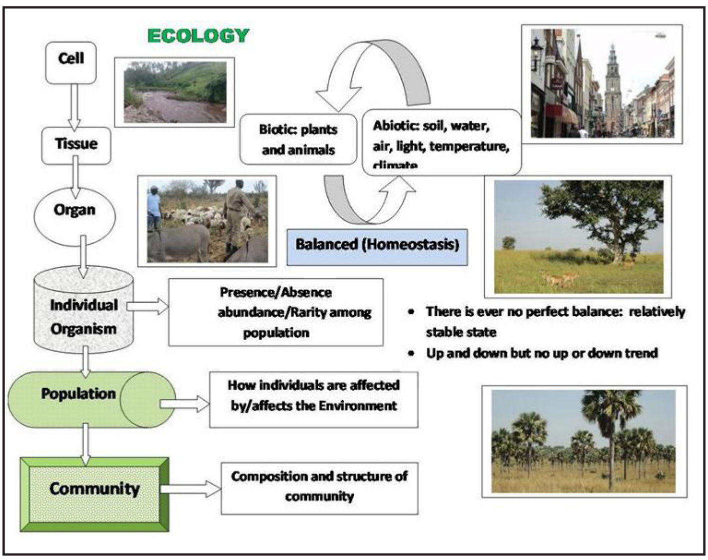
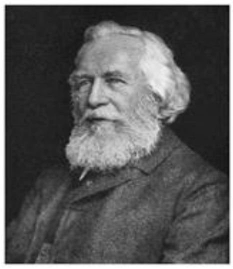


Figure 3: Ecology illustrated



(Adopted with modifications from Enger E.D and Smith B.F, 1995)

During that time the term ***'ecology'*** was coined by the scientist **Ernst Haeckel – *'It is a dynamic system on living and non-living components that exist together in more less balanced state influenced by both internal and external factors'*. Ernst Heinrich Philipp August Haeckel** (German: 1834 –1919) was a *biologist, naturalist, philosopher, physician, marine biologist, professor and artist* who discovered, described and named thousands of new species, mapped a genealogical tree relating all life forms, and coined many terms in biology.	 ***Ernst Haeckel (1834 –1919)***

The science of ecology helped scientist to understand nature and its dynamics better. The better understanding of ecosystems and the dynamics therein led to the recognition of its importance for our own (humans) wellbeing. It also started to ***become apparent that humans were in some cases not interacting with the environment in a sustainable manner.***

In the mid-1800's scientists in the northern hemisphere were becoming more aware and focused on the environment and its protection. One such effort was by an American **John Wesley Powell** (1834-1902) who wrote a report to the government of the United States Of America (USA) that led to the establishment of the **Smithsonian Institution in 1849,** that worked to collect and store information across the sciences and is now the world's largest museum and research centre.	 ***John Wesley Powell (1834-1902)***
However it was **George Perkins Marsh** whose book '***Man and Nature'***, in 1864 was the first to raise concern about the negative impacts by humans on the environment. Notwithstanding all these scientists derived their intuition from ***traditional knowledge*** that existed among communities combined with emerging scientific skills to understand the environment better. **'Environment'; *'It is the surrounding, object, circumstances, all external conditions, both biotic and abiotic that affects a person or community and his/their properties, and other organisms or groups of organisms within'***	 ***George Perkins Marsh (1801-1882***

Another prominent scientist of the past that contributed much in developing conservation practices is Dr. George **William Carver** a prominent a botanist, agronomist, chemist and inventor who introduced modern day farming in the USA. Despite all odds as a black, during that time he was able to contribute to agriculture (crop rotation, soil conservation, value addition) and technology. Apart from his work to improve the lives of farmers, Carver was also a leader in promoting environmentalism.

George Washington Carver (1865-1943)

Some conservation Philosophers of long ago with impact on the environment and its conservation were;

- John Muir (1838-1914): his love for nature resulted in the creation of conservation areas in the USA (Yosemite National Park, Sequoia National Park). First of its kind in the world.
- Aldo Leopold (1887-1948) is considered as one of the most influential conservationist and ecologist
- Theodore Roosevelt (1858-1919) was a politician and conservationist.

In Africa on the other hand using culture the ancestors were also observing and assessing the environment and came out with their own ways of environmental assessment, forecasting and making predictions about soil and water quality, the weather and climate. For example in Uganda every tribe through customs (e.g. taboos, totems) and folklore have their norms on natural resources and their utilization that members of the communities are instructed on from childhood. These rule that are similar among the tribes allowed the communities to live in harmony with the environment for sustainability. ***Unfortunately modern times have taken their tolls here in Uganda, Africa and most LDCs where few individuals with influence are causing massive destruction to the environment for selfish gains.***

The 1900s and especially the 1960s was the period that disasters struck frequently and opened up new thinking about socioeconomic development and the need for environmental conservation. In the early 1900s major environmental issues started becoming very public. Examples of occurrences that had serious consequences on humans and the environment were:

Air pollution:

i. **1943: Los Angeles smog -** during World War II residents of Los Angeles believed the Japanese were attacking them with chemical warfare. However this was a thick fog that made people's eyes to sting and their noses run that had taken hold of the city. Visibility was cut down to three city blocks.

ii. **1952: The Great Smog of London** - caused by severe air-pollution event that affected London. Visibility was reduced and even penetrating indoors. It was estimated that up to 4,000 people died as a direct result of the smog and 100,000 more were made ill by the smog's effects on the human respiratory tract.

iii. **1961:** Y**okkaichi Asthma** was caused by industrial air pollution from sulphur dioxide at Yokkaichi Japan.

Water pollution:

i. **1912:** Massive cadmium poisoning from mining companies in Japan caused a disease known as itai-itai. The company was successfully sued for damage.

ii. **1956:** methyl mercury was released in the industrial wastewater from the Chisso Corporation's chemical factory causing **Minamata disease** sometimes referred to **as Chisso-Minamata disease** a neurological syndrome(1932 to 1968).

iii. **1965: Niigata Minamata disease** caused by discharge of methyl mercury from Niigata Prefecture by Showa Denko Company.

iv. **1969: The Cuyahoga River** is famous for having been so polluted that it **"caught fire"** in 1969. Oil and debris burned in the river. The event helped to spur the environmental movement in the US

Oil spills:

i. **1969: Santa Barbara** spills in January and February 1969 in the Santa Barbara Channel, near the city of Santa Barbara in Southern California.

ii. **1978: Amoco Cadiz** spills of 16th March 1978 off the coast of Brittany, France

iii. **1989:** Exxon Valdez in Alaska, 1989

iv. **1991: Gulf- Kuwait** oil spills of 1991 that was caused by Iraqi forces when withdrawing from Kuwait

v. **2010: Deepwater Horizon** in the Gulf of Mexico, 2010

vi. **2019:** Ship ran aground **Solomon's Island** 5th February 2019 causing oil spill

Land pollution:

i. **1978-2004:** Love Canal is a neighbourhood within Niagara Falls, New York. Became a dumpsite in 1920s. When site was later inhabited a massive environmental pollution occurred from various chemicals at the site harming the health of hundreds of residents culminating in an extensive Superfund cleanup operation.

ii. **Chernobyl (26 April, 1986),** former USSR spewed radioactive materials into the atmosphere that settled in many parts of Europe polluting soils, water and resources like crops, and dairy products.

Figure 4: Impact of abandoned Jinja smelter on the environment

Looking close at home here in Uganda the impact of poor management of Kilembe mines waste is still very visible almost 41 years from when it was closed (at Kilembe, Kasese and Jinja). When in operation the copper ore was transported from the mines at Kilembe to a smelter at Jinja and the impact at the smelter site is still visible (Fig 4). Kilembe waste still continue to pollute much of the land, water, vegetation and contaminate humans and livestock in the vicinity of the mines (Ssenku et al., 2014; Mwesigye et al., 2014) because of the tailings dumps and mines drains.

Kilembe mines was opened 1950 by the Canadian firms Frosbisher Ltd and Ventures Ltd

Pollution of Kasese Town area by the Kilembe mine's stockpile extended to Lake George (Owor et al., 2007; Ssenku et al., 2014) and is now being mitigated by Kasese Cobalt Company Ltd- KCCL. The company KCCL was established in 1992 to recover cobalt metal from the stockpile that is a cobalt-rich concentrate called pyrite. KCCL used bioleaching process to recover cobalt from the wastes. The KCCL project has scored positive impact in the immediate surrounding areaby removing the threat of acid water runoff and contamination ofcritical ecosystems (wetlands and water) of Lake George and Queen Elizabeth National Park.

Other disasters in Uganda include ***landslides*** common on the slopes of Mt. Elgon due to degraded mountain slopes, ***droughts*** in the northeast and southwest of the country and ***floods that*** have been experienced in the Teso and Kasese areas and also in urban areas like Kampala city attributed to climate change and poor land use.

Globally the most recent disasters have occurred in; Brazil on 25th January 2019, where a mine dam collapsed and released tailings killing one hundred and forty-two people and 194 could not be accounted for (Brumadinho in Minas Gerais state); in Mozambique and Zimbabwe over 700 people perished with some missing from ***cyclone Idai,*** which was closely followed by ***cyclone Kenneth***. Large area of land was flooded and the risk of diseases was immense. It is estimated that about a year worth of crops is lost and this will definitely cause famine in this area.

The anthropogenic and natural adverse impacts on the environment therefore caused the need for a science that would be able to assess, analyse and understand better, the natural and built environment and how they respond to human activities. As described above this was a gradual process that was accelerated by available information and evidence on unacceptable impacts on natural systems and humans. Environmental science therefore evolved in this way as a response to the necessity to have in place a systematic way of avoiding and or mitigating the adverse impacts on the environment. The section hereafter discusses the response by scientists to adverse impacts of human activities and the development of environmental science

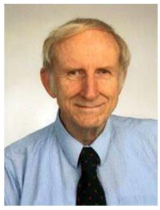
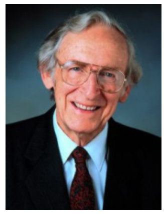
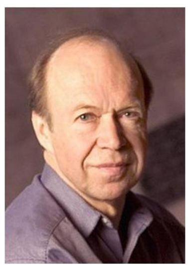
1.2 Response To Environmental Problems By Contemporary Scientists

Environmental disasters that were harming humans and degrading the environment helped increase the visibility of environmental issues that required better understanding. Whereas ecology traditionally looked at interactions within the natural systems (ecosystems), human influence and their effects began to be apparent within ecosystems. It is the interaction of humans with the natural world that moved scientists a step further in the investigation and understanding of human surroundings and the interactions therein, thus **environmental science**.

The way people including some politicians viewed human roles in both preservation and destruction of the world only changed when it became clear that humans are polluting the air, water and soil/land. Recent and more progressive history of environmental concern were from the 1960s and were mainly in response to the impact of rapid human developments in agriculture, industries and infrastructure to support the population explosion of the 60s. During this period people became more aware through information from books and newspapers. The book '***Silent Spring***' by **Rachel Carson in 1962** alerted the world on the danger associated with uncontrolled industrial development.

Rachel Carson1907-1964

Other first rate individuals and scientists who in the previous and current century contributed to the transformation of human thinking towards the environment and its conservation are;

The Odum brothers; ***Howard Thomas Odum (1924 – 2002)*** was an ecologist who is known for his pioneering work on ecology and the understanding of thermodynamics of ecosystems. While ***Eugene Pleasants Odum (1913-2002)*** is known for his pioneering works on ecosystem ecology. The brothers wrote the popular ecology textbook, Fundamentals ***of Ecology.***	  H.T Odum E.P Odum
Wangari Maathai (1940-2011) was an activist and environmentalist in Kenya. Her environmental movement alerted many in East Africa, Africa and the world about the unabated degradation of the environment in Kenya and Africa. Although not very popular with politicians, her movement caused change in the way we view, understand and value the environment and its interaction with humans.	 Dr. Wangari Maathai
Jerome Nriagu is Nigerian born and now in the US. He is an internationally recognized authority and is among the most cited scientists in the field of environmental studies and ecology. He studied at Ibadan in Nigeria and the USA. Now Professor Emeritus in the USA. He is particularly a prolific writer on environmental pollution.	 Prof. Jerome Nriagu
George Tchobanoglous (1935 --) is an American who devoted his professional career to teaching ***courses on water and wastewater treatment and solid waste management***. His contributions have enabled scholars to understand better the dynamics in the environment and how to eliminate or minimise pollution in a systematic manner. An Environmental Engineer with immense contributions to Environmental Science literature.	 Prof. G. Tchobanoglous
Dr. James Hansen is known for his work in climatology and creating awareness on global warming. One of the initial scientists to articulate issues on climate change. Climate change is now affecting almost all aspect of environmental management because all renewable natural resources are directly or indirectly affected by climate variation.	 Dr. James Hansen

The above are some of the scientists that contributed to a better understanding of nature, the environment, human impacts and therefore environmental science. ***By its nature Environmental Science demands for Environmental Scientists to have a broad knowledge or understanding and appreciation of the different disciples mentioned earlier with flexibility.***

Environmental scientists therefore are professionals who work on the understanding of natural and human induced processes, evaluating them in terms of impacts on the natural systems, manmade systems and society at local, regional and global scales. **Environmental issues almost always include an interaction of physical, chemical, and biological processes.**

1.3 Environmental Flows and Storages- Basic Laws of Science

To the Environmental Scientist, knowledge of the ***flows, storages and transformations of Energy and Matter*** of biological, chemical and physical elements (of a system) is critical for understanding all systems, that provide information for planning and their management. The fundamental laws of science should therefore be understood. Examples of such laws are: **1) Total amount of energy and matter is constant (Fig. 5);**

- The **law of conservation of mass** states that the ***total amount of mass remains constant in an isolated system*** in spite of any physical or chemical changes that may take place
- First Law of Thermodynamics - **law of conservation of energy** states that ***energy can be converted in form, but not created or destroyed***

The law of conservation of mass was first described by ***Antoine Lavoisier in 1789*** as a fundamental principle of physics in 1789.

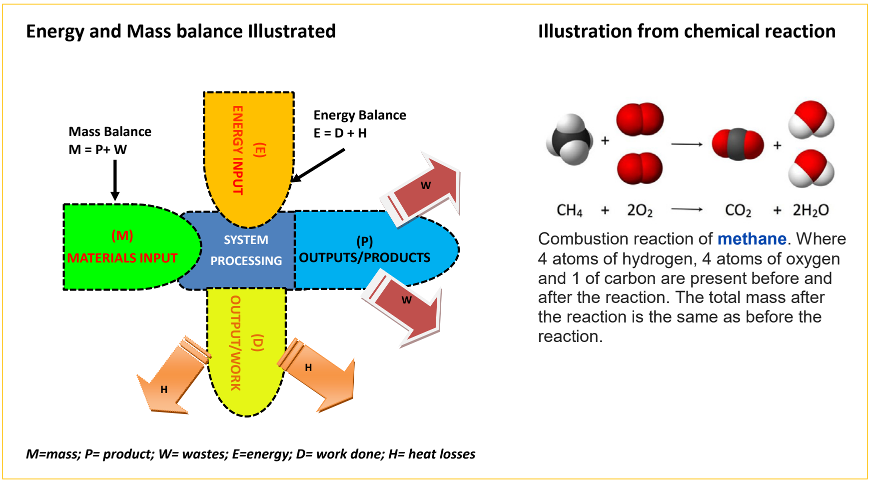
The energy equation explaining the first law of thermodynamics is provided in Equation 1 that relates it to heat and work done.

$$\Delta E = Q + W$$

Equation 1: Energy- Heat-Work

Were; E is internal energy; W is work and Q is heat

Figure 5: Illustration of the balance of energy and matter



This law was later ***amended by Einstein*** in the law of conservation of mass-energy, which describes the fact that ***the total mass and energy in a system remain constant*** (Equation 2). Mass and energy are closely related; when you increase energy of an object you also increase its mass and vice versa.

$$E = mc^2$$

Equation 2: Mass-Energy Relationship

Where; E is energy of a physical system; m is mass and C is speed of light.

The science laws on matter and energy are most fundamental in the investigation, understanding and planning for management of systems- nothing is created and nothing is lost; systems tend towards the conserved status that is most stable or balanced- it is a dynamic equilibrium; however no system is perfectly balanced. Positive and negative feedbacks control and sustain the equilibrium in systems. Environmental scientists therefore bring a systems approach to the analysis of environmental problems. In the understanding, assessment or analysis of systems Environmental Scientists apply this concept of dynamic equilibrium (towards conserved status). By doing so, the scientists reinforce the feedback mechanisms and strengthen conservation. A great deal is being done now by Environmental Scientists and more still must be done to address the current world environmental problems and also be able to make predictions or forecasts more accurately for appropriate planning and management actions.

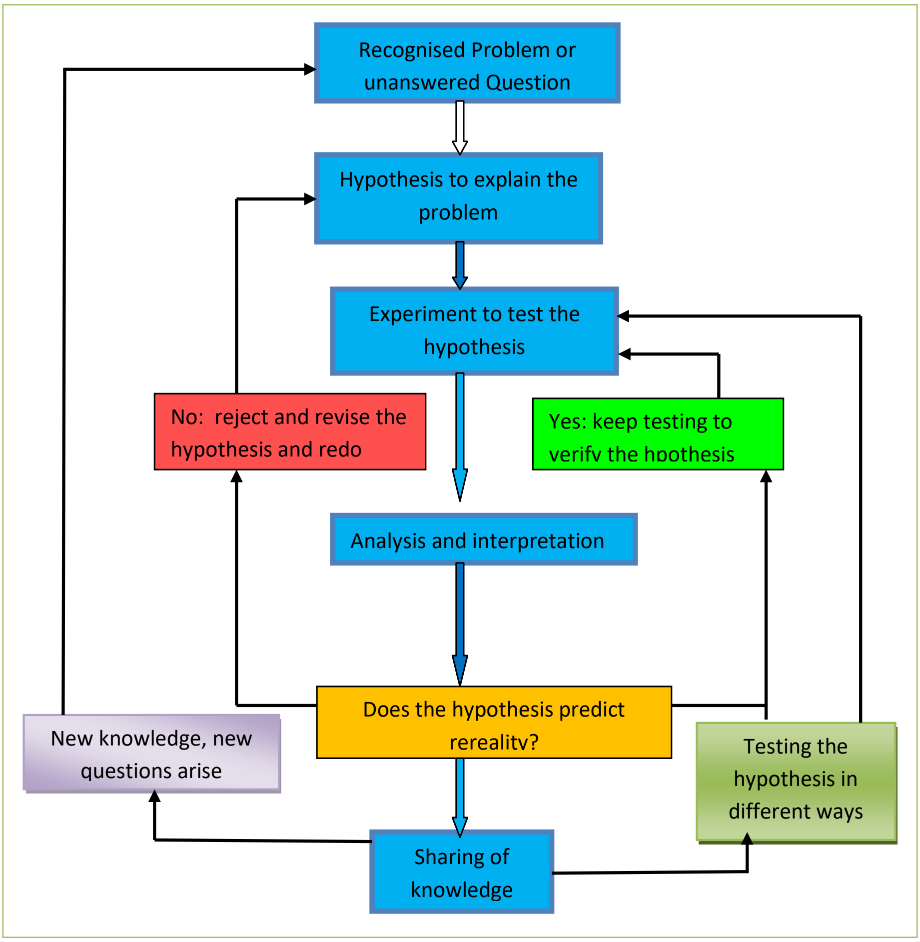
Taking a systems approach enables Environmental Scientists to understand how human activities are **impacting environmental parameters (e.g. Temperature, TOC, CO_2, BOD, COD, land cover, soils, O_3, pH, N, P**) and mitigate the impacts on the environment. Environmental Scientists like in all other sciences ***collect objective data by observation***

or experiments and then analyse and interpret them and conclusions are inferred from the data. The conclusions must be ***as objective as possible and not based on faith, emotion or intuition***. The process of scientific investigation is summarised by Figure 6.

Scientific problems can be addressed in five different stages. It is started by gathering data or information. Here the problem is first defined followed by data collection and experiments or performing simulations. The second stage involves risk analysis that evaluates the potential effects of interventions. ***Public education and involvement is important to obtain consensus and also to have a more informed position as regards alternatives positions on available management alternatives.*** The public are important because of **local knowledge and local needs.** In many cases ***political actions take place because of purely economic, social or political considerations rather than on scientific evidence***. Finally long-term evaluation takes place to monitor if the environmental problems are being solved and to improve on the initial assessment or modelling (Raven et al., 2010).

The isolated operation of the traditional science subjects and highly defined direction or focus caused inadequacies in the assessment and analysis of the environment, impacts and possible solutions of mitigation. The realisation by scholars and activists some of whom are mentioned above that development in industries, infrastructure, science, etc have associated adverse impacts initiated the search for ways of understanding and solving problems. This resulted in the birth of environmental science that is guided by the concepts and principles of sustainable development. Environmental science guides managers to operate as close as possible to the characteristics of the natural environment where there is no 'waste' and everything is a resource to ensure sustainability. With the fundamental laws of the conservation of energy and matter at the back of our mind we scientists have developed techniques within environmental science based on theories and practice of conserving energy and matter and preventing or minimising wastes. The science that have come out of this to support environmental science are: Cleaner Production (CP), Lean Production (LP), Industrial Ecology (IE), Sustainable consumption and production (SCP), Pollution assessment and analysis, Ecotoxicology, Waste Management, Environment and Social Impact Assessment (ESIA), Environmental Audits (EA).

Figure 6: Scientific approach to research



(Adopted with modification from Raven et al., 2010)

The five stages are ideal in the process that can be summarised by the Deming cycle of Plan, Do, Check, Act (PDCA). This is a cycle of continuous improvement at each complete turn of the project or research cycle when a self-assessment is done to see gaps that can be addressed and successes scored are strengthened. However in real life sometimes it is the public that come up with the problem to trigger a discussion before the problem has been clearly assessed. In many cases the real scientific information required is not known until the later stages.

The PDCA is a good way to plan, implement and monitor (conservation) projects for sustainability. It provides the opportunity for detecting inadequacy and achievement of the different aspects or dimensions of environmental conservation project. In doing so the management cycle is repeated during which mitigation is done to correct inadequacies and enhance achievements for better results and sustainability.

1.4 Environmental Monitoring

Environmental management calls for adequate knowledge on the particular ecosystem of focus. The information requirements can only be satisfied by carefully planned systematic monitoring regimes. Monitoring can be done to establish a current situation- baseline monitoring or to determine or detect impacts- impact monitoring. The chemical, physical and biological nature of the environment can be determined at appropriate times to indicate the quality of the environment. A quick and cheap method to assess the quality of the environment that has been used for ages by both scientists and communities is the use of bioindicators. ***Bioindicators*** are living organisms, plants and animals found in ecosystems and are used to screen the health of the natural ecosystems in the environment. Their presence or absence indicate the quality of the environment or what is taking place in the particular ecosystem be it water, soil, forest, wetland or savannah land. The organisms may be used as source for early warning for possible consequence on society.

Environmental Quality Assessment

The effect of pollution or environmental condition on whole organism representative of the environment is *bioindicator*

The effect of pollutants at the physiological , biochemical or molecular characteristics of an organism is *biomarker*

Pollutants effects on organisms can also be tested in laboratory using environmental samples -*(ecotoxicology- NOEC,* EC_{50}, LC_{50})

The history of the use of bio indicators is apparent because through folklores we know that our ancestors were looking for birds, insects, worms, vegetation types, etc to assess land and water quality and for prediction of season's onset and the weather. For example the appearance of certain birds will indicate the beginning of rains or dry seasons

Presence of certain insects, worms and amphibians indicate water quality characteristics and certain plants indicate soil quality or its sogginess. No equipment or chemicals are used here, just the eyes and experience.

Having discussed environmental science and its evolution it is now important to understand more the environment and how it operates. In the next chapter therefore discusses the environment and its dynamics	**Examples of bio-indicators**: **Air Quality**: Lichens, Roses **Water Quality:** Macro-invertebrates, green algae **Soil Quality:** earthworms, insects, other worms **Overall environment Quality**: insects, birds, plants, diversity, etc.

CHAPTER 2:

THE ENVIRONMENT AND ITS DYNAMICS

2.1 The Environment

In most of the countryside where nature abounds, the atmosphere is welcoming with freshness and beauty that radiates the comfort of life. Herein the surroundings and the elements interact naturally and the air is fresh, the waters are soothing and the land is supportive, all of which are usually still ***able to provide adequate services***. These conditions however no longer apply to some rural areas of the world, including our own in Uganda. In urban areas, the ***'natural services'*** abundant in rural areas are dwindling fast and being replaced by human creations ***(artificial services).*** As a result the inhabitants have to use artificial means to come anywhere close to the rural experiences and also have to ***pay for these services in hard cash.*** The narrative here is about the ***'environment'***, for some human being, organism or something. The situation, experience or occurrence in these environments can be **awfully different**.

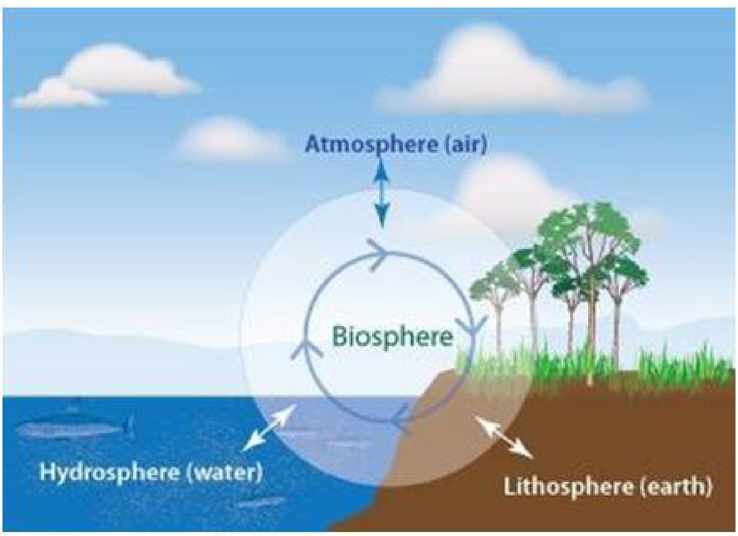
The **quest for better lifestyles** whereby rapid urbanisation, large scale mechanized agriculture, industrialisation, expansion of transport systems, mining and ores processing and the use of complex machines all have led to ***discernible serious consequences on the environment***. Rapid socioeconomic transformations together with exponential population growth in the last century resulted in undue pressure on earth and its resources. This has caused ***undesirable impacts***, which include ***natural resources overexploitation, degradation, pollution and disasters in some cases.*** It is therefore our noble responsibility to see that these trends are halted and reversed. *This writing therefore will explore how the traditional sciences responded to this and gradually gave birth to* ***Environmental Science*** *while trying to understand nature more and obtain solutions to the negative impacts of society transformations for a better future.* Before proceeding further, we need to have a common understanding of what the term **'environment'** denotes, and this is explained hereafter.

> Instinctively we would prefer a world of plenty where supplies are unlimited and we just enjoy the services- 'the cornucopia'.

A satisfactory definition should lead to a common understanding of what the ***'environment'*** is and also as to its attributes and worth, which leads to shared important and lasting beliefs about what is good or bad for the environment. In other words a common understanding would leads to ***shared values***. Knowledge of the term ***'environment'*** is essential for the critical understanding of where we were, are now and would probably be in the near future. I will now proceed to define the term **'Environment'; *'It is the surrounding, object, circumstances, all external conditions, both biotic and abiotic that affects a person or community and his/their properties, and other organisms or groups of organisms within'*.** With this definition it is apparent that ***everything with interactions between and among themselves forms an environment within a certain defined boundary.*** This definition also leads us to understand that environment ***is our basic life support system.*** Every element within the environment is like a biological cell, which is the functional individual unit of life, but coherently connected to form organised higher level of functions that is for the whole. Just as organs and organisms (individuals) are formed by a unique combinations of different kinds of cells, though similar are unique in their own rights. The environment is also made of different elements in various kinds of combinations and arrangements that give rise to unique **habitats and ecosystems**; **water, air, soil/lithosphere** (Fig 7).

We obtain all our requirements from the environment; that is the air we breathe, the water we drink, the land we use for food (that we eat) production and other socio-economic activities. It is clear that we also influence the environment by our activities, outputs and transformations that may be good or bad and create conditions desirable or undesirable, such as conservation activities, harvesting of resources, disposal of wastes, and modification of water courses and mining of ores. The environment by its nature also influences the distribution of organisms on earth. Life forms stay (**exist**) where they have adjusted best **(adaptation)** comfortably.

Figure 7: The Biosphere concept displaying ecosystems



(Source: https://www.quora.com/)

Having known what the environment is, we can now proceed to the nature of the planet earth as regards its ability to sustain life forms together with the non living elements.

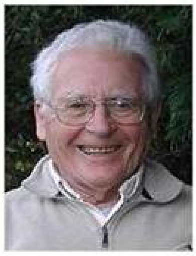
2.2 The Earth And Its Naturally Balanced Environment

Earth's dynamics is driven by ***energy mainly from the sun.*** The sun's energy heats up the atmosphere, water and land and without it the whole world would be frozen solid and supports no life. This energy is temporarily ***trapped by CO_2 and the other GHGs in the atmosphere that release it gently to us on earth.*** It is this controlled energy release that is taken up by green plants (autotrophs) and used to convert CO_2 and water into energy rich carbon compounds that animals obtain from the plants through consumption. On the other hand fossil fuels (oil, gas, coal, etc) that are used for industrialization, release the energy (to do work) that was trapped long ago by photosynthetic plants and when they burn they release carbon to the environment affecting climate. ***The earth's existence and wellbeing revolves around energy, plants and animals, termed as 'resources'***. Later on we shall see that environmental dynamics are determined by these resources and climate.

The Earth is just a remarkable place for supporting life. ***So we are in the right place at the right time, selected and adjusted over time with our biotic neighbours and non-biotic surroundings.*** Imagine if we were slightly away from the sun the earth would freeze and life would disappear and if we were a bit closer, all the water on earth would evaporate, living things would die of desiccation or burn. ***The earth is therefore in just the right position in the planetary system.*** The earth's atmosphere consists of the essential gases to support life (O_2 and CO_2), moderate radiation (energy), transmit just the right amount of light, and allows darkness once a day. Water is about three quarters of the earth and it is within and around living things to support and moderate life, it controls weather and climate, physical and chemical transformation, it is the super liquid from the atomic to molecular levels. Land has the soils that support life and food resources, the rocks weather to form the soils, the mountains control weather and erode to give the soils and are water reservoirs. The earth's natural resources like trees, ponds, lakes, rivers, caves, ground water, wetlands and forests provide homes and resources for a vast variety of organisms. So everything living and non- living are together in a connected dynamic way that is stable and self- perpetuation **(Gaia paradigm)**.

The ***Gaia hypothesis also known as the Gaia theory or the Gaia principle***, proposes that ***living organisms interact with their inorganic surroundings on Earth to form a synergistic and self-regulating, complex system that helps to maintain and perpetuate the conditions for life on the planet*** (Lovelock, 2009). Gaia theory was proposed by a chemist (with PhD in medicine) ***Prof. James Lovelock in the 1960s*** and supported by an Evolutionary Scientist ***Dr. Lynn Margulis*** in the 1970s.

The Gaia paradigm describes the ***tendency by nature to balance itself by self regulation where living and non-living parts of the Earth form a complex interacting system that can be akin to a single organism.*** This is akin to '***homeostasis'*** in living organisms and ***'cybernetics'*** of ecosystems (Fig 8).

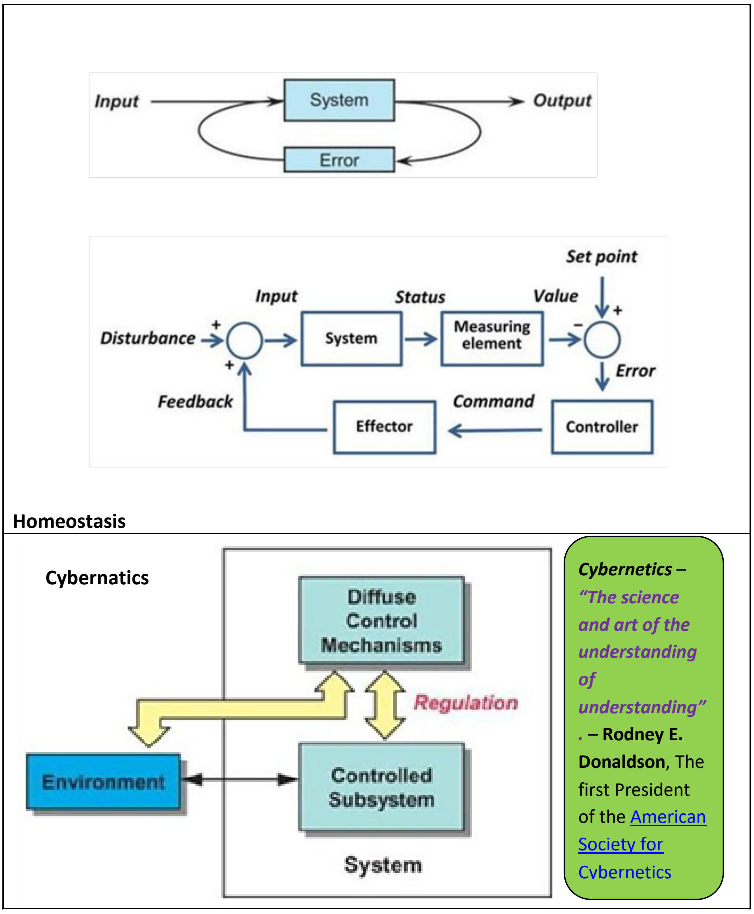


Prof. James Lovelock

Dr. Lynn Margulis

Cybernetics (Fr. Kybernetes= pilot or governor) is the ***self-maintenance and self-regulating capability of ecosystems*** as are their component populations and organisms (Odum, 1971), which have very important applications in ecology since humans tend to disrupt natural controls and replace it with artificial ones. ***Cybernetics*** is the science of ***communication and control o***f systems. ***Homeostasis (homeo=same; stasis=standing)*** is the tendency for biological systems to resist change and maintain a state of equilibrium (Odum, 1971).

Figure 8: Homeostasis and system control - cybernetics

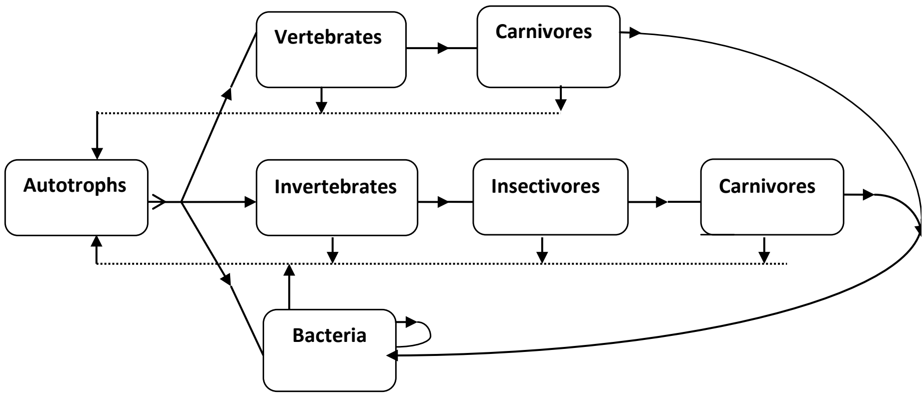


(Source: https://en.wikipedia.org/wiki/Setpoint_ (control system))

Homeostasis is the natural cycle of matter and energy in biological systems with inputs and outputs that are ***continuous and sustained by self -adjusting systems;*** while **cybernetics** explains the control and communication in ecological systems responding to environmental signals as illustrated by terrestrial ecosystem (Fig 8). Figure 9 illustrates the adjusting forces in ecosystems that keep a balance between organisms in the food chain is another example of feedback mechanisms illustrating the ***inherent understanding (cybernetics) of self-adjustments within systems.***

The ***Gaia theory widens our view of the world as the 'living earth' that we are part of and should not shift the balance to points non conducive to us or for ecosystems health.*** As Martin Ogle (2010) said ***"Gaia helps us transcend misleading divides between disciplines, as well as transcend any false dichotomy between humans and nature"*** 'Once each one of us grasps the scientific base, call it metaphor of Gaia as a whole with its physiology, our view and practice are bound to change profoundly with ways to solve what now seems unsolvable' (Sahtouris, E, 1989). ***The thinking about the flows and storages tending to balance the status quo of matter and energy and efforts to sustain the equilibrium is what environmental science would emerge to be all about as we shall consider later in this lecture.***

Figure 9: The feedback system in terrestrial ecosystem



It can be observed that we are able to live ***in relative comfort and harmony with everything*** around us, biological and non-biological because of the ***overall energy and materials storage and flows tending towards a balanced state.*** *Can you imagine a world without the 'balancing forces'? We would probably be in disarray, floating about aimlessly, some would probably explode, while others will shrink, dissolve or sublime to 'nothingness'! It is not to be.* The laws of science on conservation of matter and energy do not agree with **'nothingness'** because you *cannot create or destroy either matter or energy*. So there is always a tendency to prevent excessive decrease or increase within ***transformations, transfers and storages. This is a 'dynamic equilibrium'.*** For Scientists knowing the fundamentals of science and thinking beyond the basics is enough for the understanding matter, energy and their communication mechanisms that control the dynamics in the environment. The environment or any other system **is not perfectly balanced** but tends to **correct any imbalance** by preventing excessive shifts away from the ***balanced position (equilibrium).***

The progression of **planet earth** to support life forms has taken over 3.8 million years to its current state and we the humans are the greatest agents of environmental change. Human beings are **altering (disrupting)** the environment at a rapid rate through exponential population increase, destructive resources abstraction, resources overuse, resources degradation and pollution of resources, despite these **resources being finite**. Air, water and soils are deteriorating, habitats are being lost and species eradicated.

Climate change is directly linked to the disruptive human activities. We tend to disrupt natural balances by our activities that are not adequately informed ***causing the adverse impacts*** we are seeing nowadays.

We as ***humans*** are on top of it all; be it the food-chain, intellectual/ intelligence power, mobility and so on and also have the ability to **deliberately manipulate and transform our environment.** However it is worth noting that the decision on whatever we do is influenced by internal and external factors that will ultimately affect the environment positively or negatively, directly or indirectly. Having now seen how the natural system has evolved to be stable with inbuilt mechanisms and how we as humans are the greatest threat to this balance we can now look at how we have been interacting with the other earth's resources.

CHAPTER 3:

HUMANS, RESOURCES AND THE ENVIRONMENT

3.1 Environmental Interactions

Humans interact with the environment that they live in (urban or rural) in various ways that is determined by population, resources availability and level of affluence. In this chapter, I will therefore introduce the major environmental problems linked to humans and explore ways to address them for sustainability. I will start by presenting the unprecedented increase in human population from the last century to now. From the 1960s to date human population has risen from about 3 billion people (Raven et al., 2010) to about 7.7 billion people in 2019 (*www.worldometers.info/world-population)*, which is more than double in just in 58 years.

Estimates indicate that by the end of the 21st century, we would be much beyond 10 billion people in this world. The rapid population increase is displayed in Table 1. With increasing populations the quality of life is worsening at an alarming rate due to heightening levels of competition for resource and governments inability to cope with the concomitant increase in demands for services by people.	God blessed them and said to them, "Be fruitful and increase in number; fill the earth and subdue it. Rule over the fish in the sea and the birds in the sky and over every living creature that moves on the ground." (Genesis 1:28).

Information now indicates that much of the world is experiencing extreme poverty, especially in Africa and some parts of Asia. Of the world's population 55.3% is urban. However much of the urban communities do not receive the necessary services and are in slums, Fig. 10. Urban slum communities have meagre resources and live in abject poverty. Slums therefore are extreme poverty areas in most countries of the world with communities at high risks of diseases, food insecurity and lack of basic survival requirements.

Figure 10: Katanga Slums of Kampala

The increasing world population would decimate the earth's resources almost irreversible if it continues unchecked. This is because the world's resources base are not increasing but instead decreasing due to the existing expanding demands.

Table 1: Trend in world population

Year	World Population	Yearly Change	Net Change	Density (P/Km²)	Urban Pop	Urban Pop %
2019	**7,714,576,923**	1.07 %	81,757,598	52	4,262,736,048	55 %
2018	**7,632,819,325**	1.09 %	82,557,224	51	4,186,975,665	55 %
2017	**7,550,262,101**	1.12 %	83,297,821	51	4,110,778,369	54 %
2016	**7,466,964,280**	1.14 %	83,955,460	50	4,034,193,153	54 %
2015	**7,383,008,820**	1.16 %	84,555,787	50	3,957,285,013	54 %
2014	7,298,453,033	1.18 %	85,026,581	49	3,880,128,255	53 %
2013	**7,213,426,452**	1.20 %	85,249,517	48	3,802,824,481	53 %
2012	**7,128,176,935**	1.21 %	85,168,349	48	3,725,502,442	52 %
2011	**7,043,008,586**	1.22 %	84,839,427	47	3,648,252,270	52 %
2010	**6,958,169,159**	1.23 %	84,428,105	47	3,571,272,167	51 %
2009	**6,873,741,054**	1.24 %	83,969,801	46	3,494,944,744	51 %
2008	**6,789,771,253**	1.24 %	83,352,660	46	3,419,420,251	50 %
2007	**6,706,418,593**	1.25 %	82,570,680	45	3,344,752,515	50 %
2006	**6,623,847,913**	1.25 %	81,688,530	44	3,271,397,980	49 %
2005	**6,542,159,383**	1.25 %	80,788,518	44	3,199,013,076	49 %
2004	**6,461,370,865**	1.25 %	79,961,878	43	3,127,242,628	48 %
2003	**6,381,408,987**	1.26 %	79,259,348	43	3,056,838,839	48 %
2002	**6,302,149,639**	1.27 %	78,737,481	42	2,987,784,981	47 %
2001	**6,223,412,158**	1.28 %	78,405,169	42	2,919,962,139	47 %
2000	**6,145,006,989**	1.29 %	78,139,598	41	2,856,131,072	

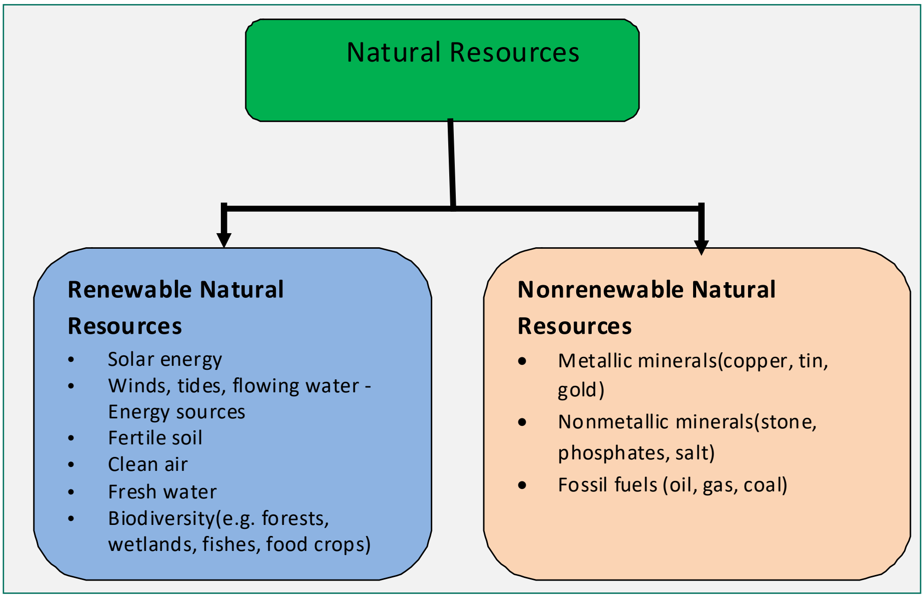
Source: Worldometers (www.Worldometers.info)

The destruction of resources can only be averted by proper planning and management of our environment. Natural resources conservation (sustainable use) and socio-economic improvements through community needs, responsive investments can also help mitigate some of the already known resources degradation. Since our survival as humans is determined by resources availability it is therefore our fundamental role as consumers to ensure that the resources are secure, available now and also for the future. I will now proceed to look at the resources of the earth and human interactions with these resources.

3.2 The Earth's Resources

The earth's resources are of two categories; renewable resources and non-renewable resources (Fig.11). When investigating impacts by humans on natural resources it is important to differentiate natural resources into the two categories for adequate planning (Raven et al., 2010). When the natural resources are subjected to human pressure from abstraction and use the non-renewable resources are replaced on a geological time scale (million years) and therefore their supply diminishes with use (Raven et al, 2010). On the other hand when the renewable resources are subjected to human abstraction they are replaced on a fairly rapid time scale (days to decades). This means the abstraction and use of natural resources have to be systematically planned to allow for sustainability.

Figure 11: Natural Resources



(Adopted from; Raven et al., 2010)

Natural resources support our livelihoods and also satisfy our basic survival requirements directly and indirectly through the services that they provide. We shall now look at natural resources consumption by humans hereafter.

3.3 Resource Consumption

Consumption is the utilization of energy and materials and it is both a social and economic act that gives the consumer a sense of identity and status among peers (Raven et al, 2010). The extent of consumption is related to the nature and size of population. In describing the intensity of consumption we can use overpopulation to describe the situation. Overpopulation may be described as people overpopulation and consumption overpopulation. **In people overpopulation the per capita consumption is not high but combined consumption has significant impact on the environment.** While in **consumption overpopulation the per capita consumption is high**. People overpopulation is typical of developing economies while consumption overpopulation is in developed economies. Less than 20% of the world's population live in highly developed world, while they consume significantly more than half of the world's resources (Table2). On the other hand when looking at the impacts of humans on the environment we find that these highly developed countries generate 75% of the world's pollution and waste (Raven et al., 2010). This is because of the excessive use of resources in the developed world resulting in excessive waste generation. ***Sustainable consumption and production (SCP)*** is a concept that is applied to address over consumption and unclean or wasteful production which, results into wastes and pollution.

Table 2: Highly developed countries percent consumption of world natural resources

Natural resources	% of world resources consumed
Aluminium used	86%
Timber harvested	76%
Energy produced	68%
Meat eaten	61%
Fresh water consumed	42%

Excessive use or poor use on natural resources apart from the direct impact of depletion and degradation also has polluting impact on the environment. During value addition when raw materials are converted to useable and marketed product there are associated by-products and wastes that in some cases are sources of serous pollution.

Communities in the least developed countries (LDCs) depend predominantly on renewable resources (water, forests, fisheries and land) for sustenance. The majority population in such countries are subsistence farmers and their methods of farming have implications on renewable natural resources. LDCs are experiencing rapid population growth that has caused overexploitation of renewable resources. In most cases poor farming methods such as clearing of forests and wetlands for agriculture, cultivating steep slopes, conversion of river banks and lake shores provide short term solutions in terms of crop yields that rapidly decline with time and overuse of land. In most cases such practices put too much pressure on natural resources (e.g. soil, water, vegetation) and do not give them time to regenerate.

Soil fertility in the encroached ecosystems rapidly declines and since subsistence farmers do not have the means for the procurement of agro inputs, they shift to fresh and potentially better land destroying them as well -the **'vicious cycle'**. You therefore find vast areas destroyed (e.g. bare soils) because of human pressure on the renewable resources for food. ***Renewable resources are in reality potentially renewable, therefore they must be used sustainably to allow time to replace or renew themselves.***

Where communal farming is practiced, crop yields are better for sometime because of the starting good soils and the initial enthusiasm. However many such efforts have collapsed and the existing ones are running below expected outputs due to deteriorating soil conditions and poor management. In Uganda such cases can be illustrated by the community irrigated horticulture farm in Nakidet, Moroto (Fig 12) that is now at the verge of collapse. Here few members have literally taken over the whole project at the expense of others and are not managing the project well. Is this an example of the "***Tragedy of the commons"?***

Water is another resource that is lacking among poor communities and where it is available there is low efficiency in its distribution or access to consumers (quality and quantity).

Figure 12: Irrigated vegetable gardens at Nakidet, Moroto Karamoja (right: the author with village leaders in a garden)

Most of the communities of LDCs use water from shallow well, springs, boreholes and open surface water (ponds, lakes, rivers, dams) that in most cases are polluted (Okot-Okumu & Otim, 2015; Nansubuga et al, 2004; Awomeso et al., 2010). Community water sources in most cases are not maintained well exposing the water sources to pollution that makes them unfit for use (Fig. 13). Polluted water cannot be put to use readily so they may become classified as unavailable water. In addition after use water generates wastewater that in many cases is not treated and is discharged into the environment with varying pollution consequences.

The most appropriate water and wastewater treatment technologies are still unaffordable by the LDCs. Water and wastewater treatment is the luxury of urban areas while the rural communities take water directly from the source that are poorly maintained or not maintained at all and in many cases also sharing the water sources with livestock (Fig. 6).

Figure 13: Community water sources in Uganda

Community well in Nabweru

Borehole at Lamit Kitgum

'Protected' spring well in Gangu/ Ndejje

Valley dam shared with livestock Isingiro

In some cases established large scale water projects are not maintained and are managed poorly. Examples include the underutilised water sources like the Adwari dam in Otuke that was rehabilitated by government at a cost of over 1 billion shilling (UGX) for community irrigation of crops and for animal watering, the Lamit dam in Kitgum District near Kitgum Town that is also under utilised and poorly maintained and the valley dams in Karamoja that are in some cases silted and abandoned. Some water project facilities are vandalised by the community like the solar powered water project of Kotido District. These infrastructures are displayed in Figure 14. However many areas in Uganda lack water as is the case in many LDCs.

Looking at national economies it is the developing countries that have their economies often tied to the exploitation of their own natural resources that are usually for export to developed countries. At this juncture it is important to note that most of the developed world (USA, UK, Canada, Spain, Portugal and others) derived their economic growth and development from exploitation of natural resources that were in some cases from Africa, Asia and the Caribbean. Continued economic growth in these highly developed countries is still relying on importation of natural resources from developing countries.

Figure 14: Water projects that have not been optimally utilised

The author at a valley dam- Kotido, Karamoja

Akwera multipurpose dam in Adwari subcounty Otuke District

Vandalised solar panels for Kotido water project

The author with LC 1 members at Lamit water dam-Kitgum

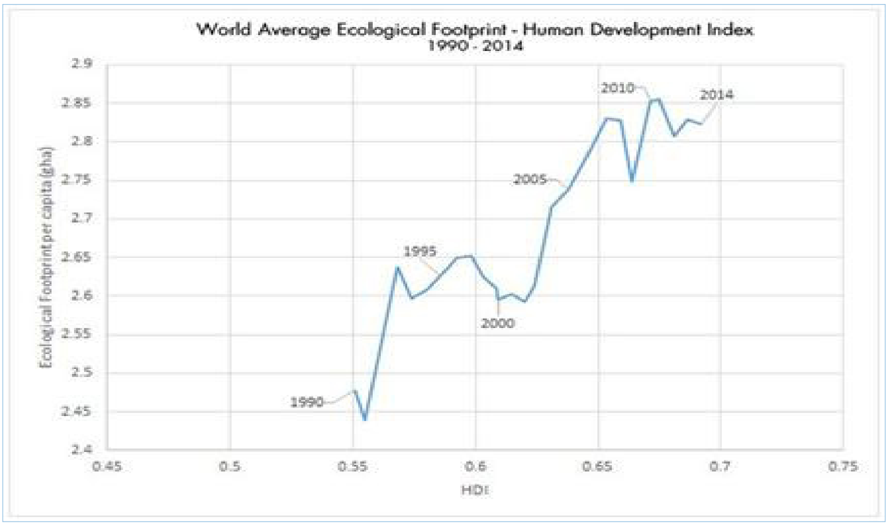
Partnership in natural resources conservation globally is one way that can help to arrest the rapid resources degradation. We shall discuss these efforts in later sections of this lecture. Nevertheless in order to make some sense of all this we need to know how much damage each one of us can do or is doing to the environment and then quantify national or regional values. This brings us to the notion of ***foot print (Ecological footprint).*** This in other words is our estimated demand for resources (pressure on the environment) as individuals, communities, nation, region or the world. Ecological footprint is discussed hereafter.

3.4 Ecological Footprint

To account for impact of human consumption of natural resources and its associated impacts**,** scientists **(Mathis Wackernagel and William Rees** in the early 1990s) formulated the concept of ***ecological footprint (EF).*** Each person has an ecological foot print which is '***a measure of natural resources(land, fresh water and ocean) required continuously to supply that person with water, food, energy, wood, housing, clothing, transportation and waste disposal'.*** More simply, ***it is the amount of the environment necessary to produce the goods and services necessary to support a particular lifestyle*** *(WWF.https://wwf.panda.org/ knowledge_23/2/2019).* Looking at it from the side of resources supply, biocapacity represents the productivityof ecological assets (including cropland, grazing land, forest land, fishing grounds, and built-up land). EF integrates core principles of sustainability and accounting applying them in context of utilisation of earth's resources by humans (Lin et al., 2018). The latest results from the National Footprint Accounts (NFA) 2018 indicate that our EF is ***1.7 Earths, and that the global ecological overshoot continues to grow*** (Lin et al., 2018). ***EF is measured in global hectares (gha).*** The ***1.7 Earths for 2014 resources demands means by 2014 we required 1.7 "Earths" for our sustenance*** or that it takes Earth more than one year and eight months to regenerate what is used in one year. This means that our life-supporting biological resources, such as fisheries, forest resources, rangeland, and agricultural land, are being depleted.

According to Filon Toderoiu (2010), the estimated productive land and water on earth was 11.9 billion hectares (29.41 billion acres) in 2006 and when this area was divided by the human population then each individual would need 1.8 hectares (4.4 acres). The current trend in world ecological footprint is illustrated by Figure 15. Though in fluctuation the footprint is generally in upward trend that is worrying to the sustainability of world resources. In 2018 the global ecological footprint was about 2.8 **hectares (6.9acres)** per person that compared to the **biocapicity of 1.7 global hectares** is an ***ecological overshoot***- this means we have depleted our allotment or resources. These are ***evident around by the destruction of wetlands, forests, lakes, rivers, fisheries and the associated loss of biodiversity.*** Individuals in the developed world like the USA exert ecological footprints nearly 10 times of those in developing countries.

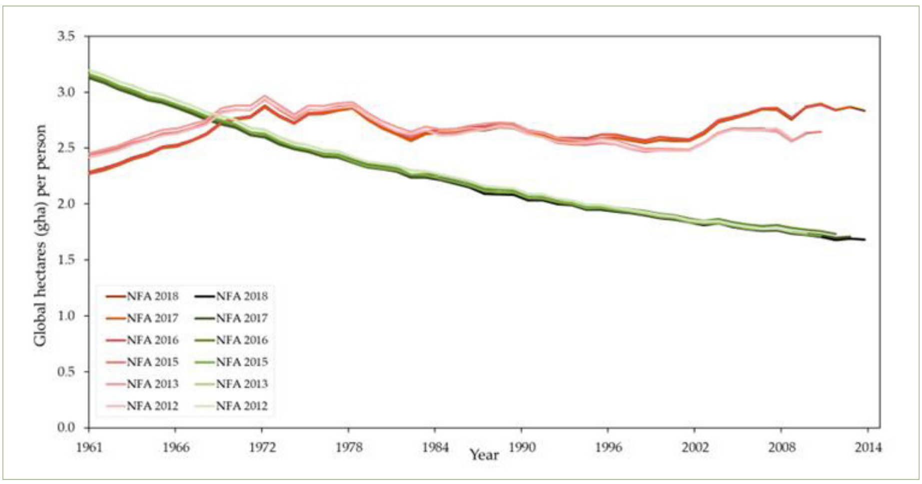
Figure 15: World footprint trend



Source: Global Footprint Network, 2018.

The world ecological footprint is rising while the biocapacity is decreasing as the world population rises. This is illustrated in data collected from 1961 to 2014, where between 1996 and 1972 ecological foot print crossed over and above the world biocapacity and the gap(deficit) has been widening ever since (Fig 16).

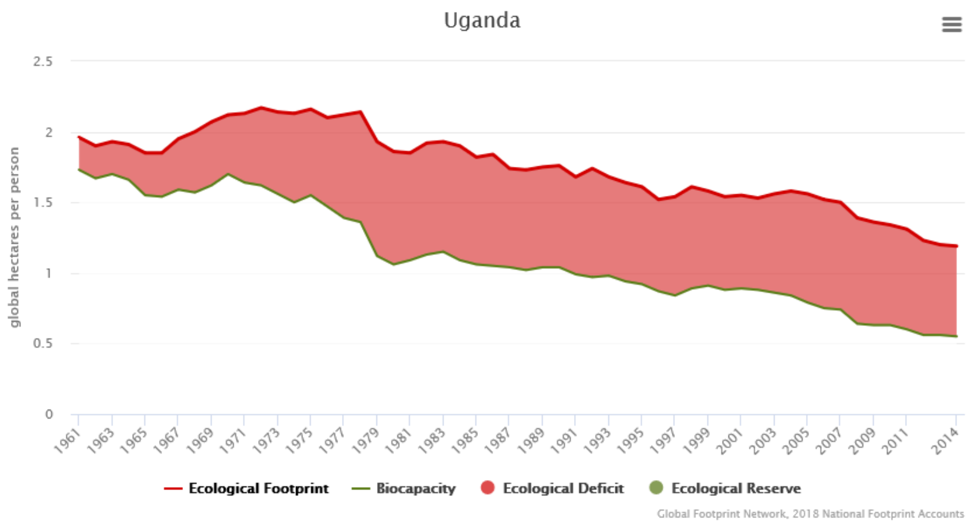
Figure 16: World Ecological Footprint (red) and biocapacity (green) per person from 1961 to 2014.



(Source: Lin et al., 2018)

As we improve our standard of living in the developing countries the living styles change towards a ***more consumer society with higher footprints.*** So the challenge we have is to provide consumers worldwide with less polluting and less consumptive forms of living. The current situation is that the ecological footprints of most countries of the world are over and above capacity that is a clear evidence of deficit in our lifestyles. The Ugandan deficit is displayed in Figure 17.

Figure 17: Uganda footprint vs bio capacity- the offshoot.



Source: http://data.footprintnetwork.org/#/countryTrends?cn=226&type=BCpc,EFCpc

Details of this world consumption patterns can be obtained pictorially on the website: ***Source: http://data.footprintnetwork.org.*** Having already seen how we can estimate our impact on the environment from per capita level up to national and global, we can now turn to how we can evaluate our impacts on the environment to illustrate the relationship. This is done ***mathematically relating our activities to environmental impact***.

3.5 Emergence of scientific description of our impact on the environment

In science we ***use models as a formal statement to describe the behaviour of a system***. The IPAT model, which is sometimes written as I = PAT or I = P x A x T, is an equation that expresses the idea that ***environmental impact (I) is the product of three factors: population (P) - number of people, affluence (A) - a measure of consumption and amounts used per person and technology (T),*** used to obtain resources. Two scientists named ***Ehrlich and Holdren in the early 1970s*** proposed this equation to calculate the impact of humans on the environment. The factors in the relation relate as:

$$I = P \times A \times T$$

Equation 3: The IPAT

This equation shows the mathematical relationship between environmental impacts and the driving forces of the impacts. The IPAT equation is the simplest mathematical expression made to make us understand the multiple causes of environmental impacts. Being very simple it is not able to identify or describe issues at a higher or complex scale, but has assisted our thinking on ways of reducing environmental impacts. However models are usually more complex than this in order to explain greater details in more implicit mathematical relationships. Models are used in environmental science to determine unknown effects of activities and also to make predictions and projections. They are vital tools in environmental science for investigations and analysis.

We now have an idea of how we can impact and are impacting on the environment and also know the basic driving forces of the impacts. We are also aware that we need the resources for survival and our well-being. Therefore we need to find ways to ensure that these resources are available whenever we need them and also ensure that they continue to be there after us since the world does not end with us. We can therefore now proceed to discuss how we can develop sustainably.

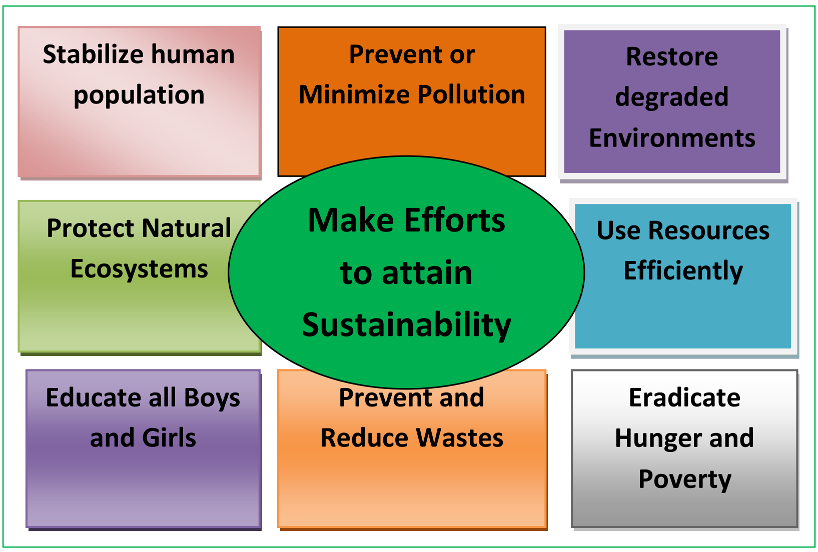
CHAPTER 4:

ENVIRONMENT AND SUSTAINABLE DEVELOPMENT

4.1 Environmental Sustainability

To develop and grow socially and economically we obtain resources or services from the environment and discharge our wastes back to the environment. If we have a well adjusted and controlled system it will maintain and sustain the continuity of interdependence. The real world is however different in that the impacts of human activities are driving the environment into decline. To address this problem the concept in science that is **environmental sustainability** is introduced. ***Sustainability*** *implies that humans can utilise and manage the natural resources indefinitely without environmental decline caused by the stresses imposed on the resources (fertile soil, clean/adequate water and clean air) that maintain life (Raven et al.,2010).* **Sustainability** *implies present human needs are met without endangering the welfare of future generation.* This therefore entails the long-term perspectives to protect humans and natural resources as described by Figure (Fig.18).

Figure 18: Focusing on sustainability



Source: Raven et al., 2010 with modification.

At a glance the display in Figure 18 looks simple when we consider overconsumption, population growth and pollution. But in reality it is not so because there are various interactions between ecological, societal and economic factors that complicate the solutions (Raven et al., 2010). We therefore still do not fully understand how the environment works and how the choices we make affect the environment. Therefore it is not easy to resolve the issues of environmental sustainability. Scientists have to continue working hard with the efforts to understand the environment and its interaction with humans better, to be able to make more informed and better predictions on consequences of human activities. A better understanding of the interactions and their consequences will allow for appropriate measures that can be implemented for safeguards and gradual improvements towards environmental sustainability.

Individual Versus Common Resources Management

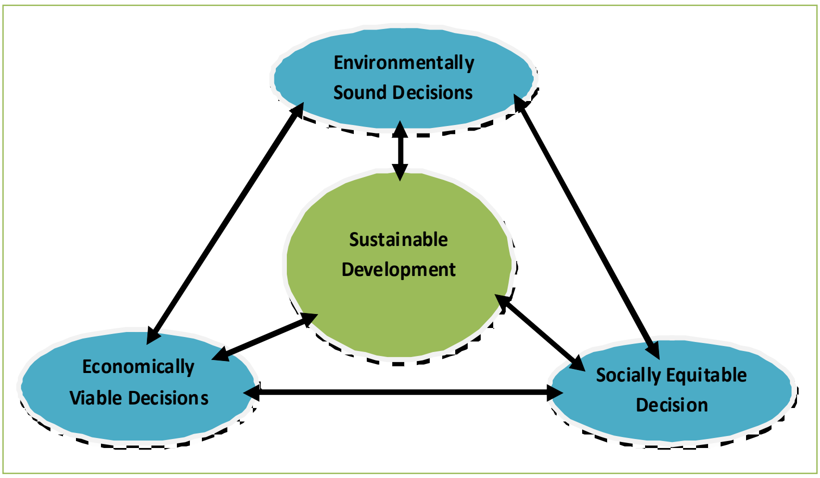
The discussion by scholars about common pool resources management and private or individual management was initiated by ***Garret Hardin*** when he wrote an essay – '***The Tragedy of the Commons'*** where he called to attention the implication of innocent actions on the environment, where common pool resources get degraded. This is attributed to the lack of care of resources in the pool and the struggle to take advantage over others without any efforts to conserve. On the other hand one may think privatisation and government control can regulate resources use better, but this has also been observed not to be effective in many cases. In all cases prevention of degradation can only be achieved through responsible action where everyone is ready to make positive contributions to sustainability.

Dr. Garret Hardin also came up with first law of Human Ecology: ***"We can never do merely one thing. Any intrusion into nature has numerous effects, many of which are unpredictable".*** This therefore identified the need for an integrated approach involving many actions of actors as the best way to go focusing on sustainability efforts illustrated in Figure 18. Hence ***"people, businesses and governments must foster stewardship-shared responsibility for the sustainable care of our planet"*** (Raven et al., 2010). In this direction there have been national and global moves towards ***sustainable development***. At national level most governments have established ***a ministry in charge of the environment*** augmented by ***semiautonomous Environmental Agencies***. These agencies have made significant impacts on natural resources conservation in many countries notwithstanding hitches involving squabbles on roles and responsibilities and being sometimes overruled by politicians. The ***institutional, policy and legal framework*** established by governments do assist in the implementation of sustainability focused actions for a nation.

At the global stage it began in 1972 with the Declaration of the ***United Nations Conference*** on the ***Human Environment***, or ***Stockholm Declaration***. This is the first documented international environmental law to recognize the right to a healthy environment. In this declaration, the nations agreed to accept responsibility for any environmental effects caused by their actions. In 1987, ***'Our Common Future or the Brundtland Report'*** was published by the World Commission on Environment and Development and its targets were ***multilateralism and interdependence*** of nations in the search for a path to sustainable development. The ***Stockholm Declaration*** was therefore re-energised and environmental issues firmly placed on the political agenda. Here issues of pollution, deterioration of the atmosphere and water and organism's diversity and forest decline were at the forefront.

To reinforce global actions the Rio Conference 1992 adopted ***Agenda 21*** that is an action plan on sustainable development in which future economic developments, particularly in developing countries have to reconcile with environmental protection and this was reinforced by ***Johannesburg Declaration on Sustainable Development 2002*** and **Rio 2012**. All these have the **goals of sustainable development** for achieving improved living conditions for all people while maintaining a healthy environment in which natural resources are not overexploited and excessively polluted (Raven et al., 2010). Decisions on environment, social and economic factors interact to promote sustainable development (Fig. 19).

Figure 19: Interacting factors to promote sustainable development



Source: Raven 2010

You will realise that to apply the principles of sustainable development many changes will be required in the fields such ***as population policy, agriculture, industry, economics and energy options.*** In the year 2000, the ***Millennium Development Goals –MDGs (200-2015)*** were declared by the ***UN Millennium Summit*** that was to be realized by 2015. The focus here was on the ***eradication of poverty and hunger; health; primary education, gender equity and empowerment; environmental sustainability and global partnership*** for development. However the levels of achievements in LDCs were mostly below expectations. The MDGS were followed by the Sustainable Development Goals (SDGs), which came into effect in 2016, with a target of 2030, which are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. The ***17 Goals build on the successes of the MDGs, while including new areas such as climate change, economic inequality, innovation, sustainable consumption, peace and justice, among other priorities.*** The goals are interconnected in such a way that the key to success on one will involve tackling issues more commonly associated with another. ***The SDGs work in the spirit of partnership and pragmatism to make the right choices now to improve life, in a sustainable way, for future generations (UNDP-Uganda, 2019).***

The African Union Agenda 2063 to which African countries are committed to implement, is both a vision and a plan to build a more prosperous Africa in 50 years. It is important to note that the agenda for Sustainable Development acknowledges the importance of the AU Agenda 2063. Uganda has developed its 2015/16–2019/20 national development plan (NDPII) in line with the SDGs and the draft NDPIII is under consideration. Despite all these good goals of international summits not much has been achieved in solving environmental problems or improving the quality of life of the poor. It is common practice that most governments are now more focused on challenges such as terrorism, global tensions, politics and the army despite the increasing scientific warnings on issues such as climate change, natural resources degradation and pollution. Some governments however have made significant progress through stringent environmental laws on pollution, fuel/energy options and ecosystems protection. The World Bank and African development Bank have also invested well in sustainable development projects in African countries. In most cases environmental laws are in place and projects undergo ESIA and EA but it is the implementation of the laws and other regulatory tools that are lacking. Environmental degradation therefore continues unabated posing health risks and impairment of smooth socioeconomic development

National and global governance of the environment are informed by science and despite the efforts elaborated here, nations and the world as a whole still experience degradation from human activities. Cognisant of the foul and degrading effects on the environment by human activities, the efforts to manage the environment has evolved through the years using science disciplines as the fundamental instrument. From these scientific disciplines '**Environmental Science**' *has emerged as unique science and is now playing a central and integrating role for investigating, understanding, planning and implementing appropriate environmental management actions*. The development of **Environmental Science** through capacity building, research and systematic data acquisition and database management are vital for the achievement of sustainable development. The next chapter therefore will take us through the understanding of **Environmental Science Research**.

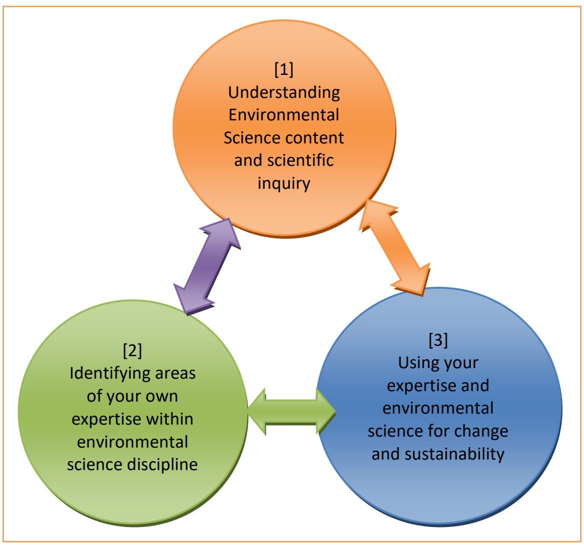
CHAPTER 5:

ENVIRONMENTAL SCIENCE RESEARCH

5.1 Environmental Research

Environmental research is from the microscopic levels where the existence of micro - atomic to particles (nano- and micro-) that are biological, chemical or physical in nature are investigated including their distributions, interrelationships, activity, speciation and stability in the environment to the macro levels were individuals, communities and ecosystems are studied. At the micro levels the impacts of these particles on others of the same kind, on others of different kinds and on environmental quality in general are also important and as of how they move up the food chain concomitant with their effects along the food chain. Scientific research interests are from the molecular level to individual organisms, to organisms associations and then to communities and ecosystems. The main aim is usually to understand how these elements exist and behave in the environment. Environmental scientists concerns are mainly with the delicate balance in the environment where resources have to be shared in a manner **'suitable'** to all without tipping the balance in one direction or the other. Environmental scientists therefore do studies applying their professional techniques usually reinforced by experience of working with other professions to better understand and plan adequately for mitigation. This situation is illustrated by Figure 20.

Figure 20: Working with Environmental Science to Cause Change



Environmental scientist therefore have to understand the interdisciplinary nature of their profession in order to appreciate other people's professions and be able to work with them applying a **holistic approach** to scientific inquiry and obtain good results that can cause **change for sustainable development**. Environmental Scientists usually study the impacts of natural and anthropogenic elements and of human activities on **habitats and ecosystems: water, air, soil/lithosphere**. At the same time Environmental Scientists also do research on methods or techniques that critically address anthropogenic impacts on the environment. The methods being researched on currently tends to mimic **the *natural ecological processes (e.g. filtration, biotransformation, decomposition, scavenging, counter current flow, coagulation, precipitation, suspended matter settling and so on) of self-purification and ecosystem stabilization***. This is because scientists already know that it is the natural systems that are most stable in their structure and functions and so ***the closer one can get to replicating them the more efficient, effective, stable and balanced system you will get.*** This also moves you closer to sustainable systems. These are clearly evident in the research and ***modern practice in water and wastewater treatment, solid waste treatment, flue gas cleaning and in the concepts of Industrial Ecology (IE), Cleaner Production (CP), Lean Production (LP), and Circular Economy (CE).***

It is against this background that I have developed as an **Environmental scientist** based on my university training in **Biochemistry, Chemistry, Environmental Science and Technology to apply my skills in environmental assessment and analysis** in different systems; **water, waste management, air quality, pollution assessmen**t and so on while working with professionals of various expertise. I will now proceed to present my research contributions in Environmental Science.

5.2 My Research Contribution

My journey in Environmental science was set off as an undergraduate at the University of Ghana, Legon in Accra studying Biochemistry and Chemistry. Here the foundation for understanding and using **Science** was laid. In my first year as an undergraduate at the university I studied **Chemistry, Botany, Zoology, Physics, Mathematic, Statistics and African Studies as well**. At that time I questioned why I had to do all these courses but it later on became clear to me that this was to lay a firm foundation for the future. Looking at the subjects in my first year at the university, it is apparent that the first six on the list above helped to support and build my understanding, analysis and inference in science. **African studies built a base for my being able to understand the social, economic and cultural** aspects when doing science. In the second year of university we took the courses that we applied for and qualified to do and mine was **Biochemistry and Chemistry**. My final year BSc (Hons) project was on enzymes activity in snails (*Achatina achatina*) (Title: Endopeptidase activity in the snail Achatina *achatina*). The use of inhibitors on enzymes for my Bachelor level research was innocently the turning point in my journey towards environmental science. I therefore focused my research towards ***ecotoxicology*** during both my Postgraduate Diploma and Masters Degree in the Netherlands. My graduate research applied what I learned in the course work subjects of my study of ***Environmental Science and Technology*** at IHE Delft, the Netherlands. The course work and research at IHE Delft prepared me for my teaching carrier, research and students supervision at Makerere University. Based on what I studied in the water resources course at IHE Delft I broadened my research scope to nutrient dynamics in the environment by doing research on Lake Nabugabo where I studied phosphorus dynamics in the lake-wetland system for my PhD at Makerere University, which further strengthened my research and teaching of environmental science. It also made me a competent consultant in many areas of science and environmental management.

My undergraduate and graduate studies background steered my research interests to: water quality, pollution assessment, ecotoxicology, innovations in drinking water treatment, innovations in wastewater treatment and solid waste management. I will now proceed to describe my research contributions in the areas of water quality, water pollution, water and wastewater treatment, ecotoxicology and solid waste management.

The central role of water in *'everything in life* and the ***intriguing properties of water*** is what attracted me to it as an area of research. For ecotoxicology my biochemistry and chemistry background gave me the interest to enquire the mechanisms of behaviour of chemical substances in the environment and what mechanisms they deploy to harm living things in the environment. In the case of wastes I got attracted because most people detest waste not realising that it is unavoidable in life and we are the ones generating it so we should take responsibility. On top of this poor solid waste management is a clear indication of a community or society overall management failure. '*If you see waste littering a place it is an indication of management weakness in that very place'*

5.2.1 Water Research

Water is the wonder substance (chemical) on planet earth. It is virtually everywhere and involved almost in everything that makes life on earth possible.

WATER A NECESSITY

Water is a chemical substance of special characteristics. It is a substance vital in all aspects of life which is attributed to the unique combination and arrangements of hydrogen (H) and oxygen atoms (O) in water (H_2O) making it able to exists as a liquid (water), solid (ice) and gas (vapour) at the same time and place on earth.

At basics we know water despite being ionic is ionic balanced (balance of charge) where the cations are balanced by the anions (***electroneutrality)***. This is very important as regards its properties as a ***'universal solvent'*** and a suitable medium for all forms of biochemistry. The ***electroneutrality*** of water is important to scientists during the analysis of water where you can check on the accuracy and precision of the analyst on samples that you have supplied for analysis or detect severe pollution. Margin of error in the balance accepted is 5% anything more is unacceptable. We know that dilute waters are usually more removed from the position of balance.

The unique properties of water make it a special chemical of life and a medium for most of the natural physico-chemical processes on earth. It is important in biochemical processes, universal solvent, moderates weather conditions and climate, transport medium and chemical reaction medium in biological systems and industrial processes (Table 3).	"If there is magic on this planet, it is contained in water." Loren Eiseley (1907-1977)

Table 3: Properties of Water

Property	Effects and Significance
Excellent solvent	Transport of nutrients and waste products, making biological processes possible in an aqueous medium
Highest dielectric constant of any common liquid	High solubility of ionic substances and their ionization in solution
Higher surface tension than any other liquid	Controlling factor in physiology; governs drop and surface phenomena
Transparent to visible and longer-wavelength fraction of ultraviolet light	Colourless, allowing light required for photosynthesis to reach considerable depths in bodies of water
Maximum density as a liquid at 40C	Ice floats; vertical circulation restricted in stratified bodies of water
Higher heat of evaporation than any other material	Determines transfer of heat and water molecules between the atmosphere and bodies of water
Higher latent heat of fusion than any other liquid except ammonia	Temperature stabilized at the freezing point of water
Higher heat capacity than any other liquid except ammonia	Stabilization of temperatures of organisms and geographical regions

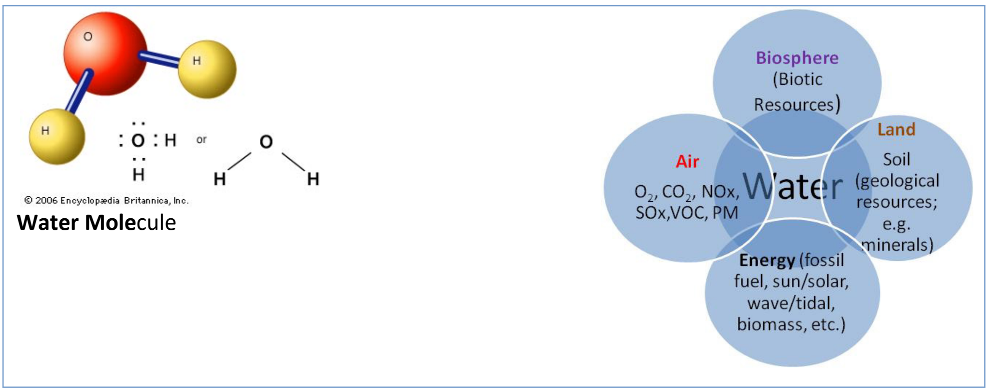
To indicate its paramount importance water is known to have attracted civilisations and human development that started and was sustained around water bodies. Water is the cleansing material for sanitation, cultural rituals and religious rite (e.g. baptism) and for maintaining our dignity. Water plays a central role on planet earth in all living and non living systems to maintain the status quo. To date water is a major element for socioeconomic development, agriculture, industries, health and energy; while at the same time it may be a source of disaster (too much, too little) or conflict.

Water as a resource is central in the provision and sustenance of the earth's systems of biosphere, atmosphere and lithosphere and in energy production (Fig. 21) and despite this freshwater is only 3 % of the total amount of water on earth. Most of the water is in the oceans as salt water that is not readily available for consumptive use by humans. However the ocean waters apart from being home to very high number of different living organisms (many still unknown) has a number of values:

- absorbs most of the atmospheric CO2
- offers recreation opportunities and attracts tourism
- is a major transport avenue
- host of variety of minerals
- is a potential energy sources

The oceans also receive most of the different kind of wastes of from land.

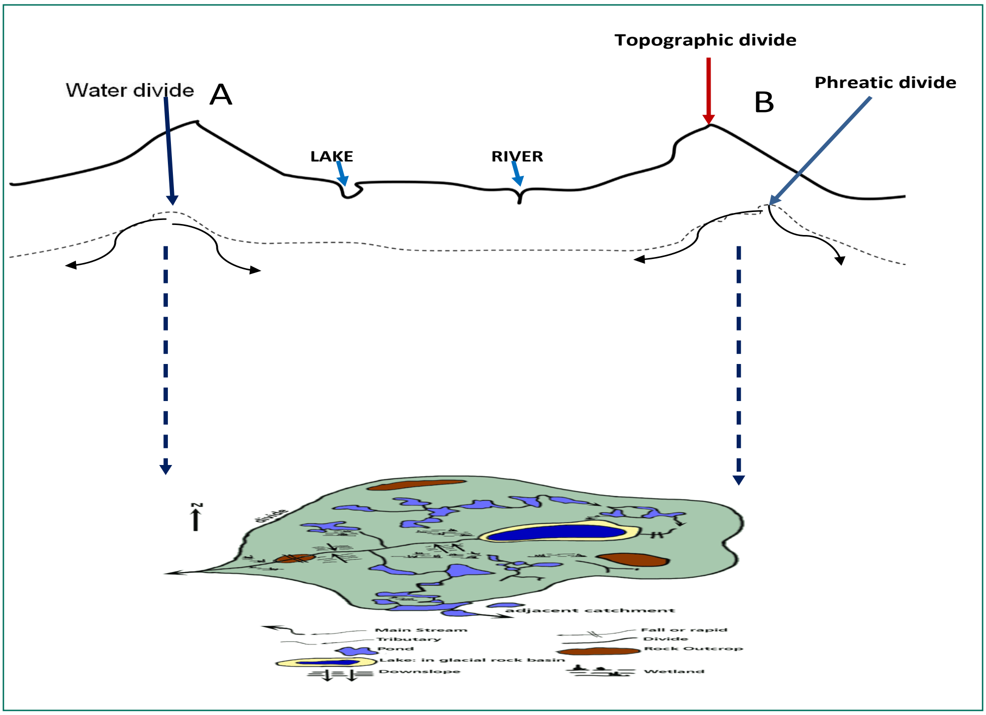
Figure 21: The central role of water in the environment



Since both society and ecosystems depend on water resources for sustenance, the resources have to be reliable, clean and satisfactory for the different uses. The different competing water uses or demands put pressure on the water resources and these are likely to be exacerbated by climate change. Most likely climate change will cause dwindling water supply while demands are increasing. The quality of surface water (rivers, ponds, lakes, etc) and groundwater is naturally determined by the surrounding geology, vegetation and climate. This implies that any imbalance in these factors will have undesired consequences on water resources.

Research levels in water moves from atoms, molecules, the liquid (surface, ground, rain, snow, and ice caps), and the hydrological cycle: uses, management, allocation; IWRM (catchment approach) as pictorially illustrated below (Fig. 22).

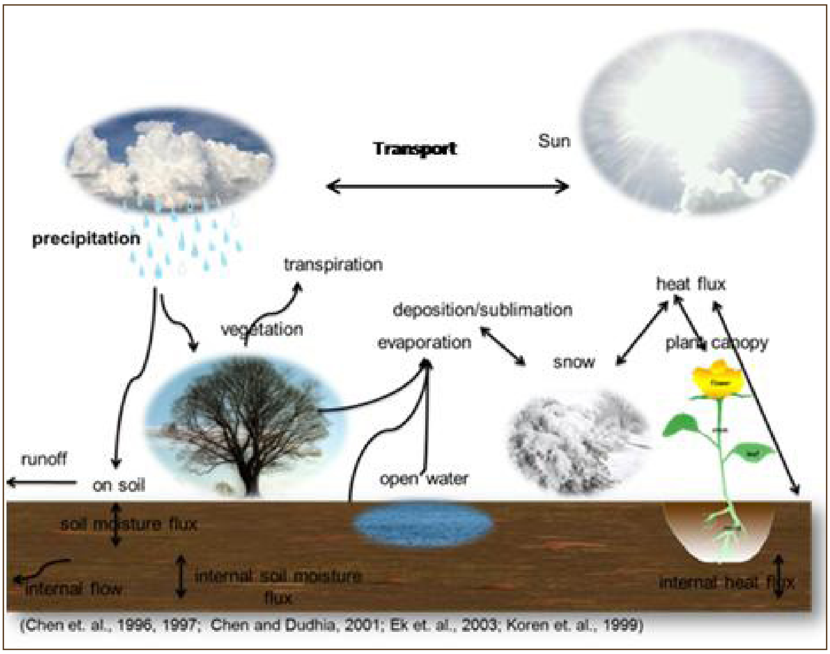
Figure 22: Water management and research based on IWRM principles is holistic



Quality
Quantity
Hydrology
Potential uses:
Domestic, Agriculture, Industry, Energy, Livestock, Wildlife, Recreation & Tourism, Environment/Ecosystems maintenance, Socioeconomic aspects

The existence of water on earth in its various forms (states- liquid, ice and vapour) is maintained, controlled and sustained by the solar driven water cycle termed the hydrological cycle (Fig. 23). The hydrological circle is the primary mechanism for the distribution of water within and between the living and nonliving structures of the environment. Water is managed and protected based on intended use(s) objectives.

Figure 23: Hydrological Cycle



Source: https://en.wikipedia.org/wiki/Water_cycle#/media/File:HydrologicalCycle1.png- 29-03-2019

5.2.1.1 Water Quality

Water ***has physical and chemical characteristics that are used to categorise water in terms of quality*** (excellent, very good, good, poor, very poor). Water can also be categorised as ***freshwater or saline water*** depending on the magnitude of the concentration of dissolved solids. The ***physical characteristics*** can be described by ***temperature, colour, taste and odours, solids and conductivities***. ***Chemical characteristics*** are described by ***inorganic and organic*** contents. To fully describe water quality its ***microbial quality*** must be known especially in terms of ***algae and indicators of pathogens***. Water quality is routinely assessed to obtain baseline data for management or for regulation. Water resources assessment is also done within the framework of quality and quantity for the intended uses. Typical concentration of elements in water can be illustrated in ions concentrations of river water (Table 4) that displays the concept of electro neutrality (ionic balance) of natural freshwaters.

Table 4: Typical concentrations of major ions in the classic "word average" river

Constituent	Concentration mg/L	Cations meg/L	Anions meg/L
Cations			
Ca^{2+}	15	0.750	-
Mg^{2+}	4.1	0.342	-
Na^{+}	6.3	0.274	-
K^{+}	2.3	0.059	-
Anions			
HCO_3^-	58.4	-	0.958
SO_4^{2-}	11.2	-	0.233
Cl^-	7.8	-	0.220
NO_3^-	1	-	0.017
Sum	**106.1**	**1.425**	**1.428**

Typical concentrations of Major Ions in the Classic "Word Average" River (Livingstone, 1963)

The dissolved ions in water are cations and anions;

Cations = electron donors, positively charged: Na^{+}, K^{+}, Mg^{++}, Ca^{++}, Fe^{++} or Fe^{+++}, Mn^{++}, Al^{+++}

Anions = electron acceptors, negatively charged: Cl^-, F^-, I^-, Br^-, SO_4^{--}, CO_3^{--}, HCO_3^-, O_3^{--}, NO_2^- .

An important fundamental of nature is that **'clean' water** is **electrically neutral**. In real solutions therefore the total sum of cations is equal to the total sum of anions. In reality however analytical errors usually occur and cause electrical imbalances. This error is measured by the charge-balance error (CBE) in percent (equation.

$$CBE = \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} \text{ x } 100 \frac{\sum Cations - \sum Anions}{\sum Cations + \sum Anions} \text{ x } 100$$

Equation 4: The water Charge Balance

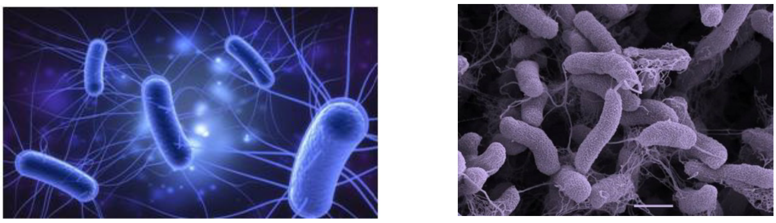
Researchers use CBE to check the validity on analytical results. Results can be accepted if CBE is less than ±5%.

Inorganic components of water are naturally derived basically from the local geology. Inorganic components of natural waters are: sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), nitrogen (N), phosphorus (P), sulphate (SOx), chloride (Cl), fluoride (F), iron (Fe^{2+}), manganese (Mn^{2+}), zinc (Zn, aluminium (Al), selenium (Se), boron (B), heavy metals: lead (Pb) and copper (Cu) are rare in natural waters. Metals that enter water from industries are; cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg) and nickel (Ni).

Organic materials in water are normally derived from decomposition of dead organisms of plant and animal origins that are leached into the environment. Alternative source of organic materials is anthropogenic where human activities from industries, homes, place of work or lifestyles can intentionally or unintentionally release organic substances into water. Anthropogenic releases into water vary from ***slightly toxic detergents to very toxic pesticides and herbicides (DDT, PCBs***). Organic materials including oil have now become major polluters of the environment because of the development in these industries. Accidental spillage of oil is a major concern since it is very destructive to the environment physically and chemically and apart from being persistent in the environment. On the other hand biodegradable organic materials that consume dissolved oxygen in water (determined by measuring the ***biochemical oxygen-BOD)*** can be very destructive to water ecosystem and its life forms. The determination of dissolve oxygen and oxygen demand in natural waters are important because they can indicate the health (potential to support aquatic organisms and quality for other uses) of the water body.

It is important to determine microbiological quality of water because of the many infectious disease causing organisms that can survive in water and get transmitted to humans by use of water. Diseases associated with human faecal matter and urine that are water borne is common and are known to cause fatalities in some cases. Water borne diseases have significant impact on household's health, productivity and wellbeing especially in the developing countries of Africa and Asia. The common bacteria in water as seen under the microscope are displayed by Figure 24). For rapid assessment indicator organism like faecal coliforms, faecal streptocci are used to detect contamination of water sources by pathogenic organism's growths on plates that are recognised by the shapes and colour of colonies (Fig 25).

Figure 24: Common bacteria in water



Escherichia coli

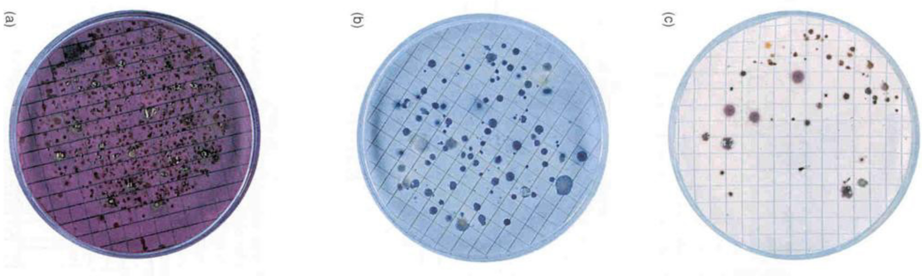
Source: By Rachel Ross, Live Science Contributor | January 7, 2019 03:47pm ET

Vibrio sp.

Source: https://www.luciacangussu.bio.br/atlas/vibrio-spp/

In situations of floods such as the one that recently occurred in southern Africa (Cyclone Idai in March 2019 and Kenneth April 2019), when it is very difficult to have adequate sanitation, water is contaminated and water borne diseases can occur at epidemic proportions. Common waterborne diseases include cholera, bacterial dysentery, hepatitis, ascariasis, typhoid, tuberculosis, and amoebic meningo-encaphelatis. These waterborne diseases can be prevented in non disaster situations by putting in place a strong defence system starting with proactive methods of proper sanitation, clean water (treated) and disinfection. It is always best to plan for and implement adequate primary healthcare for the community.

Figure 25: Total coliforms and Faecal coliforms indicator test plates



Total coliform (Endo agar)

Faecal coliform (m-FC agar)

Faecal streptococci (M-enterococcus)

Pollution

A major problem of water resources is pollution causing deterioration of water quality due to chemical, physical and biological pollution agents. Nutrient enrichment cause eutrophication, BOD cause oxygen depletion, acidification due to lack of buffering capacity cause catchment to leach away minerals as well as heavy metals (HMs) into water bodies, poor sanitation cause microbial contamination and erosion cause increased TSS and siltation Plastics have now become a major pollutant from macro to nano levels in marine ecosystems. Pollution a problem from plastics was first identified in marine environment in 1965 when it was found intertwined with a plankton sampler. Nowadays all sorts of plastics are found in water bodies such as lakes and oceans, where bottles, raincoats, jackets, boots, car parts, cups, plates, general household items, even toilet seat covers end up.

5.2.2 Water Quality Research

The existence and availability of water is only satisfactory if it is adequate for the intended use or uses. Human activities that discharge *pollutants into the environment can significantly alter water quality.* For effective water protection and allocation for intended uses, the quality of water is one of the most important factors that should be known well and protected. Water quality standards therefore will determine its use suitability. Water quality parameters are physical, chemical and biological. Physico-chemical parameters in water are determined both *in situ* (e.g. temperature, pH, conductivity, TDS, colour, depth of light penetration) and in a laboratory for parameters that require more elaborate preparation for analysis. For the laboratory analysed parameters guidelines for sampling, treatment, transport and temporary storage are strictly followed for realisable results (APHA 2005). The whole process must be carried out by qualified personnel and analysis carried out in accredited water laboratories only. There are regulations, proficiency testing (interlaboratory comparison) and standards that accredited laboratories follow to ensure integrity. I will now proceed to consider the kind of water quality studies I have done.

Drinking water for communities can be from centralised distribution systems that supply homes, farms, offices and businesses, directly from pipes to taps. This mode of supply is for treated water using the conventional methods usually of the use of coagulants, sand filtration, and disinfection with chlorine or ozone and supplied piped. This is the supply system for most of the population members in the developed world and urban populations in general. It is however common for most poor communities especially in African countries to use non-piped water that is commonly from shallow groundwater sources. These alternative water sources (protected springs, shallow wells, boreholes, rivers, ponds) to piped water are often contaminated by pollution (Nsubuga et al., 2004; Cronin et al., 2006; Awomeso et al., 2010; Okot-Okumu & Otim 2015). Water sources for communities in slums and rural areas that have poor or no sanitation provisions are usually contaminated with faecal matter (Nsubuga et al., 2004; Haruna et al, 2005; Okot-Okumu & Otim 2015). Water sources in such situations are open to contamination because of poor human waste disposal (e.g. indiscriminate defecation, poor location of latrines), indiscriminate disposal of solid wastes, wastewater discharges, sharing water sources with livestock, catchment degradation (WHO/UNICEF, 2000; Cronin et al., 2006; Horak et al., 2010, Aboyeji, 2013). Drinking water in such cases becomes a source of diseases. Worldwide, waterborne diseases are a major cause of morbidity and mortality in humans (WHO/UNICEF, 2014).

To illustrate the point in case I will present a study with we did in the year 2015 that elucidated the quality of drinking water from different sources used by communities in Uganda (Okot-Okumu & Otim 2015). The physical, inorganic, organic and microbial parameters of drinking water analysed were: NO_3 (0.01-4.6 mg/l); turbidity (< 5-97.6 NTU); total dissolved solids (59 - 420.9 mg/l); conductivity (28-760 μS/cm); pH (5.3-7.2); temperature (23-25.90 °C), total coliforms (0-940 cfu/100 ml), faecal coliforms (0-200 cfu/100 ml), faecal streptococci (0-435 cfu/100 ml). The water quality obtained in this study did not comply with the Ugandan potable water specification (UNBS 2017) and the WHO (2017) guidelines for drinking water. These water sources were therefore unsafe for drinking by the community. The conclusions here is corroborated by others studies in the country (Nsubuga et al., 2004; Haruna et al, 2005; Howard et al., 2003; Kulabako et al., 2007). Unfortunately in most of the cases these are the only drinking water sources for the communities. It is therefore not surprising that water borne diseases are prevalent in such areas and it peaks during the rainy seasons of the year.

For these drinking water sources studies we confirmed that the widely used method for Risk of Contamination (ROC) assessment (scoring) of community water sources (WHO, 1997) is a quick and cheaper method to detect the danger of using a particular water source. ROC is a reliable method since it has demonstrated a strong correlation with water quality data according the study of Okot-Okumu & Otim (2015) with (faecal coliforms, $y=0.1096x+0.077$; $R^2=0.8672$) in agreement with Mushi et al 2012. Studies of ground water pollution have demonstrated that pollution risk factors model faecal contamination of wells acceptably (Howard et al., 2003; Kulabako et al., 2007; Mushi et al., 2012). Comparing community water sources for safety of use it was found that boreholes were the safest and protected springs though acceptable, were generally unsafe in areas of poor sanitation. Shallow wells, unprotected springs and surface water (e.g. streams) are high risk water sources for drinking.

Assessment of river water for agriculture: Rapid assessment methods were done on rivers in the ***Acoli region of Gulu and Nwoya*** districts for their ***suitably for agricultural uses***. Research on water for production is also important and estimates are usually done by water resources management institutions so that water allocation is done reasonably. Projections are usually done using models that use climatic data and hydrological parameters. I will not go to models and their uses in this lecture because this is another area of specialisation in itself that would require much presentation beyond our discussion. Here I will look at water suitability for agriculture based on water quality parameters.

Water from lakes and rivers have use potential to for various purposes such as potable water, water for production (e.g. Irrigation, livestock watering, aquaculture), water for recreation and maintaining the ecosystems or the environment (e.g. environmental flows). So researchers should obtain baseline data on water quality and the abstraction potential (available quantity) from the water sources to assess their suitability for use. For my preliminary study in the Acoli region I am presenting river water suitability as assessed for agriculture (irrigation) presented in terms of sodium adsorption ratio (SAR) using Equation 5 according to Richard 1954. Salinity is other parameters that are relevant to agricultural water because of its hazard. Analysis of rivers in the Acoli region of Gulu and Nwoya is used to illustrate potential for river use for agriculture in this region of the country. The rivers were found to have good water (SAR: 2.03 - meq/l, % Na – 19.2). Salinity assessments by measured EC indicate good water quality for irrigation (279 – 386 μcm^{-1}).

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

Equation 5: Sodium adsorption ration

$$Na\% = \frac{Na}{Ca + Mg + Na + K}$$

Equation 6: Sodium%

Results of the river water analysis are displayed in Table 5. Conclusions on this water sources were done based on literature on assessment of water sources for agriculture –irrigation.

Rivers that are important for Ecosystem Maintenance and Environmental Conservation:

Rivers traverse various ecosystem types and on their journey pick up characteristic water quality depending on the geology, climate and land use/land cover (LULC). Forests Rivers therefore have unique characteristics and functions because they usually feed larger water bodies like lakes or oceans and have some contributions to the hydrological cycle of forests and lake basins. Forest Rivers are unique in that they either originate from forests springs, forest wetlands or are in transit and apart from sustaining the forest hydrology they carry along water with nutrients and other materials obtained from the forests that feed the downstream ecosystems. The hydrological components of such catchments are tightly linked to the forest, rivers and streams and all must work unimpaired to sustain the hydrological cycle. I have illustrated this with the Forest Rivers near Kampala city at Mabira, Kitubulu, Zika and Mpanga that in our study generated the water characteristics displayed in Figure 26 (Jovanelli et al, 2015).

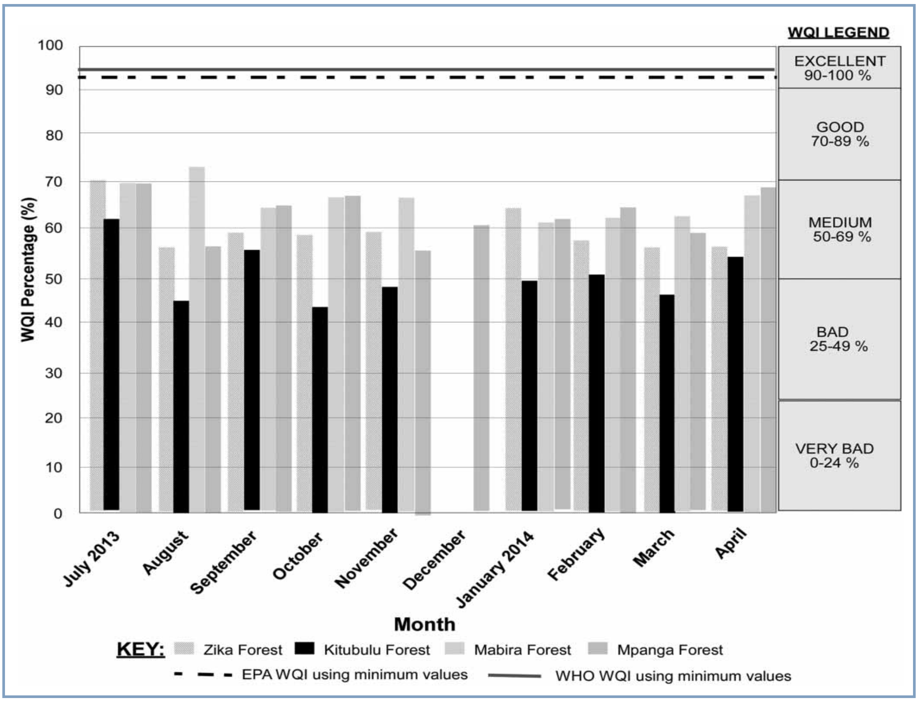
Table 5: River Water use suitability for agriculture (irrigation and aquaculture) – Acholi region Gulu and Nwoya Districts

	A- L	A-O	A-P	CA	CK	NYK	CD	AWR	Mean	Water Class Comments
pH	7.4	7.3	7.5	7.2	8.4	7.35	6.8	6.4	7.3	
Conductivity	386	301	340	352	342	279	356	348	338.0	Good
TN	1.54	1.46	1.5	1.52	1.54	1.35	1.42	1.44	1.5	
Nitrate	0.43	0.32	0.42	0.42	0.42	0.35	0.42	0.4	0.4	Very Good
Ammonia-N	0.53	0.54	0.52	0.52	0.52	0.56	0.63	0.62	0.6	
TP	1.06	0.88	1.04	1.04	1.06	0.98	1.04	0.92	1.0	
O-Phosphate	0.24	0.22	0.22	0.24	0.24	0.24	0.28	0.28	0.2	
Turbidity	58	42	54	56	56	36	58	64	53.0	
TDS	186	138	180	180	182	134	198	184	172.8	Freshwater **Very good**
Colour (Pt)	14		13	12	12		16	14	13.5	
Fe2+	0.4	0.4	0.3	0.2	0.4	0.2	0.3	0.4	0.3	
Ca2+	24.8	30.6	22.8	22.4	24.6	28.2	26.8	26.2	25.8	
Na+	8.6	8.4	8.2	8.4	8.2	8.4	8.2	8.0	8.3	
Mg2+	7.28	13.16	7.26	7.32	7.28	7.28	7.32	7.34	8.0	
Cl+	4.8	7.8	5	5.2	4.6	7.2	5.8	6.2	5.8	
K+	1.4	1.9	1.2	1.2	1.4	1.6	1.2	1.2	1.4	
Alkalinity	20	20	18	16	18	16	20	18	18.3	
Hardness (CaCO3)	70		72	70	68	68	72	68	69.7	Soft water
SAR	2.14	1.79	2.12	2.18	2.05	1.99	1.98	1.95	2.03	Excellent
%Na	20.4	15.5	20.8	21.4	19.8	18.5	18.8	18.7	19.2	Excellent
WQI	61.4	62.6	61.3	61.4	59.3	67.9	56.0	54.4	60.5	Medium

All values are in Mgl^{-1} except: Conductivity =µcm^{-1}; turbidity=NTU; colour unit, pH= no unit

Key: A-L= Aswa/Lulyano ; A-O= Aswa/Onegi; A-P = Ayago Pakwach Rd; CA=Cai; CK= Ceke; NYK = Nyamokino; CD= Cuda; AWR = Aworanga

Figure 26: Average monthly water quality indices for four forest reserves



Water quality in the four forests streams are within the classification medium to bad and are therefore best for ecosystem maintenance compared to other uses (Jovanelli et al, 2015; Jovanelli et al, 2012). These forest rivers are involved in sustaining the hydrological cycle of the Lake Victoria basin. With the rapid degradation of these forests mainly from illegal felling of trees, the evapotranspiration (ET) and infiltration (I) components of the hydrological cycle are reduced while runoff water losses are increased in these locations within the Lake Victoria basin and are putting stress on environmental maintenance requirements of the rivers. Water balance in such catchment can be describes as in Equation 7, the water catchment balance equation.

$$\Delta SM + \Delta GWS = P - I - AET - OF - GWR$$

Equation 7: Water Balance Equation

Where;

ΔSM: soil moisture storage change, ***ΔGWS***: groundwater storage change, ***P:*** precipitation,

I: interception, ***AET***: evapotranspiration, ***OF***: Overland flow, ***GWR***: groundwater runoff base flow

This means the significance of these zones to Lake Victoria supply of adequate (quantity & quality) water is being substantially diminished.

If the forests destruction is unchecked, the catchment area may experience erratic rainfall and even floods and also unexpected dry spells. This calls for more rigorous studies of forest water systems (rivers, streams, ponds, and wetlands), LULC changes, hydrology and meteorological data of the northern Lake Victoria catchment forest areas, in order to draw more concise conclusions about the significance of the Forest Rivers in the catchment. This study has also demonstrated the importance (potential) of forest covers in catchment hydrology. Forest are known to control local and world hydrological cycle for example it is know that the Congo forest influences rainfall in some parts of South America including the Amazon area itself and the Amazon influence goes as far as Texas in the USA. Following from here I will now proceed to describe our study on the influence of LULC on water quality of rivers.

Impact of Land Use/Cover on Water Quality of Rivers and Streams

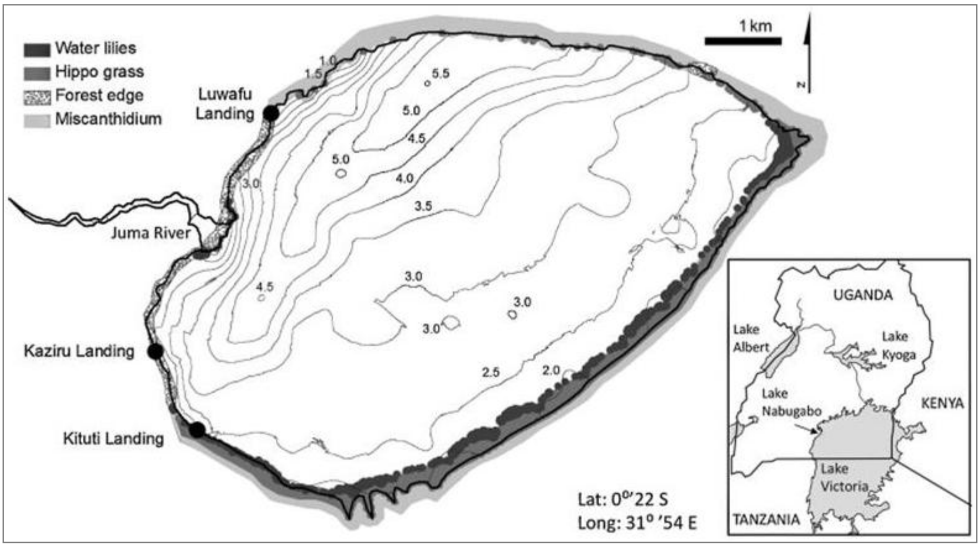
To illustrate LULC influence of surface water quality I will now describe a study on River Rwizi in Mbarara Municipality (Nyiramugisha & Okot-Okumu, in press). Results confirmed land degradation and human discharges are the main polluters of the river. The main sources of pollution within the municipality boundary were poor uncontrolled agricultural practices that have degraded land and industrial effluents. The study confirmed the link between the river pollution and the riparian LULC during both the rainy and dry periods of the year. Water quality index (WQI) classified the river from bad to very bad and therefore the river water is not good untreated for consumption by humans or livestock that is in agreement with a study on the same river by Ojok et al 2017. Similar studies have been done on Nsooba Stream, Bwaise, Kampala were the main pollutants were found to be latrines, solid waste dumps and abattoir and at Ntinda industrial area in Kampala that indicated effluent loads from industries into a stream in the industrial zone causing significant pollution (Walakira & Okot-Okumu, 2011).. The pollution of the water bodies were found to be greater during the rainy seasons compared to dry seasons. The pollution determinant factors were confirmed by Principal Component (PC) analysis: where only PCs accounting for > 80% were considered.

Industrial effluent studies in Africa have indicated t industries to be a major source of water pollution (Kayima et al, 2008; Muwanga & Barifaijo, 2006; Ojok et al, 2017 and Oladele et al., 2011, Walakira & Okot-Okumu, 2011). The research outputs above have demonstrated how human development activities can impact water quality diminishing their use potentials. Rivers normally flow into lakes, oceans or seas and are very important to the hydrology of these larger water bodies and so must be adequate in quality and quantity in order to support these ecosystems. I will now turn to look at Lake Nabugabo to illustrate water quality aspects of lakes.

Lake Nabugabo Water Quality And Nutrient (N and P) Dynamics studies

Lake Nabugabo was studied for water quality and nutrient dynamics in open lake and the surrounding wetlands. Lake Nabugabo is a satellite lake of Lake Victoria and was separated from the latter by a sand bar of only two kilometres wide about 5,000 years ago. The Lake is about 5 km long with a surface area of about 25 km^2. It is situated at an altitude of approximately 1140 m asl. The lake is shallow (average 2.5 m and max 5.5m deep) with light penetration to about 0.52 m (Secchi depth), see Figure 27.

Figure 27: Lake Nabugabo bathymetry



River Juma that flows under a dense papyrus mat is the main water input into the lake. The soils of the Lake Nabugabo catchment are highly leached with low salts contents and underlain by old bedrocks. The lake is therefore so dilute that it cannot support shelled aquatic life forms like the snails. For this reason the snail intermediate host for bilharzias is absent in this ecosystem and this lake has ever been safe for swimming. Lake Nabugabo catchment nutrient poverty is evident by the presence of *Sphagnum moss* and ***Drosera sp.,*** in the eastern and northeastern portions of the wetlands. Water quality from 1996 to 2014 is displayed in Table 6 and is rated by WQI to be generally good.

Table 6: Lake Nabugabo water quality

Parameters	Years				Lake Victoria
	1996	2010	2013	2014	Offshore
EC (μS/cm)	27.9	27.7	27.2	27.9	95.7
pH	6.9	6.7	7.1	7.1	8.6
TN (mg/l)	0.9	0.8	1.24	1.3	90.3
Nitrate (mg/l)	0.09	0.08	0.05	0.04	0.01
Ammonia (mg/l)	0.26	0.26	ND	0.6	0.1
TP (mg/l)	0.3	0.33	0.9	0.8	0.15
Ortho-P (mg/l)	0.02	0.02	0.02	0.02	0.03
Turbidity (NTU)	ND	21.5	22.0	20.8	5.5
TSS (mg/l)	ND	ND	ND	13.2	1.2
TDS (mg/l)	14.7	13.6	15.2	14.9	61.2
Colour (Pt co)	ND	7.0	10.0	10.3	119.5
Fe2+ (mg/l)	ND	ND	0.24	0.24	ND
Ca2+ (mg/l)	1.5	1.68	1.69	1.6	ND
Mg2+ (mg/l)	0.7	0.73	0.49	0.5	ND
Na+ (mg/l)	2.1	2.03	1.86	1.8	ND
K+ (mg/l)	1.1	1.01	2.4	2.3	ND
Alkalinity (mg/l)	0.14	0.18	0.29	0.29	ND
Hardness (CaCO3 ,mg/l)	ND	9.0	3.34	3.25	ND
Total coliforms cfu /100 ml	ND	6.5	12.2	14.5	38
Faecal coliforms /100 ml	ND	4	11.6	11.5	10
Escherichia coli cfu /100 ml	ND	1	0	2.5	
Faecal streptococci cfu /100 ml	ND	1	0	1.2	

Maximum secchi depth = 0.52 m, WQI = 71.64 Good

Lake Victoria samples were taken 30 metres off the Island (near Munyonyo Landing) Water Quality Data Island. Sampling No. 1 is directly opposite the Munyonyo Landing site and the other sampling points from No2 to No 10 in a clockwise direction. Each of the stations is directly opposite a house on the Island

The sediment of Lake Nabugabo in areas away from the beaches have muddy or free flowing organic matter containing plant debris that is evident of accumulating organic matter, while around the beaches are sandy. During strong winds mixing of the lake water column reaches the bottom bringing up sediment debris and suspended matter to the surface. My study demonstrated the lake mixing phenomenon and the net phosphorus (P) input from the surrounding wetlands into the lake. However there have never been any dramatic changes in water quality of the lake for many years indicating a delicate equilibrium with the catchment, especially the wetlands. The phosphorus utilisation and storage mechanisms in the lake are still functioning well to avoid massive release into the water column, meaning much of the P inputs are rapidly taken up by biota and or sink deeper to the consolidated zone of organic matter and probably clay materials. However the capacity of these mechanisms of P uptake could easily be overwhelmed with increased inputs from anthropogenic sources from the catchment.

The wetland that surrounds Lake Nabugabo has a big role in maintaining its nutrient status and productivity. Apart from the predominant hydrological input from Juma River the wetlands also make significant exchanges with the open lake water especially during the rainy seasons and windy days when water levels rise and waves from the lake push water into the wetlands. The drawback action drives water from the wetlands with nutrients into the lake (nutrients in dissolved and suspended forms and even debris; Okot-Okumu 2000. Decomposition processes especially of the predominant plant species *Loudetia phragmitoides* within the wetland cycles matter and releases nutrients into the wetlands water that have continuity with the lake water and therefore seem to influence the lake water quality (Okot-Okumu, 2004, 2012). Nutrient spiralling mechanisms keep the cycle of nutrients active as they travel from wetlands interior towards the lake along hydrologic gradients. Laboratory experiments have demonstrated nutrient leaching from the dominant wetland species *Loudetia phragmitoides* that follows first order kinetics (Okot-Okumu, 2004).

Being in a highly leached catchment Lake Nabugabo organic and inorganic requirements for production seems to be derived predominantly from the surrounding wetlands nutrient pool (Okot-Okumu 2000). The wetlands are a good nutrient supply source to the lake since the recoded nutrient concentration in Lake Nabugabo is comparable to other lakes in the region. However the lake water and sediments the total ions content is several times lower than for other lakes in the region which is a reflection of the catchment soils (Okot-Okumu 2000). This is an illustration of another system that has balanced itself out despite the poor catchment minerals. The Nabugabo wetland in this case is in a dynamic equilibrium with the open lake through hydrologic connectivity and is maintaining the lake production. This balance is beginning to be disturbed by the shore line developments for hotels and recreation and if this is not properly controlled (managed) this lake will progress towards eutrophication.

Further study was done on Lake Nabugabo suitability for recreation during 2013 and 2014 because much of the western and north-western part of the lake is now turning into hotels, vacation centres and recreation areas (swimming, sports, and parties).

These activities are the main routes for human wastes into the lake and at the same time bring humans in contact with water. For human safety and health we did a study that assessed the level of microbial contaminants indicator organisms (Total coliforms, faecal coliforms, Escherichia coli and faecal streptococci) in the lake water areas accessible to swimmers. Results indicated that the lake is still safe for swimming. But the rise in levels of contamination between 2010 and 2014 calls for precautions to be taken by the hotels on the lake shores. Regular monitoring of the contamination indicator organism in the recreation areas should be done to protect the public using the lake. Much of the lake catchment is now being invaded by developers except the eastern and north eastern portions. These conversions areas for hotels and recreation are the major pollutants inputs points by humans to the lake. Shore line conversions and the developments along the shorelines are causing increasing inputs into the lake that is the main threat to water quality of the lake. Being shallow generally, small in size and also with no apparent outlets the threat of eutophication is also high.

My additional study on lakes was on Lake Victoria that was limited to water quality and benthic macro-invertebrates and demonstrated the distribution of these organisms between the bays determined by environmental conditions and extent of pollution (Sekiranda et al, 2004). In the last 30 years or so the bays of Lake Victoria have experienced various levels of pollution from the catchment that in some cases resulted in algal blooms evident of eutrophication. These bays are important to the surrounding communities and the water board (NWSC) because of the services that they provide. Despite the various attempts to manage the bays using environmental laws-regulations the progression of pollution continues unabated. I have therefore also used the rule of thumb- 'problems are best solved at source' to analyzed the situation in one of the bays. For this I investigated the root cause(s) and the problems of Murchison Bay. Analysis of the root cause(s) of pollution of Murchison bay and catchment degradation were done. I used information gathered from my work on waste management, pollution analysis and the hydrological system in the Murchison bay catchment and secondary data from other sources to derive this chain of factors that are significant in this case. This involved a thorough analysis and systematic build up of the case and scenarios. Carefully designed questionnaires were administered to my students (Bachelor and MSc) and experts in their own specialties of environmental management, industries and local government. Analysis of the questionnaires together with literature data helped to develop a picture of the problems, root causes and consequences. The problems were later scored to priorities to significant ones only. Results of these analyses are presented in the form of causal chain analysis diagrams (Figs 28 &29). The root causes are therefore identified and are taken as areas of concern from the strategic levels through management plants to investment projects in the catchment that will assist to alleviate the problems.

Figure 28: Causal Chain analysis - Murchison Bay – Kampala catchment causal chain analysis on pollution

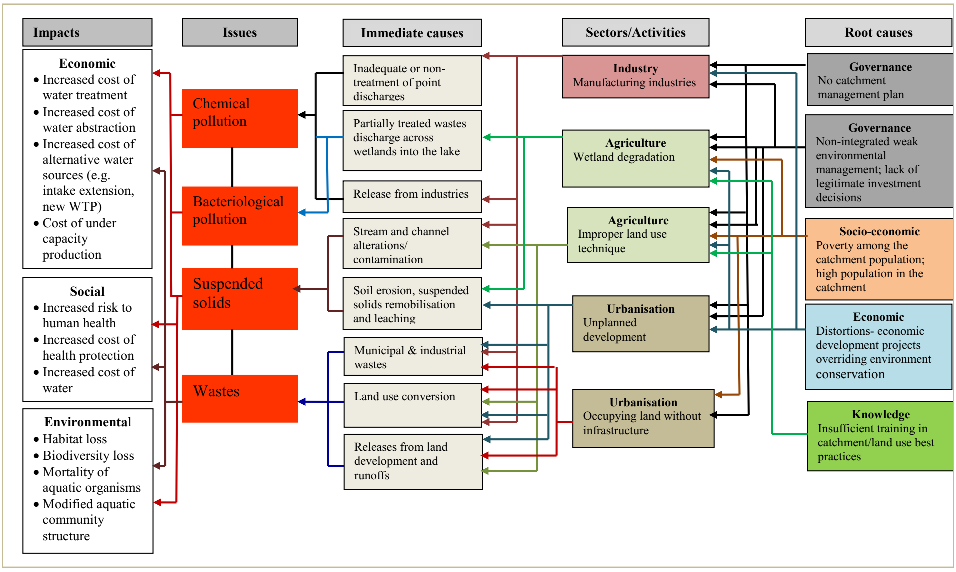
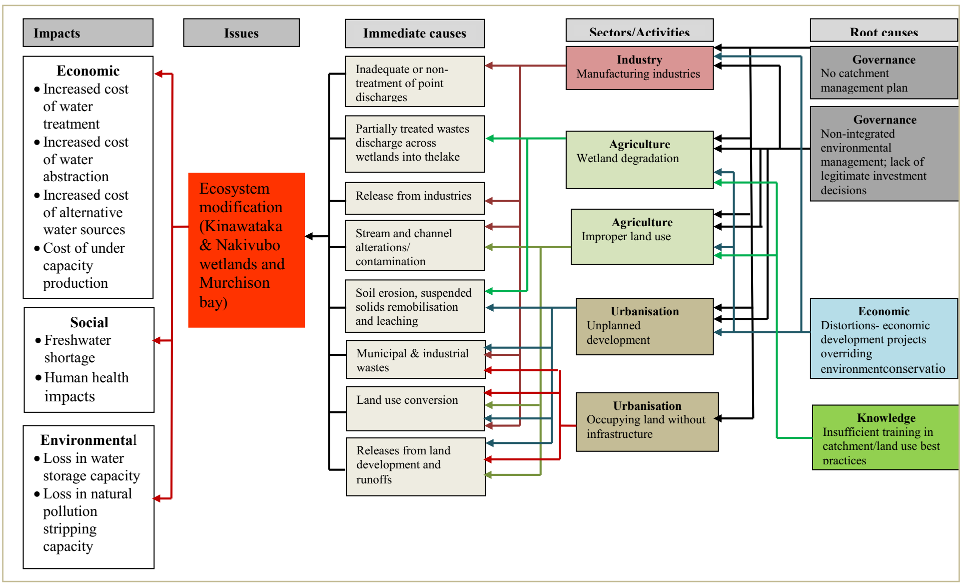


Figure 29: Causal Chain analysis - Murchison Bay – Kampala catchment causal chain analysis on habitat modification



The research results described before this section illustrated techniques used to understand the baseline characteristics and also the phenomena or dynamics that make and maintain the uniqueness of a particular aquatic ecosystem. My further studies therefore are from the area of eco-toxicology and water treatment.

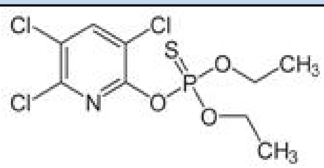
5.2.3 Ecotoxicology

Ecotoxicology refers to a scientific method to study of the effects of toxic substances / chemicals on organisms and the environment. The ultimate goal is to be able to assess and reveal the effect of what is being tested on the population within the context of all other environmental factors. Based on the knowledge obtained appropriate action can be taken to prevent or mitigate any effect found. So apart from testing the impact of newly manufactured products like, pesticides, herbicides, pharmaceuticals and other chemical residues and so on it can also be used to what is suspected to be already in the environmental systems in water and sediments. Results of such studies are provided hereafter

For my MSc I carried out eco-toxicology research to screen sediments for pesticides (Chlorpyrifos) residues and their toxicity in aquatic environment using the three-spined stickleback (***Gasterosteus aculeatus***) and water flea (***Daphnia magna)*****. The ecotoxicity tests found** *Chlopyrifos from sediment pore water to be* toxic to both fish and water fleas at very low concentration **(NOEC 0.1µg/L, 48hr LC_{50} = 0.42 µg/L (***Daphnia magna***); (NOEC =0.5 µg/L, 92hr LC_{50} = 8.9 µg/L** (*Gasterosteus aculeatus*). It was concluded that the release of chlorpyrifos from the sediments into the water would have detrimental impact on aquatic organisms. This pesticide (insecticide, acaricide and miticide) is a broad spectrum n organophosphate pesticide used on crops, animals, and buildings, and in other settings, to kill a number of pests, including insects and worms. During application it can easily get into water bodies by wind drifts and find its way into the sediments as potential toxicants to the aquatic environment

***Gasterosteus aculeatus* (three-spined Stickeback)**

Daphnia magna(water flea)



Chlorpyrifos: O,O-diethyl O-3,5,6-trichloro-2-pyridyl phosphorothioate

Chlorpyrifos inhibits acetylcholinesterase (AChE) through its metabolite chlorpyrifos oxon a key enzyme in the nervous systems of most animals. The toxicity is reversible and organisms may recover after exposure to low doses. However at certain concentrations thresholds permanent damage occurs. It is more toxic to insects than to fish and amphibians. In areas of intensive use of chlopyrifos therefore determinations in both sediments and water column are desirable since sediment can release such concentration into water column causing zooplankton and fish kills. We shall now proceed to see how innovative ways of using plant extracts can be useful to society

5.2.4 Innovation in Water Research

Plants have chemicals that have developed in them through evolution and adaptation to their environment that are in some cases argents of defence against attacks by parasites or pathogens. Knowledge of such chemicals of defence is valuable to man because we can use them to treat disease, eliminate pests, parasites or even clean the environment. In one such study we have deliberately used ecological toxicity of a natural plant extract (***Pytolacca dodecandra)*** to control the snails (***Biomphalaria sudanica***) that are intermediate host of biharzia parasites. ***Pytolacca dodecandra*** is a common plant in all parts of Uganda and therefore easily assessable for use. The toxicity range of the varieties in Uganda to snails is **LC_{50}: 1.4-7.8mgl^{-1},** depending on where they were grown and the berries storage regime. Potency varied between districts of cultivation and also among soil types. Storage as berries affected potency while storage as powder did not significantly affect potency.

This plant has been used in Ethiopia for many years and its effectiveness in killing snails is widely known and so it can be developed into a cheaper way of eradicating snails in water of areas where bilharzias is endemic. Another innovative way of using plants extracts is for the treatment of community drinking water. To investigate the use of natural products in treatment of community drinking water, our study looked at the potential of seeds extracts from three homestead trees. These studies will be described hereafter under water treatment

Water Treatment

Water available from the different sources is not always of acceptable quality for the intended uses. To satisfy use such as drinking engineers and scientists have develop water treatment technologies that remove the unwanted elements from the raw water. For example drinking water treatment objectives are to protect human health and aesthetics. For other intended uses the raw water also has to be treated to meet set objectives. The conventional water treatment technologies are now facing challenges as raw water sources become polluted. Using more effective newer technologies is expensive especially to the LDCs and as the costs also are always transferred to the water consumers A typical example is the case of polluted Murchison bay of Lake Victoria that supplies the raw water for treatment at Ggaba Water Works owned by the National Water and Sewerage Corporation (NWSC), Kampala. Water treatment at this utility is now gradually replacing Aluminium sulphate (Al_2 $(SO_4)_3$ with synthetic polymers as coagulant at an added cost to consumers. Additionally disinfection by chlorine is also now becoming a problem because it is difficult to maintain acceptable residual chlorine level in the distribution (Ecuru et al., 2011) and chlorine also reacts with organic matter in the water formic unacceptable chlorinated compounds like trihalomethane that is carcinogenic.

$$\mathbf{Al_2 (SO_4)_3.18H_2O \quad 2Al^{3+} + 3SO_4^{2-} + 18H_2O \quad 2Al (OH)_3 + 6H^+ + 3SO_4^{2-} + 12H_2O}$$

Equation 8: Alum treatment of raw water.

Though not very expensive the use of alum is now being discouraged because it reduces pH of water that in many cases have to be adjusted before distribution. It also works within a certain pH range only and may not be able to treat very dirty water. It also causes sludge that has to be disposed off later by the water agency. There is therefore need to think about innovative cheaper way to treat water especially for the sector of the community who cannot afford the current costs of water.

Having seen drawbacks in some of the conventional methods we have tested some readily available plant materials (seeds) that required simple preparation methods and were cheap to use. These are seed powders from *Syzygium cumini* (Java plum), *Artocarpus heterophyllus* (Jackfruit) *and Moringa oleifera* (Moringa) that worked very well as coagulates to clarify water from community wells (Natumanya & Okot-Okumu, 2015). Turbidity remoival was > 95% and bactericidal against: (*E. coli, P. aeruginosa, S. Typhii, S .dysenteriae, S. aureus and S. faecalis*) effects were 98 -100% in certain concentrations making the water safe for drinking (Natumanya & Okot-Okumu, 2015). Figure 30 displays the plants materials and clarification process. The research on water purification with readily available natural materials is very important since most rural communities in Africa are without access to safe water and therefore use unsafe water sources exposing them to water borne diseases. This calls for the need for action to search for affordable and simple solutions. Such treatment methods can be established at small scale for communities covering some households.

An alternative method that has also been tried is the application of sand filtration to clean community water supply that also achieved. Here sand grain size effects and column depths were tested for effectiveness. The smaller grain sized sand was better in removing turbidity and bacteria and increasing depth worked better to an optimal depth. Filtration treatment achieved removal as: Turbidity (89.2 – 98.2%), *E. coli* (65.5 – 96.4%), Faecal coliforms (73.4 – 93.5%), colour (85- 90.5%). Sand filtration alone does not achieve complete elimination of bacterial hence it would be better to couple it with addition of plant extracts treatment. This is an area for further research.

Figure 30: Turbidity removal by plants extracts

1. Moringa seeds and seed cake

2. Jackfruit seeds and seed powder

3. Java plum fruits (ripe) and seed powder

Useful seeds as coagulants: Seeds and seeds powder of Moringa, Jackfruit and Java plum plants

Standard Jar test setup for coagulation of turbid water with seed extracts. Concentration ranges 1 to 6 in the order **0, 20, 40, 60, 80 and 100 mg/**l respectively

Wastewater Treatment

When water is used it generates wastewater that varies in quality from moderately contaminated to very contaminated with chemical, physical and microbiological agents. When much polluted it becomes unsafe to discharge wastewater directly into the environment because of the undesirable pollution and the health risks to humans. There are standard conventional methods for treating wastewaters to acceptable levels before discharge. The concepts in wastewater treatment are borrowed from nature where materials and energy are cycled in a harmonized manner. In wastewater treatment the physical, chemical and microbiological burdens are corrected to values deemed not deleterious to the environment and with reduced risks to humans and wildlife. The acceptable wastewater (effluent) quality standards are usually set by the central government using the relevant government Ministry or by the Local Authorities. Despite this most effluent discharges in the developing world are in violation of such standards.

The conventional wastewater treatment system have traditionally been centralised in urban centres where all effluent generators discharge into networks of sewerage pipes or storm water drains that eventually lead to the wastewater treatment plant(WWTP).

In most countries of the LDCs the wastewater network coverage is so limited that most of the wastewater do not reach the central WWTP and are either handled privately or find their way into the environment minimally treated or not treated at all.

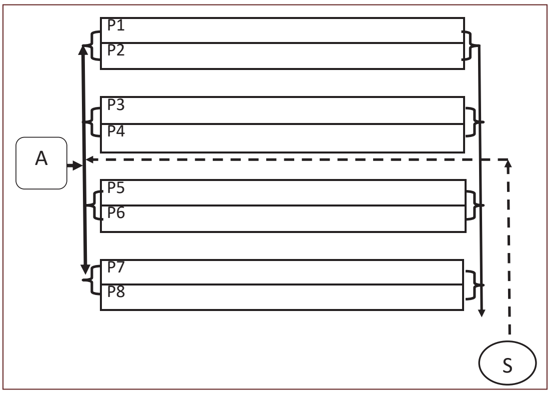
Due to this many institutions have their own stabilization ponds that treat wastewater and discharge the effluents directly into the environment usually wetlands or streams. Most household in urban areas of Uganda have private septic tanks that are emptied by evacuation trucks when full while the sewage generator has no idea or control on where the emptied sewage will go. Because of these difficulties experienced worldwide especially in the LDCs, scientist have come up with innovative methods that include the use of constructed wetlands, wetlands mesocosms and so on to treat effluents of varying volumes and qualities. I will now move to describe two such cases.

The Use of Constructed Wetlands

Constructed wetlands are engineered artificial systems that are designed and built to specifications depending on the characteristics of the wastewater it is intended to treat. Its treatment of wastewater depends on the natural functions of plants, soils, sand, gravel and microorganisms in the built environment. They also treat grey water, storm water land reclamation after mining or general land reclamation treatment. Very strong wastewaters (e.g. high BOD or COD) should undergo primary treatment before feeding into constructed wetland to avoid destruction of the system. There are two types of constructed wetlands, subsurface flow and surface flow constructed wetlands. The flows are either horizontal flow or vertical flow and the latter requires smaller land area. Vegetation plays a critical part in the functioning of constructed wetlands. Because of its uptake capabilities of pollutants in the wastewater and the physical structure of the wetlands because of the rooting systems that apart from the gravels, soils, or sand are the residents for the microorganisms performing biological treatment and also act as physical barriers and filters. Although not a primary function some wetlands may also act as homes of local wildlife or migratory species like birds

For a student MSc study we used a constructed wetland with the designed outlay below (Fig. 31) to achieve wastewater treatment of; BOD(65%), NH4-N(70.6%), o-PO43-(54.4%) at semi-continuous flow and it did not perform well under batch flow compared to continuous flow regimes(Okuta, 1999). This is a layout that is small enough for domestic use and the cost for both construction and management is affordable. One downside of constructed wetlands is that it attracts wildlife like snakes and frogs which may not be compatible with domestic setting. Mosquitoes may also become a nuisance.

Figure 31: Schematic display of constructed wetland units A = P1-P8= etc



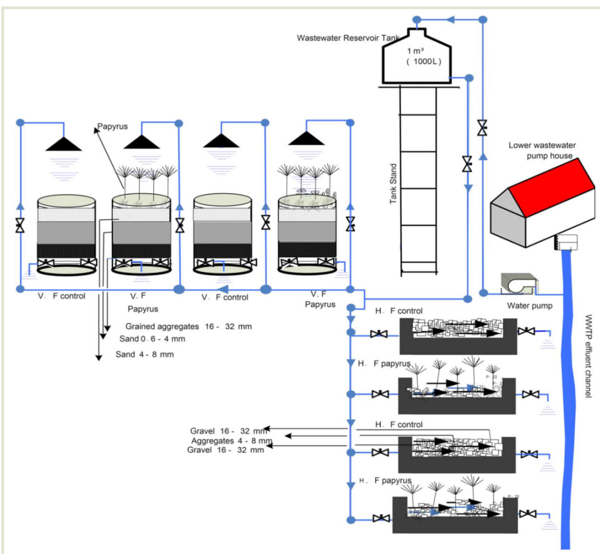
Another experimental effort on the use of wetlands has been on the use of mesocosms (Fig. 32) for treating sewage and this produced promising results. The pollutants removal is explained by Equation 9.

$$\text{Removal efficiency\%} = \frac{(Qin\ x\ Cin) + (Qout\ x\ Cout)}{(Qin\ x\ Cin)}\ x\ 100$$

Equation 9: Wetland performance equation

Our study on a trial in Uganda indicate pollution removal efficiency for planted setups at; BOD_5: 83.5% and COD: 77.0 % , 87.0% for NH_4-N , 78.4% for TN, 78.1% for PO_4-P,79.0% for TP, 86.3% for TSS (Kazibwe, 2015, Najib et al, 2015).

Figure 32: General Layout and design of the WBS mesocosms set at Bugolobi WWTP, Kampala, Uganda.



In this type of system nutrient accumulation in plants and sediments are essential processes for the removal of pollutants. The wetland treatment system of this nature is flexible enough and technologically less intensive to be adopted at a local scale for wastewater treatment.

The most accomplishing level of water management is at the water catchment level whether it is for a river or a lake. At the catchment level the water resources are looked at in totality in relation to other resources in the catchment and the community. In other words it is a holistic approach that applies the concepts of Integrated Water Resources Management (IWRM). IWRM is a framework designed to improve the management of water resources based on four key principles adopted at the 1992 Dublin Conference on Water and the Rio de Janeiro Summit on Sustainable Development.

These principles hold that:

- fresh water is a finite and vulnerable resource essential to sustain life, development, and the environment;
- water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels;
- women play a central part in the provision, management, and safeguarding of water; and
- water has an economic value in all its competing uses and should be recognized as an economic good.

In conclusion water in its different forms and management, there is a deliberate effort by the Environmental Scientists to find the best way possible in which the natural equilibrium is maintained and sustained. When dealing with freshwater the constituents have to be maintained in the electroneutral status for purity and use potentials and when it is wastewater the treatment processes mimics the natural ecosystem elements; physical (such as soils, sands, gravels), the chemicals (such as the cations Al^{+++}, Ca^{++}, Fe^{++}, plants organic releases, exudates, pH) and biological (microorganisms, macro-organisms) that are found to combine in the natural environment to maintain water quality. All these are guided by the fundamental laws of conservation of matter and energy allowing the environment to exist energetically and in matter wise in the most stable states in a dynamic equilibrium. Having dealt with water and wastewater we can now move to another interesting area of environmental science that is solid waste management in the next section.

5.2.5 Solid Waste Management

The use of materials and energy from the environment is associated with production and consumption and in all cases this transformational process is not 100% efficient. This means some materials (matter) and energy are lost at the expense of the achievements of the system which is either to have a product or to use materials and energy. This explains what happens in habitats or ecosystems. The same is the experience in our daily life of obtaining our requirements using them and disposing off what we no longer desire. Manufacturing industries also go through a similar process of obtaining raw materials processing them (value addition) to products that are sold to consumers and in the process generate by-products, waste matters and heat. The cycle then continues. It is real and it is part of our existence that is fundamental and we have now made it more complex through industrialization and other socioeconomic development activities.

The text above explains how processes that are chemical, physical or biological are closely linked to waste production. Wastes can be in the form of matter/materials (solid, liquid, gases) or energy (usually heat and light). The efficiency of systems either natural or artificial is measured by the relative amounts of wastes it generates and the lower the amount of wastes generated the more efficient a system is. Environmental scientists have therefore introduced techniques of waste elimination or minimization in the areas of Cleaner Production (CP), Lean Production (LP), Industrial Ecology (IE), Circular Economy (CE) and Sustainable Consumption and Production (SCP) all following the concept waste minimization.

My emphasis here will be on solid wastes since it is the one that that is most visible and I have done some work on. I will therefore be looking at solid wastes since we have already discussed wastewater management under water resources. The term waste has different meaning for different people or organisations. Generally one can say "***'waste' is anything, which is no longer useful*** (unwanted) to someone and one needs to get rid of. It is something, which the first user does not want anymore, and therefore throws it away" (van der Klundert 2001). As you may have realised ***'unwanted' is subjective*** and in reality the unwanted-wastes may still be useful to someone in certain circumstances, including belief, religion culture or social status. For regulatory purpose waste can be defined in legal documents such as the Ugandan Regulations on waste management ***"Any matter prescribed to be waste, and any radioactive matter, whether liquid, solid, gaseous or radioactive which is discharged, emitted or deposited into the environment in such volume, composition or manner as to cause an alteration of the environment (UG. Waste Management Regulations, 1999).*** From the definitions of wastes it is apparent that wastes can be a nuisance if not handled appropriately. Indeed wastes can cause aesthetics problems, pollute the environment, create health risks to humans and other life forms, is hazardous and can cause physical harm. Environmental scientists together with civil engineers and public health experts have studied and established the most appropriate methods for the management of solid wastes. This is a holistic approach to waste management 'Integrated Solid Waste Management (ISWM) that is describing hereafter.

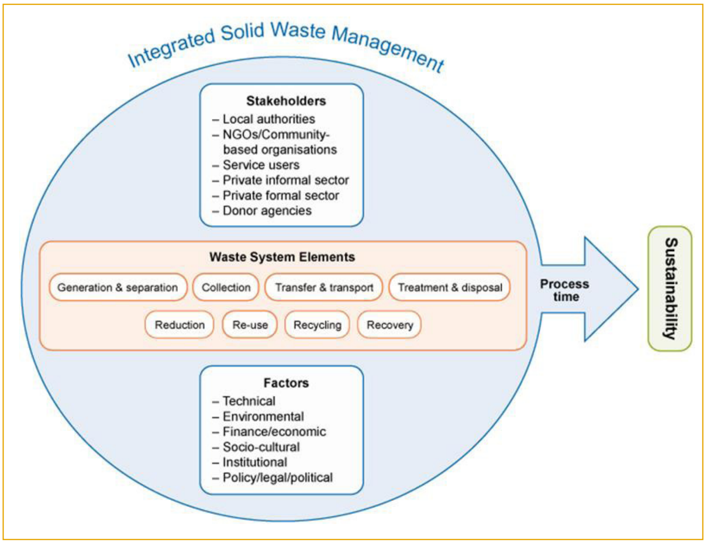
Integrates Solid Waste Management

In the contexts of integrated solid waste management (ISWM) the stakeholders, values of wastes, social, economic, cultural, characteristics and technology become apparent in the definitions of wastes. This is because the ISWM employs a holistic approach to manage solid wastes where waste is in fact a free resource for creating jobs or making a living and several deliberate approaches are deployed to make good of what has potentials of disrupting the environment. ISWM concept is based on four principles: **Equity** (all citizens are entitled to appropriate waste management system for environmental health reasons); **Effectiveness** (WM model applied should lead to safe removal of all wastes); **Efficiency(** WM done by maximizing the benefits, minimizing costs and optimizing use of resources taking into account equity, effectiveness and sustainability); **Sustainability(**WM system is appropriate to local conditions and feasible from technical, economic, environmental, social, financial, institutional and political perspective). Therefore WM can maintain itself without exhausting the resources upon which it depends.

Like in all other aspects of environmental management it is important that one understands well (comprehensively) what is to be managed, which in this case is solid waste. For ISWM the dimensions include the **stakeholders** that should be comprehensively assessed and understood in terms of socio-economic status, culture, behaviour. The **practical and technical elements**: Good information should also be obtained on the infrastructure, equipment, available technology and vehicle fleet. It is a situational analysis that will allow managers to strategically plan for and implement effective solid waste management schemes with inbuilt monitoring and evaluation provisions. Then finally the **local contexts**: that is the uniqueness of the particular setting (environment, political/legal, institutional, socio-cultural, financial-economic, technical-performance. These factors are all intricately set and linked and have to be considered together in the planning and execution of ISWM (Fig.33), which requires therefore an approach that is integrated and multi-disciplinary.

Data requirements for solid waste management are summarized in Table 7. Solid wastes have to be properly studied and documented to cause effective planning and management. The main classes or categories of solid wastes are Municipal wastes (Residential, Commercial), E-wastes, Hazardous wastes, Biomedical wastes, Plastics. A rapid field survey that determines the waste generators (sources), types of wastes generated characteristics, current storage and transport facilities, final treatment or disposal is the initial step of assessment. In addition to this it is very important to know the properties of the wastes you are dealing with. From the years of learning and experience by authorities in waste management, policymakers have evolved a method that considers waste from origin to final disposal. This is what is termed waste management hierarchy where waste management options are ranked and used according to their environmental benefits. The waste management hierarchy considers products from **'cradle to grave'** and it is closely linked to production and consumption processes. This means wastes should be looked at from generation, collection and treatment or disposal. Separation at source, reuse and recycling are very important in the waste management hierarchy. Separation at source should be emphasized because it ensures or improves the quality of materials to be reused, recycled (including composting) to reduce energy usage and also improve working conditions and efficiency at all stages of WM.

Figure 33: The integrated solid waste management model.



(Source: Van de Klundert and Anschütz, 2001)

Advantages of the use of waste management hierarchy that promotes reuse and recovery; reduction in the amounts of waste materials requiring collection and disposal, which means:

- Longer lifetime for landfills; more capacity for waste to enter other kinds of treatment facilities
- Lower transport and landfill costs
- More reliable and local supply of raw materials to local industries, avoiding using foreign exchange and associated procedures

- Reduced extraction of non-renewable raw materials and associated environmental degradation
- Reduced deforestation
- Conservation of resources, energy and water
- Provision of income and employment
- Availability of affordable products for the poor

Policies based on hierarchy reduce impacts on the environment and resources while at the same time providing investments and livelihood opportunities at all social levels as much as possible.

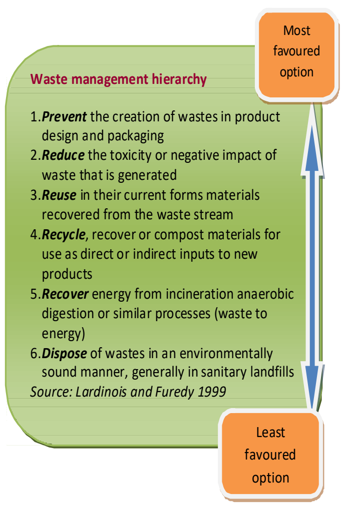
Table 7: Solid waste properties vital source of information for management planning

Waste survey:	Comments
Sources	Households, business, schools, markets, etc
Waste types	Domestic, commercial, plastics, E-wastes, etc
Generation rates	kg/person/day for residential waste and in kg/m2/day for commercial waste
Bulk Density	kg/L or in kg/m3
Composition of solid waste generated in percentage by weight	e.g. 80% Organic, 3% plastic, 1% paper, 0.4%glass, etc
Laboratory determination:	
Moisture content,	$M = \frac{w-d}{w} \times 100M = \frac{w-d}{w} \times 100$ Where M = moisture content (%) w = initial weight of sample (kg) d = weight of sample after drying at 105°C (kg)
Particle size and distribution,	Sc = l Sc = $\frac{l+w}{2}\frac{l+w}{2}$ Sc= $\frac{l+w+h}{3}\frac{l+w+h}{3}$ Where: Sc = size of component (mm) ; l = length (mm) ; w = width (mm) ; h = height (mm)

Field capacity, and porosity	The field capacity of MSW = the total amount of moisture which can be retained in a waste sample subject to gravitational pull. Values of uncompacted wastes (50-60%)
Permeability- uncompacted	The hydraulic conductivity of compacted wastes is an important physical property because it governs the movement of liquids and gases in a landfill.
Chemical Properties	
Proximate analysis: loss of moisture when heated to 105°C for 1 hour; volatile combustible matter (loss on ignition); fixed carbon and ash (weight of residue after combustion).	
Fusing point of ash	Burning of waste will form a solid (clinker) by fusion. Typical fusing temperatures are from 1100 - 1200°C.
Elemental analysis	carbon, hydrogen, oxygen, nitrogen, sulphur, and ash
Energy content	SI unit of measurement is kJ/kg.
Essential nutrients	Nitrogen (as nitrates, ammonium N); phosphorus and potassium.
Biological properties	Water-soluble constituents, Hemicelluloses, Cellulose, Fats, oils and waxes, Lignin, Lignocelluloses, Proteins

Looking at data requirements the most of general information can be obtained from local authorities in areas like demographics, income, household census, equipment, vehicle fleets as secondary data. For confidence a researcher should plan and verifies some of these data by direct measurements. On the contrary it is always advisable to obtain primary data on waste generation, characteristics, collection and treatment. Waste survey objectives include;

1. to determine the volume required for on-site storage, transportation, transfer facilities and disposal of solid waste;
2. to identify recycling/resource recovery potential of solid waste;
3. to determine appropriate methods of collection and disposal of solid waste; and
4. to estimate the expected life span of a disposal site.



My studies have characterized solid wastes in Uganda to be predominantly biodegradable (78%) with generation rate of 0.55 (0.3 to 0.66) kg/capita/day and collection coverage of about 45% (Okot-Okumu & Nyenje, 2011). This data is similar to other urban centres in East African Region (Okot-Okumu, 2012). Waste characteristics are in Table 8 and quality are; pH range 5, 7–6, 9; moisture contents 50–75 per cent; volatile solids66–79 per cent; decomposable organic carbon 74–86 per cent; and volatiles66, 2 – 84, 1 per cent (NEMA, 2007)

The current operating waste management system in Ugandans towns is illustrated by Figure 34. However very low waste collection rates are evident in most towns of Uganda and of the developing world in general. It is not uncommon to find waste littering and the visible impacts in many locations of urban areas including blocking of storm water channels and reduced aesthetics. Transport methods though being improved by compressor trucks there is still also use of open trucks that inconvenience other road users.

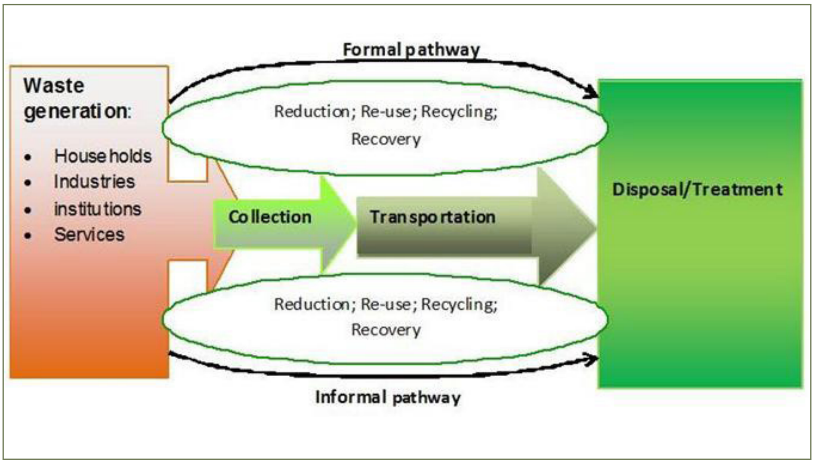
Table 8: Composition of solid wastes generated by municipalities in Uganda

Composition (%)*	Fort Portal	Jinja	Kabala	Kasese	Lira	Mbale	Mbarara	Mukono	Soroti	Kampala
Food	36,6	31,9	40,5	49,8	36,4	31,9	55,6	28,8	28,3	58,2
Garden	36,1	36,7	29,6	24,2	32,3	36,0	24,5	46,2	37,7	22,1
Paper	6,8	8,0	5,2	5,4	5,5	7,5	2,6	5,7	7,2	6,1
Plastic	8,4	7,9	8,1	5,1	6,8	10,8	4,7	7,9	8,8	7,2
Glass	0,7	0,7	0,5	0,4	1,9	0,9	0,6	0,4	0,7	0,7
Metals	0,0	0,5	0,5	0,1	2,2	1,0	0,2	0,3	0,4	0,3
Textile	1,0	1,8	1,8	0,5	1,2	1,0	0,3	0,4	2,5	1,8
Soil, ash, stones and debris	10,2	12,5	13,7	14,7	13,7	10,8	11,5	10,2	14,4	3,6
Others	9,8	9,0	10,1	13,4	12,2	7,7	9,9	8,4	11,1	2,6

(Source: Okot-Okumu &Nyenje 2011&Okot-Okumu 2012)

Solid waste can pollute environmental systems; the air, soils/land and water. Water pollution is determined by water quality analysis and visual inspections. Water pollutants from wastes are usually from leachates that have high BOD, Colour, and TSS and may have heavy metals (HMs), low pH and microbial agents.

Figure 34: Solid waste management system in Uganda



Source: Okot-Okumu 2012

Air pollution from wastes is estimated by internationally prescribed scientifically accepted methods for determinations of the pollutants (e.g. POPs, UPOPs and GHGs, NOx, SOx, O_3, VOC, PAH). Emissions from wastes are of concern because of global warming gases, ozone depleting substances and toxic substances that get into the atmosphere. Here below are outlines of emissions determination methods as examples of existing methods.

Methane-Emission Potential

Calculation of methane emission potential was based on IPCC 1996, adapted from NEMA

$$CH_4 (Gg/yr) = (MSW_T \times MSW_F) \times MCF \times DOC \times DOC_F \times F \times (16/12 \ \ R) \times (1 \ \ OX)$$

Equation 10: Greenhouse gas emission calculation

Where:

1 Gg/yr = 1000 tonnes/yr

MSWT = total municipal solid waste generated (Gg/yr)

MSWF = fraction of MSW disposed of at landfills (FDS)

MCF = methane correction factor (fraction); default 0,8adopted for Kampala

DOC = degradable organic carbon (fraction)

DOCF = fraction of DOC dissimilated

F = fraction by volume of CH4 in Landfill gas (LFG; default is 0,5)

R = recovered methane (Gg/yr) = 0 for Uganda; no methane is collected

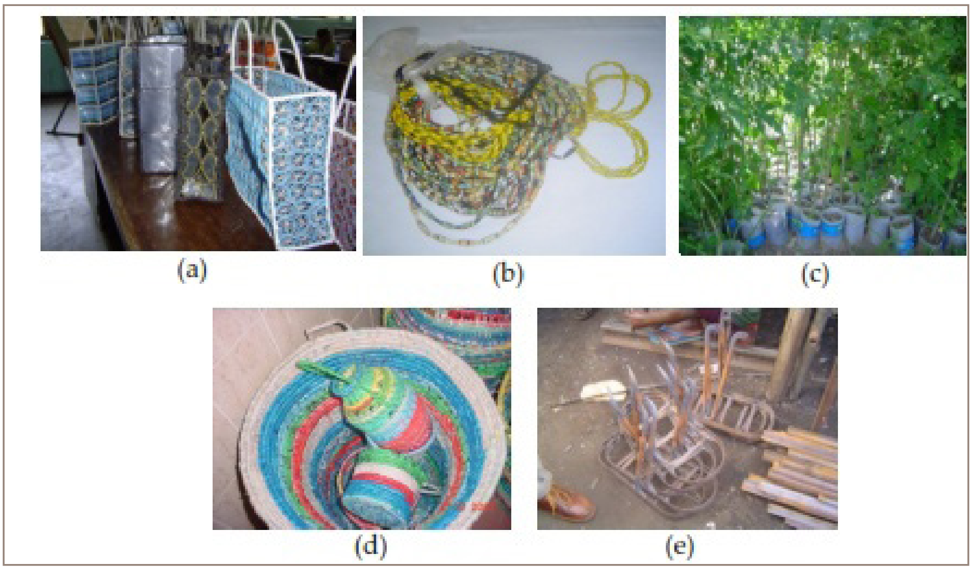
OX = oxidation factor (default is 0).

The amount of methane generated can be converted to CO_2 equivalent by multiplying by a factor of 25 ($1kgCH_4*25=25kgCO_2e$). There are several other greenhouse gases whose impacts are well known.

Another significant pollutant from solid wastes are the persistent organic pollutants (POPs); Unintentional Persistent organic pollutants (UPOPs) and Perfluorooctane sulfonic acid (PFOS) that are of international concerns because of their serous pollutants potentials. Their impacts are estimated by the UNEP spreadsheet provided to national agencies to enable reporting. The Kyoto Protocol controls the GHGs while POPs are controlled by the Aarhus Protocol on Persistent Organic Pollutants of 1998.

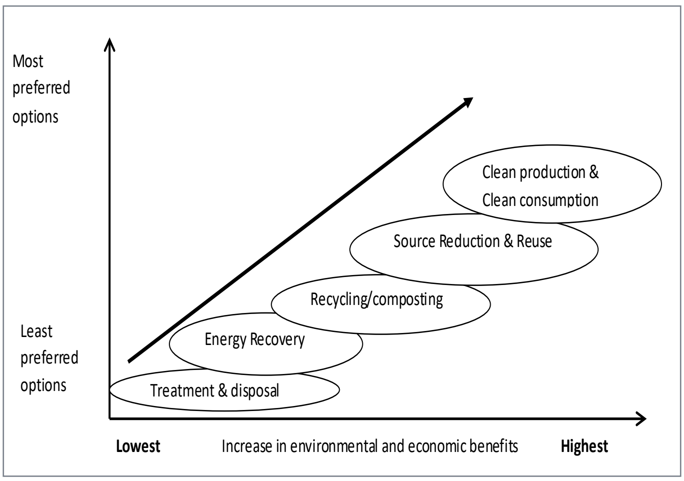
Having considered the impacts of poor solid waste management we can now revisit existing waste management methods. The simplest methods are the instinctive reaction of throwing wastes away no matter where it lands. This however has both social and environmental problems resulting from it. It pollutes, decreases aesthetics, impact public health, antagonise neighbours, and can cause harm to infrastructure like wastewater drains, storm water drains, roads, recreation areas and so on. Having seen the impact of wastes, towns have developed a method of collection, transport and disposal at designated sites called landfills. At the landfill disposed wastes are contained, managed and allowed to decompose naturally. Depending on the method used methane gas may be recovered and used for energy production (waste to energy) or flared. Landfills have life spans depending on the designed capacity and resources from wastes (composts, nutrients, biogas, recyclables, etc) can be derived from there. As already indicated the best existing method is the one applying the concepts of ISWM, whereby approaches such as Cleaner Production (CP, Lean Production (LP), Industrial Ecology (EC), Circular Economy (CE) and Sustainable Consumption and Production (SCP) that are Green Development Strategies are commonly applied to mitigate the impacts of solid wastes. In these methods the principles of waste elimination or minimisation that apply recycling, reuse, recover are used where what could have been waste becomes an input in another productive process (Fig 35). This illustrates the use of science to copy from nature where there is no 'waste' , that is waste from one organism or system becomes a raw material or input for another (a very efficient system for sustainability). Hierarchal waste management efforts in Uganda are illustrated by Figure 36.

Figure 35: Recycled wastes (A)-bags; (B) - necklaces; (C) –tree seedling in plastic cups, (D) - hats and baskets, all from plastic wastes and (E) - bicycle carrier from scrap metals



Source: Okot-Okumu 2012

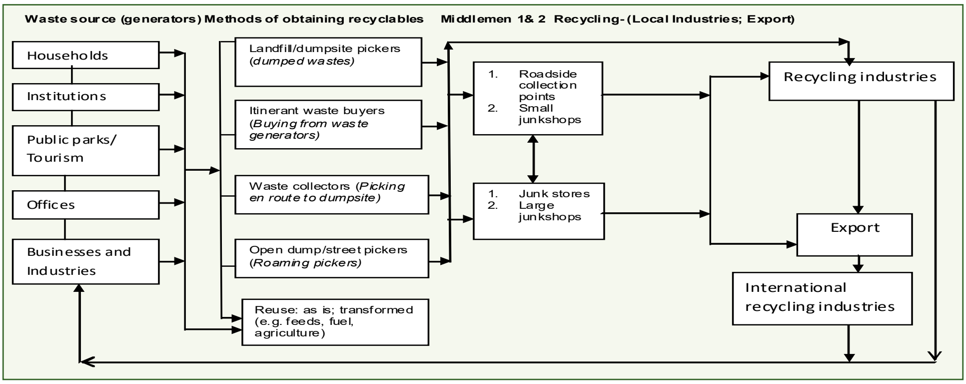
Figure 36: Waste-management hierarchy



Source (Okot-Okumu, 2015)

Waste recycling especially of plastics and metals is practiced in Uganda and the real extent of this business venture is not well documented. However this is a very important input in solid waste management because it can significantly reduce on waste loads, the cost of solid waste management and environmental burdens. Figure 37 illustrates the waste-recycling system in Uganda.

Figure 37: Solid waste recycling system in Uganda illustrated by flowchart



Source: Okot-Okumu 2015

Wastes are unavoidable component of our existence as humans and nature in general. We produce wastes naturally as we consume and discharge what we no longer desire and also artificially when we add value to items we would like to use at improved quality states. In nature or ecosystems actually nothing is waste since all outputs or discharges from individual members become material or energy inputs of others thus making a very efficient system where nothing goes to waste. The concepts of CP, LP, SCP and circular economy borrow heavily from these natural processes of recovery, reuse and recycle (the 3Rs). The natural dynamics described above that explained by cybernetics previously ensures a stable and sustainable environment or ecosystem that we as environmental scientists are using for the design of pollution prevention and treatment systems with emphasis on mitigation measures that prevent and minimise wastes.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

In this lecture I have discussed how Environmental Science evolved from the traditional sciences and most specifically from the science of Ecology. Environmental Science operates in a holistic manner that integrates the sciences and arts in a systematic manner to study, analyse, plan and manage the environment and its resources. For the purpose of common understanding the term 'Environment' was defined and its dynamics elaborated with special emphasis on the equilibrium in ecosystems that is maintained by natural resources, man and the climate through the flows and storages of matter and energy that are driven primarily by solar energy. The concepts of 'cybernetics' and 'homeostasis' were used to describe the control of the delicate balance of nature. At the highest level the natural balance system is illustrated by the planet earth that is just at the right position in the planetary system short of which it would not have been able to support life. Humans were identified as the main agents in destabilization of the natural equilibrium/balance with adverse impacts that cause natural resources degradation including pollution and reduced potential for ecological services. Ecological foot prints, biocapacity, ecological deficit and ecological reserves of the world and nations were used to illustrate and also quantify the impact of people on the environment. It is noted in this lecture that we are globally experiencing deficit of ecological reserves that means we are consuming more than what the environment can support and this is more pronounced in the developed countries of the world. These destabilising effects have caused undesirable consequences such as environmental degradation, pollution and in worst cases disasters. These impacts alerted scientists and activists to act and caused the gradual emergence of environmental science from the traditional sciences. Environmental science employs integrated approach to assessment, analysis and problem solving that makes it more efficient as a science discipline. To illustrate environmental science in practice I presented my research contributions in the area of water quality, pollution, ecotoxicology and waste management that acquired, assessed and analysed environmental data for informed planning and management of the environment.

Finally I would like to say that it is the role of Universities and other higher institutions of learning to train people in environmental science. Makerere University through the Department of Environmental Management (DEM) has taken a leading role in this in Uganda and I believe the best Environmental Science graduates still come from the DEM. The university can still do better by allowing the training programs at the DEM to evolve together with the national and global challenges of environmental management. Working in collaboration with other departments in sciences and social science at the university the DEM can improve on the training and research in environmental science to support Uganda sustainable development efforts.

Education and Employment

I began my education at ***Kweyo Primary School*** in Ongako Koc, Gulu District in the 60s .My ***secondary School education*** was at ***St. Josephs College Layibi (O-level) in Gulu*** in the 70s. I attended ***advanced level (Higher)*** secondary education at ***Namilyango College*** (***Senior 5)*** and ***senior 6*** at ***St. Marys School, Nairobi*** where I completed my A-level education with ***London, GCE***. I did my ***Bachelor degree at the University of Ghana Legon, Accra*** and obtained ***BSc (Hons) Biochemistry and Chemistry***. My education in ***Environmental Science*** began in the late 1980s when I obtained ***Post Gradate Diploma in Environmental Science and Technology from IHE- Delft, the Netherlands*** and ***MSc (Environmental Science and Technology) IHE- Delft, the Netherlands*** in 1990 (specialised in ***Ecotoxicology***). When in the Netherlands I did my laboratory research work at the world renowned laboratory of the Netherland National Institute for Public Health and Environment- RIVM at Bilthoven. My ***PhD*** was obtained ***from Makerere University, Kampala*** where I did research on ***nutrient (N&P) dynamics in Lake Nabugabo and the surrounding wetlands.***

My first employment was at the then ***Uganda Polytechnic Kyambogo (UPK),*** where I taught ***Biochemistry and Chemistry***. This was a very exciting and rewarding experience in my life because it is here that I learned how to adapt to work with meagre resources and how to handle diverse situations. I left UPK in the late 1980s to go for studies in the Netherlands and when I returned I joined the then ministry in charge of Environment as an Environment Officer where I was promoted to Senior Environment Officer. When joining the ministry for Environment we underwent training for public servants. What I learnt there is extremely important for people working in government and it is what has enabled me to always be what I am in employment. Finally I got into Makerere University as a lecturer in early 1990s and I have been lecturing, doing research, supervising students and also mentoring young professionals. The courses I have been handling at the university include; ***Integrated water resources management (IWRM), solid waste management, Cleaner Production (CP), Environment and Social Impact Assessment (ESIA) and Pollution Analysis***. Through the years at Makerere University I have grown from the rank of Lecturer to Professor. I have also been the Chair (Head) of the Department of Environmental Management from 2011 to May 2019.

REFERENCES

1. Aboyeji, O. O. (2013). Freshwater Pollution in some Nigerian local communities, Causes, Consequences and Probable Solutions. Academic Journalof Interdisciplinary Studies, 2(13), 111-117.
2. APHA, (2005). *Standard Methods for the Examination of Water and Wastewater,* APHA, AWWA and WEF, 21st EDITION, 2005.
3. Awomeso, J. A., Gbadebo, A. M., Taiwo, A. M., & Obayomi, O.(2010). Hydrochemical haracteristics of springs in Oke-Igbo, Ondo State, Nigeria. *J. Appl. Sci.Environ. Manage*, 14(3): 41 - 45.
4. Barinova, S. (2017). On the classification of water quality from an ecological point of view. *Int. J. of Environ. Sci. Nat. Res.* 2(2), 555581.DOI:10.19080/IJESNR.
5. Begon, M., Townsend, C. R., Harper, J. L. (2006). *Ecology: From individuals to* ecosystems. (4th ed.). Blackwell. ISBN1405111178.
6. Cronin, A. A., Breslin. N., Gibson, J., Pedley, S. (2006). Monitoring source and domestic water quality in parallel with sanitary risk identification in northern Mozambique to prioritise protection interventions. *Journal of Water and Health*, 4(3), 333- 345
7. Ecuru, J., Okot-Okumu, J.,& Okurut, T. O. (2011).Monitoring Residual Chlorine Decay and Coliform Contamination in Water Distribution Network of Kampala, Uganda. *J. Appl. Sci. Environ. Manage*. 15 (1), 167 – 173
8. Enger, E.D., & Smith, B. F. (1995). *Environmental Science. A Study of Relationships*. (5th Ed). McGraw- Hill
9. Global footprint network (2018). *Advancing the science of sustainability*. https://www.footprintnetwork.org/2018/04/09/has_humanitys_ecological_footprint_reached_its_peak/. 18/03/2019.
10. Government of Uganda (1999). *The national Environment (waste Management) Regulations 1999.* Statutory Instruments Supplements to the Uganda Gazette No. 61 Volume XCII 3rd December, 1999.
11. Haruna, R., Ejobi, F.,& Kabagambe, E. K. (2005). The quality of water from protected springs in Katwe and Kisenyi parishes, Kampala city, Uganda. *Afri. Health. Sci.*, **5**(1): 14-20.
12. Horak, H. M., Chynoweth, J. S., Myers, W. P., Davies, J., Fendorf, S., & Boehm, A. M. (2010). Microbial and metal water quality in rain catchments compared with traditional drinking water sources in East Sepik Province, Papua New Guinea. *J. Wat. Health,* 8(1), 126-138.

13. Howard, G., Pedley, S., Barret, M., Nalubega, M., & Johal, K. (2003). Risk factors contributing to microbiological contamination of shallow groundwater in Kampala, Uganda. *Water Research,* **37(**14), 34213429.

14. Jovanelly, T., Okot-Okumu, J.,& Erima, G. (2012). A preliminary investigation of water and soil quality infour forest reserves near Kampala Uganda. Journal of Environmental *Hydrology; at http://www.hydroweb.com*

15. Jovanelly, T., Johnson-Pynn, J., Okot-Okumu, J., Nyenje, R., & Namaganda, E. (2015). Pioneering water quality data on the Lake Victoria watershed: effects on human health. *J. Wat and Health. (13)3.*

16. Kayima, J., Kyakula, M., Komakech, W., & Echimu, S. P. (2008). A study of the degree of pollution in Nakivubo Channel, Kampala, Uganda*. J. Appl. Sci. Environ. Man* 12(2), 93 – 98.

17. Kazibwe, A. (2015). *Performance of Papyrus Based Batch Loaded Vertical subsurface flow Constructed Wetland Mesocosms in Kampala, Uganda*. MSC Thesis, Makerere University.

18. Krebs, C. J.(1972). *Ecology*. Harper & Row, New York.

19. Kulabako, R., Nalubega., M & Thunvik, R. (2017). Study of the impact of land use and hydrogeological settings on the shallow groundwater quality in a peri-urban area of Kampala, Uganda. *Science of The Total Environment* 381(1-3),180-99

20. Lin, D., Hanscom, L., Murthy, A., Galli, A., Evans, M., Neill, E., Mancini, M. S., Martindill, J., Medouar, F-Z., Huang, S &Wackernagel, M. (2018).Ecological Footprint Accounting for Countries: Updates and Results of the National Footprint Accounts, 2012–2018. *Resources* (7), 58; pp doi:10.3390/resources7030058.

21. Livingstone, D. A. (1963). Chemical composition of rivers and lakes. Data of eochemistry, chapter G. USGS Prof. Pap

22. Lovelock, J (2009). *The Vanishing Face of Gaia*. Basic Books, ISBN 978-0-465-01549-8

23. Mushi, D., Byamukama, D., Krischner, A. K. T. 2012. Sanitary inspection of wells using risk-of-contamination scoring indicates a high predictive ability for bacterial faecal pollution in the peri-urban tropical lowlands of Dar es Salaam, Tanzania. *J. Wat. Health.,* **10**(2), 236243.

24. Muwanga, A.,& Barifaijo, E. (2006). Impact of industrial activities on heavy metal loading and their physico-chemical effects on wetlands of the Lake Victoria basin (Uganda). *AJST* 7 (1), 5163.

25. Mwesigye, A.R., Young, S. D., Bailey, E.H.,& Tumwebaze, S. B. (2016). Population exposure to trace elements in the Kilembe copper mine area, Western Uganda: A pilot study. *Sci Total Environ.* 573:366-375. doi: 10.1016/j.scitotenv.2016.08.125.

26. Najib, L. B., Kazibwe, A., Langergraber, G., Okot-Okumu, J ., & Hein, T. (2015). Performance of subsurface flow constructed wetland mesocosms in enhancing nutrient removal from municipal wastewater in warm tropical environments. *Environmental Technology.* Taylor and Francis. http://dx.doi.org/10.1080/09593330.2015.1095245

27. Nakirya D., Okot-Okumu, J., & Muyodi, F. J. (2015). Microbial Safety Assessment Of Recreation Water At Lake Nabugabo, Uganda. *Afr. J. Environ. Sci. Technol.* 9(10), 773-783. doi. 10.5897/AJEST2015.1979.

28. National Environment Management Authority (NEMA), 2007. *Clean Development Mechanism (CDM).* Uganda solid waste composting project.

29. Natumanya, J., & Okot-Okumu, J. (2015). Evaluating Coagulant Activity of Locally Available *Syzygium cumini*, *Artocarpus heterophyllus* and *Moringa oleifera* For Treatment of Community Drinking Water, Uganda. *Int. J. Biol. Chem. Sci.* ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

30. Nsubuga, F. B., Kansiime, F., & Okot-Okumu, J. (.2004). Pollution of protected springs in relation to high and low density settlements in Kampala—Uganda. *Physics and Chemistry of the Earth.*, 29(15), 1153-1159.

31. Nyiramugisha, J., & Okot-Okumu, J. (2019). Impacts of Land use/Land Cover on Water Quality of River Rwizi, Mbarara Municipality, Uganda

32. Odum, E. P. (1971). *Fundamentals of Ecology*, 3rd Ed. Saunders College Publishing. Philadelphia. ISBN 0-7216-6941-7.

33. Ogle, M. (2010). Gaia Theory: Model and Metaphor for Twenty-First Centuary. In (Crist E and Rinker H. B Eds), *"Gaia in Turmoil; Climate Change, Biodepletion, and Earth Ethics in an Age of Crisis".* SBN-13: 978-0262513524 ;ISBN-10: 0262513528

34. Okot-Okumu, J. (1990). *Development of toxicity tests with Gasterosteus aculearus and Daphnia magna for screening sediments using chlorpyrifos as a model compound.* MSc Thesis. IHE –Delft.

35. Okot-Okumu, J. (2000). *Interaction between a littoral wetland and open lake (Lake Nabugabo) with special reference to phosphorus dynamics.* PhD Thesis, Makerere University.

36. Okot-Okumu, J. (2004). Primary Production and Decomposition of *Loudetia Phragmitoides* (A.Peter) In the Littoral Wetland of a Small Satellite Lake (L. Nabugabo, Uganda). *Afr.J. Ecol.* 42 (suppl.1), 108-113.

37. Okot-Okumu, J (2010).Seasonal Physico-chemical Variation in the Nabugabo Wetlands. *Int.J.Biol.Chem.Sci* 4 (6),2035-2045.

38. Okot-Okumu, J., & Otim, J. (2015). The Quality of Drinking Water Used by the Communities in Some Regions of Uganda. *Int. J. Biol. Chem. Sci*. 9(1), 552-562. ISSN1991-8631.

39. Okot-Okumu. J. (2015).Solid Waste Management in Uganda: Challenges and Options. In: Romeela Mohee, Thokozani Simelane (Eds). *Future Directions of Municipal Solid Waste Management in Africa.* Africa Institute of South Africa, South Africa. ISBN 9780798304238

40. Okot-Okumu, J. (2012). Solid Waste Management in African Cities – East Africa. In: Luis Fernando Marmolejo Rebellon (Ed). *Waste Management an Integrated Vision*. InTech, ISBN 978-953-51-0795-8

41. Okuta, J. .S. (1999). *Nutrient Removal in Semi-continious flow Constructed Wetlands*. MSc Thesis, Makerere University.

42. Ojok, W., Wasswa, J., & Ntambi, E. (2017). Assessment of Seasonal Variation in Water Quality in River Rwizi Using Multivariate Statistical Techniques, Mbarara Municipality,Uganda. *J Wat Res and Protect* (9), 83-97. ISSN Online: 1945-3108;ISSN Print: 1945-3094. http://www.scirp.org/journal/jwarp

43. Oladele, O., Adegbenro, P. D.,& Adewole, M. G. (2011).The impact of industries on surface water quality of River Ona and Riva Alaro in Oluyole Industrial Estate Ibadan, Nigeria. *Afric J F Biotech*. 10 (4): 696-702.

44. Owor, M., Hartwig, T., Muwanga, A., Zachmann, D., &Pohl, W. (2007).Impact of tailings from the Kilembe copper mining district on Lake George, Uganda. *Environ Geol* . (51), 1065–1075. DOI 10.1007/s00254-006-0398-7

45. Raven, P.H., Berg, L.R., & Hassenzahl. (2010). *Environmen*t. (7th Ed). John Wiley and Sons, Inc.ISBN- 13 978-0470-11857-3; ISBN- 13 978-0470-55658-0.

46. Richard, L.A. (1954). *Diagnosis and improvement of saline and alkali soils*. Agric. Handbook 60, Wash., USDA, DC, p. 160.

47. Rowell, D. J. (1994). *Soil science: methods and applications*. Longman

48. Sahtouris, E. (1989). *Gaia the Human Journey From Chaos to Cosmos*. New York.

49. Sekiranda, S. B. K., Okot-Okumu, J., Bugenyi, F.W.B., Ndawula, L.M., &Gandhi, P (2004). Variation in Composition of Macro-invertebrates As an Indication of Water Quality Status in Three Bays in Lake Victoria. *Uganda Journal of Agricultural Sciences*, 9:396-411

50. Ssenku , J. E., Ntale, M., & Oryem Origa, H. (2014). Physico-chemical characteristics of copper tailings and pyrite soils in Western Uganda: Implication for phytoremediation. *Int. J. Env. Monit. Anal.* 2(4), 191-198. doi: 10.11648/j.ijema.20140204.12 ISSN: 2328-7659 (Print); ISSN: 2328-7667 (Online)

51. Toderoiu, F. (2010*). Agricultural Economics and Rural Development*, New Series, Year VII, no. 2, p. 213–238, 2010

52. UNDP–Uganda (2019). *Sustainable Development Goals.* www.ug.undp.org/content/uganda/en /home/sustainable-development-goals.html . (19/03/2019)

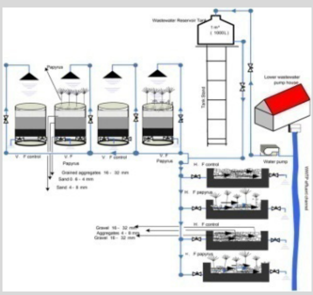
53. Van de Klundert, A., & Anschütz, J., 2001. In; Scheinberg A. Ed. *Integrated sustainable waste management – the concept*. Gouda: WASTE.

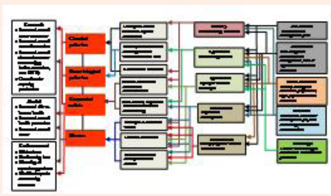
54. Walakira, P., & Okot-Okumu, J. (2011). Impact of Industrial Effluents on Water Quality of Streams in Nakawa-Ntinda, Uganda. *J. Appl. Sci. Environ. Manage*. Vol. 15 (2) 289 – 296.

55. WHO/UNICEF. 2000. *Global Water Supply and Sanitation Assessment Report*. United Nations, New York

APPENDICES

Summary of my research

	Themes	Research Done
Research and Publications Water	Water Quality	Lake Nabugabo system: Water quality, nutrient dynamics; recreation values (PhD project)
		Streams and channels: Land use/cover on Nakawa; Nakivubo, Rwizi, Bwaise
		Forest waters: Mabira, Kitubulu and Zika streams
		Rivers: Gulu and Nwoya districts.
	Community Water Supply	Country wide: Wells, Springs, Boreholes
		Kampala: residual chlorine and quality of piped in the distribution system
	 Alternative Water Treatment	Moringa, Jack fruit (*Artocarpus heterophyllus*), Java plum (*Syzygium*  **Turbidity removal: coagulant concentrations 1 to 6 in the order 0, 20, 40, 60, 80 and 100 mg/l respectively**
		Sand Filtration
	 Wastewater treatment	Constructed wetlands: Kiringa Jinja
		Wastewater treatment using wetland Mesocosm UASB treatment of brewery wastewater: Port Bell

	  *Gasterosteus aculeatus* *Daphnia magna*	Chlorpyrifos($C_9H_{11}Cl_3NO_3PS$) Pesticide toxicity to *Daphnia magna* and *Gasterosteus aculeatus* *Phytolacca dodecandra* toxicity to snails- *Biomphalaria sudanica*
	Air Quality	Urban and rural air quality: Kampala, jinja road Mabira, Kitubulu
Wastes	Solid wastes	Solid waste characterisation Solid waste management 3Rs GHG Emission from solid waste
Pollution	 Environmental pollution	Pollution assessment by Causal chain analysis

Prof. James Okot-Okumu

PROFILE

Prof. James Okot-Okumu holds a PhD in Environmental Science and Natural Resources (Mak), MSc in Environmental Science and Technology (IHE- Delft, The Netherlands), PGD Environmental Science and Technology- Distinction (IHE- Delft, The Netherlands), BSc Hons - Biochemistry and Chemistry (University of Ghana, Legon), Certificate in Environmental Management in Industries (University of Tampere, Finland), Certificate in Basic Principles of Decentralisation (UMI, Kampala). He has over 30 years of professional experience in Environmental Science that includes teaching, research and student supervision at Makerere University and working with Government Departments and the community.

He was the Head of Department of Environmental Management at the School of Forestry, Environmental and Geographical Science, College of Agricultural and Environmental Sciences for 8 years (2011 -2019). His teaching and research interests include: **Water Resources Management, Cleaner Production, Waste Management and Pollution analysis, Environmental and Social Impact Assessment (ESIA) and Environmental Audit.** At Makerere University, he chaired the Course restructuring committee for Environmental Science courses and the review committees on all courses at the Department of Environmental Management. His work experience also includes extensive consultancy in Environment and Natural Resources Management. His academic and professional expertise has enabled him to contribute to Uganda national development in various capacities such as Chairperson of the Technical Committee (UNBS/TC16/SC1) on Petroleum and Petrochemical Products, steering committee member Uganda Water Partnership- Ministry of Water and Environment, steering committee member Global Biodiversity Information Landscape- NEMA. He is am a member of professional bodies including the **International Water Association (IWA), Nature Uganda, Uganda Association for Impact Assessment.** Previous assignments include Lecturing (Biochemistry and Chemistry) at the then Uganda Polytechnic Kyambogo and serving as **a Senior Environment Officer**, Government of Uganda.

Designed & Printed by
Makerere University Printery
P. O. 7062 Kampala - Uganda
Tel: +256 414 541 171
e-mail: pmanager@admin.mak.ac.ug
Website: www.printery.mak.ac.ug