A Systematic Review of Effects of Emerging pollutants on Human Health and Livelihoods of Population living in the Lake Victoria Basin of Kenya

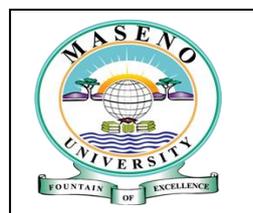**Case study report**

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Acronyms and Abbreviations

ABR	Antibiotic Resistance
ADCL	Appropriate Development Consultants Limited
ARB	Antibiotic Resistant Bacteria
ARGs	Antibiotic Resistance Genes
BDL	Below Detection Limit
BHC	Benzene Hexachloride
BPA	Bisphenol A
CDC	Centers for Disease Control
CE	Cephalosporins
CEC	Contaminant of Emerging Concern
CPs	Chlorinated paraffins
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichloromethyltrichloroethane[1,1,1-trichloro-2,2-bis(4-Chlorophenyl)Ethane]
DEET	Diethyl Toluamide
EDC	Endocrine Disrupting Compound
EMCA	Environmental Management and Coordination Act
EQS	Environmental Quality Standards
FAO	Food and Agricultural Organization
FGD	Focus Group Discussions
FQ	Fluoroquinolones
GC-MS	Gas Chromatography - Mass Spectrometer
GDP	Gross Domestic Product
HBCD	Hexabromocyclododecane
HCB	Hexachlorobenzene
HPLC	High Performance Liquid Chromatography
ICIPE	International Center of Insect Physiology and Ecology
ICRAF	International Center of Research in Agro-Forestry
KBS	Kenya Bureau of Statistics
KEMRI	Kenya Medical Research Institute
LC-MS/MS	Liquid Chromatography- Mass Spectrometric
LOD	Limits of Detection
LV	Lake Victoria
LVB	Lake Victoria Basin
LVEMP	Lake Victoria Environmental Management Project
LVWATSAN	Lake Victoria Water and Sanitation Program
m.a.s.l	Meters Above Sea Level
MA	Macrolides
MAIL	Maximum Allowable Industrial Loading
MFT	Membrane Filtration Technique

MRSA	Methicillin-Resistant Staphylococcus Aureus
MS/MS	Mass Spectrometric
NEMA	National Environment Management Authority
NES	National Environmental Secretariat
NI	Nitroimidazoles
Nm	Nanometers
NMs	Nanomaterials
NPs	Nanoparticles
OCDD	Octachlorodibenzo-p-dioxin
OCDF	Octachlorodibenzofuran
PAHs	Polycyclic aromatic hydrocarbons
PBDEs	Polybrominated Diphenyl Ethers
PCAs	Polychlorinated Alkanes
PCBs	Polychlorinated Biphenyls
PCDD	Polychlorinated Dibenzo-p-Dioxins
PCDFs	Polychlorinated Dibenzofurans
PCFs	Pperfluorochemicals
PCNs	Polychlorinated Naphthalenes
PCPB	Pest Control and Product Board
PCPs	Personal Care Products
PDMSs	Polydimethylsiloxanes
Pen	Penicillins
PFAAs	Perfluoroalkyl acids
PFASs	Perfluoroalkyl sulphonates
PFCs	Perfluorochemicals
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulphonate
POPs	Persistent Organic Pollutants
PPCPs	Pharmaceuticals personal care products f
PPHs	Pharmaceuticals and Hormones
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
QACs	Quaternary Ammonium Compounds
QUOROM	Quality of Reporting of Meta-Analyses
RTDA	Regional Transboundary Diagnostic Analysis
SA	Sulfonamides
TC	Tetracyclines
TCC	Triclocarban
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCS	Triclosan
TrOC	Trace Organic Compound
UHPLC	Ultra-high performance liquid chromatography

UNEP   United Nations Environment Programme
UNFCCC   United Nations Framework Convention on Climate Change
UPLC   Ultraperformance liquid chromatography
U-POPs   Unintentional persistent organic pollutants
US EPA   United States - Environmental Protection Agency
USA   United States of America
USEPA   United States - Environmental Protection Agency
WHOLIS   World Health Organization Library and Information Networks for Knowledge
WWTPs   Waste Water Treatment Plants

Executive Summary

Background and problem statement: Emerging pollutants are synthetic or naturally occurring chemicals or any microorganisms that are not commonly monitored in the environment but have the potential to enter it and cause known or suspected adverse ecological and (or) human health effects. Pharmaceuticals, pesticides, veterinary and personal care products, antibiotic resistant microorganisms, antibiotic resistance genes (ARGs), nanoparticles (NPs), and nanomaterials (NMs) all under the broad category of emerging pollutants. These are commonly derived from municipal, agricultural and industrial wastewater sources and pathways. They pose a growing threat to both surface and groundwater quality and there is an urgent need to better understand their environmental behaviours. Significant research has been performed on this subject worldwide in attempts to obtain information regarding their occurrence, fate and effects on health. In Africa sources of emerging pollutants are not well documented. As a result, information on the extent of their occurrence remains fragmented and scarce. Past studies and projects done in the Lake Victoria basin have focused on commonly known pollutants such as nutrients (nitrogen and phosphorous), biodegradable organic matter, heavy metals and microbial contaminants which have always been considered to be critical pollution parameters within the lake and its basin. Information on the emerging pollutants within the basin is currently not well documented. This document summarizes important findings on review of emerging pollutants in water and wastewater within the Lake Victoria basin of Kenya, the monitoring approaches and existing regulations and guidelines, and the required relevant policy options that are in place.

Methodology: Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, relevant publications on "Emerging pollutants in the Lake Victoria Basin of Kenya", were systematically searched focusing on the five main rivers (Mara, Nyando, Yala, Gucha and Sondu-Miriu) that drain into the Lake Victoria from the Kenyan part of the basin. The search was conducted in repositories of the World Health Organization Library and Information Networks for Knowledge (WHOLIS), U.S Centers for Disease Control and Prevention (CDC), and Food and Agricultural Organization (FAO). Detailed searches were also performed in Google Scholar, SpringerLink, SCOPUS, Web of

Science and PubMed databases and included peer reviewed journals and book chapters that focused on emerging pollutants within the Lake Victoria basin of Kenya for the period between 1996 and 2015.

Results and discussion: A total of 15 studies were found to be relevant and included in this review; the majority reported on emerging pollutants from Nzoia River basin. Not a single study was found touching on emerging pollutants in the Gucha/Migori River basin of Kenya. Only three categories of emerging pollutants (pesticides, perfluorochlorine and antibiotic resistant microbial populations) were found, most (66.7%) of which were studied recently (2010-2015). The findings are a clear attestation to the limited research that has been conducted on other known emerging pollutants over the last 15 years within the Lake Victoria basin of Kenya. This confirms that most of the other known emerging pollutants globally have not been studied in the Lake Victoria basin creating a huge research gap. The discharge of untreated domestic and industrial effluents or of treated effluent from Waste Water Treatment Plants (WWTPs) was highlighted as the major pathway for the introduction of some of the emerging pollutants to surface water sources. Based on the findings, the evaluation of emerging pollutant removal from municipal wastewater should cover a series of aspects from sources to end uses, though this would largely depend on the proportion of waste water that is treated in an area.

Conclusion and recommendations: Despite evidence of increasing sources of emerging pollutants within the Lake Victoria basin, the limited availability of articles on most of the emerging pollutants like veterinary, pharmaceuticals, personal care products, microorganisms, antibiotic resistance genes, endocrine disruptors and other nanomaterials in the five selected river basins within the Lake Victoria watershed of Kenya points to a major gap that needs to be addressed urgently given the potential risk posed to humans and the environment. The review thus recommends more proactive studies on the different categories of emerging pollutants in surface waters and wastewater within the larger Lake Victoria Basin. A better understanding and modelling of the fate of emerging pollutants in surface water is also essential to effectively predict their impacts on the receiving environment. This study further advocates for the development and optimization of highly

advanced, sensitive and accurate analytical methods for the determination of emerging pollutants in environmental samples.

Keywords: Antibiotic resistance genes, contaminant of emerging concern, effluent- derived contaminants, endocrine disruptors, emerging pollutants, human health, Lake Victoria basin, pharmaceutical and personal care products, nanoparticle, nanomaterial, PRISMA, wastewater.

1.0. INTRODUCTION

1.1. Background and Rationale

Emerging pollutants broadly refer to substances for which no regulation currently requires monitoring or public reporting of their presence in water supply or wastewater discharges. Some of the reasons that curtail their regulation include lack of information regarding their occurrence and toxicity and lack of appropriate analytical methods for their determination, or both. The terms "constituents of emerging concern (CECs)', "microconstituents", "trace organic pollutants", and other similar terminologies are often used in the literature as terms for classes of chemicals that fall under the umbrella term "emerging pollutants" (Thomaidis *et al.*, 2012). The United States - Environmental Protection Agency (US EPA) defines emerging pollutants as new chemicals without regulatory status which impact on the environment and human health and are poorly understood (Deblonde *et al.*, 2011).

Over the last few decades, the occurrence of emerging pollutants in the aquatic environment has become a worldwide issue of increasing environmental concern. Scientific research on emerging pollutants has been expanding globally in recent times, aiming to increase the knowledge on the sources, occurrence, fate and toxicity of emerging pollutants and their transformation products. By mid-2000s, there were increasing reports of the occurrence of pollutants in surface waters and sediments of most African lakes (Scheren *et al.*, 2000). Research has also shown the existence and continuous formation of metabolites and transformation products of pharmaceuticals and related compounds in water and wastewater (Calza *et al.*, 2004; Snyder *et al.*, 2006). Findings from various studies conducted in the recent past across the globe also provide evidence of contamination of aquatic system by different types of emerging pollutants partly owing to their ability to persist through wastewater treatment plants (Seehausen, 1997).

However, despite recent advances in research on emerging pollutants, the full extent, magnitude and consequences of their presence in aquatic environments remain largely

unexplored. Furthermore, even the paltry available documented evidence of these pollutants remains scattered and unavailable for review, especially those covering the major rivers and Lakes of Africa.

Up to forty five [45] compounds were listed in the European Union Water Framework Directive by 2013 (EC, 2013) as priority substances accompanying environmental quality standards (EQS) to be followed with respect to aquatic environments, while 10 others were listed on the complementary watch list (Decision 2015/495, published on the 24th of March 2015). Additional studies on emerging pollutants have furtively highlighted the persistent nature of many of these compounds, including pharmaceuticals and hormones (PPHs) and personal care products (PCPs), in wastewater treatment plants (Choubert *et al.*, 2011; Clara *et al.*, 2007; Sipma *et al.*, 2010). Although wastewater discharges present a significant point source of unregulated pollutants including those of emerging concern into aquatic ecosystems, their determination at these point sources, especially in developing countries remains limited. Furthermore, the reasons that prevent their regulation are mostly the lack of information regarding their occurrence and toxicity, the lack of appropriate analytical methods for their determination or both, creating an important gap in knowledge that needs to be addressed.

Emerging pollutants can generally be divided into six categories namely: pharmaceuticals, personal care products (PPCPs), steroid hormones, surfactants, industrial chemicals and pesticides. This systematic review also includes discussion of antibiotic resistant microorganisms and antibiotic resistance genes (ARGs) as well as nanoparticles (NPs) and nanomaterials (NMs) under the broad category of emerging pollutants. A wide range of these pollutants including pharmaceuticals and hormones (PPHs), preservatives from personal care products (PCPs), pesticides, phthalates or artificial sweeteners, steroid hormones, industrial chemicals among others have been reported in some aquatic systems in different parts of the world (Deblonde *et al.*, 2011; Lange *et al.*, 2012; Loos *et al.*, 2013; Luo *et al.*, 2014; Verlicchi *et al.*, 2012). A more recent study by Duris *et al.* (2013) suggests the inclusion of other human source pharmaceuticals, such as antibiotics, caffeine and antiretroviral drugs as emerging pollutants

(Duris *et al*., 2013). Similarly a study by Madoux-Humery, *et al*. (2013) also additionally reported a wide range of pharmaceuticals (carbamazepine, theophylline, and acetaminophen) in a wastewater sewer and singled out carbamazepine as a suitable tracer for wastewater contaminant as it correlated well with presence of *Escherichia coli*.

Studies show that most of the emerging pollutants are harmful not only to the aquatic environment but also to humans (Bolong *et al*., 2009). The low concentration and high diversity of emerging pollutants not only pose a health risk to water users but also creates challenges for water and wastewater treatment processes, further complicated by the fact that current wastewater treatment plants (WWTPs) are not specifically designed to eliminate emerging pollutants. The occurrence of emerging pollutants in aquatic environments have been frequently associated with a number of negative effects, among them short-term and long term toxicity, endocrine disruption, and antibiotic resistance of microorganisms (Fent *et al*., 2006; Pruden *et al*., 2006).

Nevertheless, the ecotoxicological and possible health risks of most emerging pollutants on human health that is associated with their occurrence in the environment are still unexplained. Similarly, questions continue to linger over the potential impacts of emerging pollutants on human and animal health following long-term exposure. The US-Environment Protection Agency (USEPA) estimated that between 10,000 and 20,000 physically diagnosed pesticide illness and injuries occurred widely among agricultural workers per year in developing countries. This in itself is a disturbingly high number relative to the amount of pesticides currently in use (Vorley and Keeney, 1998).

Currently, restricted use of some of the organochlorine compounds is allowed under the Stockholm Convention, for health purposes, though it is suspected that there is ongoing illegal or legal use of some of these compounds in the agricultural, health and other sectors in most developing countries. For instance in Kenya, some organochlorine compounds such as heptachlor are currently allowed for the treatment of power and telephone wire posts to

prevent termite damage. Similarly lindane (gamma-hexachlorocyclohexane, [γ-HCH] is also allowed for use as a component in the manufacture of lotions, creams, and shampoos for the control of lice and mites in humans and in veterinarian products (Abongo *et al.,* 2015). In a joint international community' efforts to phase out Persistent Organic Pollutants (POPs), the Stockholm Convention on Persistent Organic Pollutants was adopted on the 22nd May 2001 in Stockholm, Sweden and entered into force on the 17th of May 2004. Since then, a number of amendments have been made to the convention by the Conference of Parties, at several meetings.

Initially, twelve POPs were recognized as causing adverse effects on humans and the ecosystem and these can be placed in 3 categories: (i) Pesticides: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene; (ii) Industrial chemicals: hexachlorobenzene, polychlorinated biphenyls (PCBs); and (iii) By-products: hexachlorobenzene; polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDD/PCDF), and PCBs. At its fourth meeting held in Geneva, Switzerland, in May 2009, the Conference of the Parties adopted amendments to Annexes A, B and C, in decisions SC-4/10, 4/11, 4/12, 4/13, 4/14, 4/15, 4/16, 4/17 and 4/18 to list 9 (nine) additional chemicals, respectively: i.e. alpha hexachlorocyclohexane; beta hexachlorocyclohexane; chlordecone; hexabromobiphenyl; hexabromodiphenyl ether and heptabromodiphenyl ether; lindane; pentachlorobenzene; perfluorooctane sulfonic acid, its salts and perfluorooctane sulfonyl fluoride; and tetrabromodiphenyl ether and pentabromodiphenyl ether.

At its fifth meeting held in Geneva, Switzerland, in April 2011, the Conference of the Parties adopted an amendment to Annex A, in decision SC-5/3, to list technical endosulfan and its related isomers as a new POP, while at its sixth meeting held in Geneva, Switzerland, in April/May 2013, the Conference of the Parties adopted an amendment to Annex A, in decision SC-6/13, to list hexabromocyclododecane (HBCD) as a new POP. During its seventh meeting held in Geneva, Switzerland, in May 2015, the Conference of the Parties adopted amendments to Annexes A and C to the Stockholm Convention to list three additional POPs: hexachlorobutadiene (decision SC-7/12), pentachlorophenol and its salts and esters (decision

SC-7/13); and polychlorinated naphthalenes (decision SC-7/14). These amendments were communicated by the depositary to all Parties on the 15th of December 2015. These amendments point to the ever increasing list of emerging pollutants into the environment which pose an ever increasing risk to human and ecosystem health.

The Lake Victoria and its basin is faced with increased pollutant load from numerous sources among them anthropogenic activities, industrial effluent, domestic wastewater, sewage – both treated and untreated, landfills among other sources (Anyona *et al.*, 2014). In recent years, the types and sources of pollutants have been diversifying to include those of emerging concern. For instance, despite the ban on the use of Dichlorodiphenyl-1, 1, 1-trichloroethane (DDT), and several other organochlorine pesticides in most countries, their use in the East Africa including the Lake Victoria basin continue unabated, mainly for pest and disease vector control. In Kenya for example, the use of chemical pesticides is still indispensable due to the hot and humid tropical environmental conditions that are conducive to the development of a myriad of pests, weeds, and disease vectors (Dida *et al.*, 2015).

Pesticide use in Kenya is already one of the highest in the sub-Saharan Africa, with many restricted chemicals sometime being used by untrained persons while adulteration of some is common (Gonzalez *et al*., 2003). After farm application, pesticides and their degradation products often dissipate into other environmental compartments including groundwater, surface water, and the atmosphere. In addition to agricultural activities, many urban centres in Kenya have also contributed to emerging pollutants most of which find their way into aquatic systems through surface runoffs and spillage through municipal sewer systems (Mwamburi, 2003; Oyoo-Okoth *et al.*, 2010).

Numerous data sources on water quality of Lake Victoria exist, though the pollutants under assessment did not often include emerging pollutants. Recent research has shown that Lake Victoria is contaminated with pesticide residues, polycyclic aromatic hydrocarbons (PAHs),

polychlorinated biphenyls (PCBs) among others which represent important groups of POPs, have caused worldwide concern as toxic environmental contaminants especially in the Winam Gulf of Lake Victoria where their concentrations have been reported to sometimes exceed the guideline limits for drinking water and aquatic life (Kwach and Lalah, 2009; Ongeri *et al.,* 2009; Wasswa *et al.,* 2011; Onyango *et al.,* 2012; Omwoma *et al.,* 2015).

Pollution of Lake Victoria waters can therefore be attributed to many sources among them domestic treated or raw sewage, industrial effluents, agricultural runoff laden with silt, residual fertilizers, agrochemicals and other indeterminate range of pollutants from urban areas as well as direct atmospheric depositions. The different types of land use practices within the Lake Victoria catchment also contributes to water quality deterioration causing enormous pollution to major water towers in the region (Anyona *et al.,* 2014; Matano *et al.,* 2015). The environmental fate of emerging pollutants has become an issue of concern in Kenya and elsewhere currently, since their residues have been detected in food, drinking water supplies as well as in export products such as fish, fruits and horticultural produce (Madadi *et al.,* 2005, Twesigye *et al.,* 2011). Interestingly, some contaminants have also been detected in edible parts of the three most common fish species Nile perch (*Lates niloticus*), Tilapia (*Oreochromis niloticus*) and Dagaa (*Rastrineobola argentea*) within the Lake Victoria basin of Kenya (Onyuka *et al.,* 2011; Omwoma *et al.,* 2015).

Despite the official ban of some pesticides in Kenya, they are still available in the market, and are being detected in the environment (Kaoga *et al.,* 2013). In addition, lack of well-established monitoring systems makes it difficult to detect or control most of the emerging pollutants. Furthermore, discharge guidelines and standards do not exist for most of the emerging pollutants worldwide.

1.2. Occurrence of Emerging Pollutants in Aquatic Ecosystems

Sources of emerging pollutants in the environment are diverse though many originate from mass-produced materials and everyday consumer products such as shampoos, sunscreens, plastics, pesticides, flame retardants and pharmaceuticals. These sources can be divided into

point-sources and diffuse sources of pollution. Point-source pollutants arise from discrete locations whose inputs into aquatic systems can often be defined. Examples include industrial effluents, municipal sewage treatment plants and combined sewage stormwater overflows, resource extraction, waste disposal sites and buried septic tanks. Diffuse pollutants on the other hand originate from poorly defined sources; often over broad geographical scales. Examples include agricultural runoffs, storm-water and urban runoffs, leakage from urban sewerage systems and diffuse aerial deposition (Thomaidis *et al.*, 2012).

The emerging pollutants like pharmaceuticals are often consumed purposefully or accidentally through ingestion of food and water contaminated with chemicals or through exposure to household chemicals. Emerging pollutants may also enter the aquatic environment through excretion in human and animal urine and feces, and also through flushing of unused medications, household uses, or bathing, and other nanoparticles in the environment. These compounds can also be derived from other human activities such as industrial effluents, agricultural activities, wastewater discharges among others (Bloutsos and Giannopoulos, 2011; Smeti *et al.*, 2011; Kalantzi and Alcock, 2012; Thomaidis *et al.*, 2012; Siddique *et al.*, 2012).

Chemicals such as pesticides are purposefully introduced into the environment to curb pests and diseases, while hospitals also contribute a significant amount of emerging pollutants to the environment through their waste waters. For instance, hospital wastewaters often contain a variety of toxic or persistent substances such as pharmaceuticals, radionuclides, solvents, microbial and disinfectants that are used for medical purposes often in a wide range of concentrations. Shala and Foster (2010) reported that by-products from pharmaceutical and personal care products in urban settings' wastewater treatment facilities can contribute between 1,000 - 2,000 nanograms/litre (ng/L) of a single compound.

Toxics Link (2000) identified several potential sources of these POPs, among them the medical waste incineration and open burning of domestic wastes. According to USEPA (1998) estimates, municipal solid waste incineration and medical waste incineration are among the top sources of

dioxins released into the air. Of all the source categories, combustion sources account for nearly 80% of air emissions. Tangri (2003) however reported that 90-95% of human exposure to dioxins is from fatty foods, particularly meat and dairy products. This is because dioxins accumulate in fats and oils.

1.3. Classes of Emerging Pollutants

Owing to their diversity, emerging pollutants are frequently grouped into categories that best describe their purpose use or characteristics. Pharmaceutical and personal care products (PPCPs) and their metabolites which are often referred to as ''effluent-derived'' contaminants, originally present in wastewater include both prescription and over-the-counter drugs such as medications, hormones, pain relievers, psychopharmaceuticals, lipid regulators, antibiotics (e.g. sulfonamides (SA), fluoroquinolones (FQ), nitroimidazoles (NI), penicillins (pen), cephalosporins (CE), tetracyclines (TC) and macrolides (MA) (Clarke and Smith, 2011; Jury *et al.*, 2011). Other products classified as emerging pollutants include personal care products such as antiseptics (triclosan/triclocarban), sunscreen components and cosmetics. Pharmaceutical and personal care products maintain chemical properties that can vary widely, while their transformation products may be environmentally persistent (Clarke and Smith, 2011; Fent *et al.* 2006).

Plasticizers, brominated compounds and chlorinated paraffins such as Polybrominated Diphenyl Ethers (PBDEs) flame retardants, plastic and insulation compounds; phytoestrogens including plant products that are similar to vertebrate hormones; fluorinated compounds such as perfluorinated compounds (found in surfactants, stain-resistant fabric protectors and non-stick cookware), synthetic musks such as fragrances in perfumes, non-halogenated compounds like formaldehyde, carboxylic acid among others; phthalates which include plasticizers; Bisphenol A: which are additive to plastics; nanomaterials that include manufactured particulates less than 100 nanometers (nm) are also classified as emerging pollutants. Studies show that all antibiotics and many other pharmaceuticals, including PPCPs have the tendency to persist or to be partially degraded during treatment and can even bypass treatment altogether via sewage overflow, therefore, contributing to the pollution load in receiving

waters, some of which are important sources for domestic use (Clarke and Smith, 2011; Hernando *et al.*, 2011; Oulton *et al.*, 2010; Reif *et al.*, 2011; Wells *et al.* 2010).

Other categories of emerging pollutants include those that describe their nature, such as surfactants used in detergents to aid in grease removal and in cosmetics as emulsifiers; or synthetic hormones, which mimic the action of natural hormones. Unfortunately, these categories may overlap, leading to some confusion, and as such there is no standardized set of categories used in most studies on emerging pollutants. For instance, Murray *et al.* (2010) in their review of literature on the occurrence, use, and toxicity of 71 individual compounds classified emerging pollutants into three broad classes of chemicals: industrials, pesticides, and PPCPs. They concluded that the highest priority pollutants that deserve regulation and treatment should include industrials (perfluorooctanoic acid, perfluorooctanic sulfonate, and di[2-ethylhexyl]phthalate), pesticides (diazinon, methoxychlor, and dieldrin), and PPCPs (17α-ethinylstradiol, carbamazepine, 17β-estradiol, Diethyl Toluamide [DEET], triclosan, acetaminophen and estrone) because they occur frequently in freshwater environments and pose a human health hazard at environmental concentrations.

Lapworth *et al.* (2012) characterized emerging pollutants into a wide range of substances among them: pharmaceuticals and PPCPs, illicit drugs, hormones and steroids, benzothiazoles, benzotriazoles, Polychlorinated Naphthalenes (PCNs), Perfluorochemicals (PFCs), Polychlorinated Alkanes (PCAs), Polydimethylsiloxanes (PDMSs), synthetic musks, Quaternary Ammonium Compounds (QACs), Bisphenol A (BPA), Triclosan (TCS), Triclocarban (TCC), polar pesticides, veterinary products, industrial compounds/by-products, food additives and engineered nano-materials.

In recent years, the list of individual compounds belonging to the various categories keeps growing as an increasing number of such compounds and their oxidation/degradation products are being detected in trace levels in the environment. This has been achieved because of the

continuous improvement of the techniques that are now able to determine and quantify some of the emerging pollutants including pharmaceuticals (Kostopoulou and Nikolaou, 2008; Fatta *et al.*, 2007).

1.4. Effect on Emerging Pollutants on Living Organisms and Environment

Scientific research on emerging pollutants has been expanding in global scale, aiming to increase the knowledge on sources, occurrence, fate and toxicity of these compounds as well as of their transformation products. However, there is a general lack of knowledge on the long-term effects of the exposure to low concentrations of emerging pollutants and especially their mixtures (Kostopoulou and Nikolaou, 2008). Therefore, determination of the toxic effects of emerging pollutants in the environment is a subject that requires urgent attention, and simultaneously a great challenge for scientists, taking also into account that they are present in trace concentrations and new ones are continuously being discovered.

1.4.1. Impact on humans and other organisms

The health effects of emerging pollutants depend on a variety of factors, including the level of exposure, duration of exposure and stage of life during exposure. Some pharmaceuticals can persist in the environment and, either via the food chain or drinking water; make their way back to humans. However, the properties and fate of metabolites and transformation products are still largely unknown (Fatta *et al.*, 2007). Recent research has shown that some of these compounds are associated with adverse developmental effects in aquatic organisms at environmentally relevant concentrations (Khetan and Collins, 2007). Studies show that biota can be important environmental 'sinks' for emerging pollutants. For instance, researchers exposed minnow livers to municipal wastewater containing CECs and detected 28 of 32 compounds tested, including PPCPs, hormones, and industrial compounds (Vidal-Dorsch *et al.*, 2013).

The accumulation of dioxins and furans in the environment can reach levels that render water resources unfit for human consumption. Some of the probable health effects of dioxins and furans include the development of cancer, immune system suppression, reproductive and developmental complications and endocrine disruption (Connett, 1998). Connett (1998) further

reported an incident in Netherlands where 16 dairy farmers in Rotterdam could not sell their milk because it contained three times higher dioxin levels than anywhere else in Netherlands.

Another study exposing mosquito fish to reclaimed water in attempts to study the uptake and depuration rates of pharmaceuticals present in the reclaimed water by Wang *et al*. (2013) reported detecting pharmaceuticals, including caffeine, diphenhydramine, diltiazem, carbamazepine, and ibuprofen in the reclaimed water and also in the mosquito fish. Brozinski *et al*. (2013) investigated presence of pharmaceuticals and six metabolites in water samples and fish bile from Lake Haaparjarvi (Finland) detected three compounds in the fish bile samples (diclofenac, naproxen and ibuprofen). Boxall (2012) showed that the occurrence of tetracycline antibiotics in the environment inhibits the growth of some terrestrial and aquatic species as well as cause endocrine disruption of aquatic species.

1.4.2. Impact of Emerging Pollutants on the Environment

Existence and formation of metabolites and transformation products of pharmaceuticals and other emerging pollutants in water and wastewater which affect the environment in various ways has been reported by a number of researchers (Calza *et al*., 2004a; b; Snyder *et al*., 2006). Soils, as the final 'sinks' for some compounds, can retain large concentrations of some emerging pollutants, depending on the physio-chemical properties of each chemical. In a survey of marine sediments conducted in the Pacific Northwest (USA), researchers evaluated 119 PPCPs and 13 perfluoroalkyl substances (PFASs). Up to 14 PPCPs and three PFASs were detected in soils (Jurado-Sanchez *et al*., 2013).

Several studies show that some antibiotics and many pharmaceuticals, including PPCPs have the tendency to persist in the environment or to be only partially degraded during treatment and can even bypass treatment altogether via sewage overflows, therefore, contributing to the pollution load in receiving waters, some of which are important sources of water for domestic use (Hernando *et al*., 2011; Oulton *et al.,* 2010; Reif *et al.,* 2011; Wells *et al*., 2010). In another study, researchers evaluated the impact of introduction of pharmaceutical compounds into the agricultural environment, and reported that irrigation with treated effluent waters increased the

mobility of weakly acidic pharmaceuticals compounds by increasing the soil pH and not through complexation with dissolved organic matter (Borgman and Chefetz, 2013).

A review of water and sediment data for 112 PPCPs in China revealed regional variations in the concentration of PPCPs (Bu *et al.*, 2013). Higher PPCP concentrations were detected in areas with higher population densities. Concerns have also been raised about practices such as wastewater reuse for irrigation, discharge into the sea and other aquatic environments. Khetan and Collins (2007) and Fatta-Kassinos *et al.* (2011) emphasize that practices such as re-use of wastewater in irrigation can raise concerns about the potential effects on non-target organisms, including plants, animals and humans.

1.5. Overview of the Lake Victoria Basin and its Potential Sources of Pollutants

Lake Victoria basin covers an area of 184,400 km^2 and is estimated to provide to the livelihood of 24,824,000 people, which is among the densest and poorest rural populations in the world. Population growth and development are key drivers of pollution and degradation of ecosystems in the basin. The catchment has been transformed from forest and shrub lands into agricultural lands, range lands, human settlement and urban development through the ever increasing human activities and natural processes (ICRAF, 2002). The basin is also undergoing accelerated soil erosion which is strongly linked to decline in agricultural activity, eutrophication of the lake and an overall deterioration of ecosystem structure and function (ICRAF, 2002). These changes have direct influence on pollutant load (including emerging pollutants) into the lake posing a risk to biodiversity and human health.

Major pollutants into Lake Victoria arise from untreated (domestic and industrial) wastewater discharge, excessive use of fertilizers and pesticides, and sedimentation from soil erosion compromising the water quality of adjacent aquatic ecosystems. In Lake Victoria, pollution has been a major problem, since the 1960s, when the lake started experiencing serious decline in water quality negatively impacting on dependent communities. Several chemical pollution studies have detected low levels of pesticides in the water, sediments, plants, and fish species of the Lake (Ejobi *et al.,* 1994; Ruud, 1995; Wasswa, 1997; Ssentongo 1998; Henry & Kishimba, 2000;

Kituyi *et al.*, 2001; Kasozi, 2001). However, though the concentration levels are below the acute toxicity level they may be of concern to the food chain (Wandiga, 2002). A recent report indicates that local authorities collect less than 5% of all household waste in the Lake Victoria Basin implying that the remaining 95% empties into aquatic ecosystems. These form the greatest potential sources of emerging pollutants into Lake Victoria, increasing the risk of harm to the basin's inhabitants. Localised (point sources) pollution has led to serious contamination of Lake Victoria water close to the urban centres and in the enclosed bays, even though the water quality in the main body of the Lake is acceptable. The main source is the direct discharge of untreated sewage into the Lake (LVEMP, 2004). Most industries discharge wastewater directly with no pre-treatment. Although legislation is in place for pollution control, no effective water quality monitoring and enforcement of the regulations is in place.
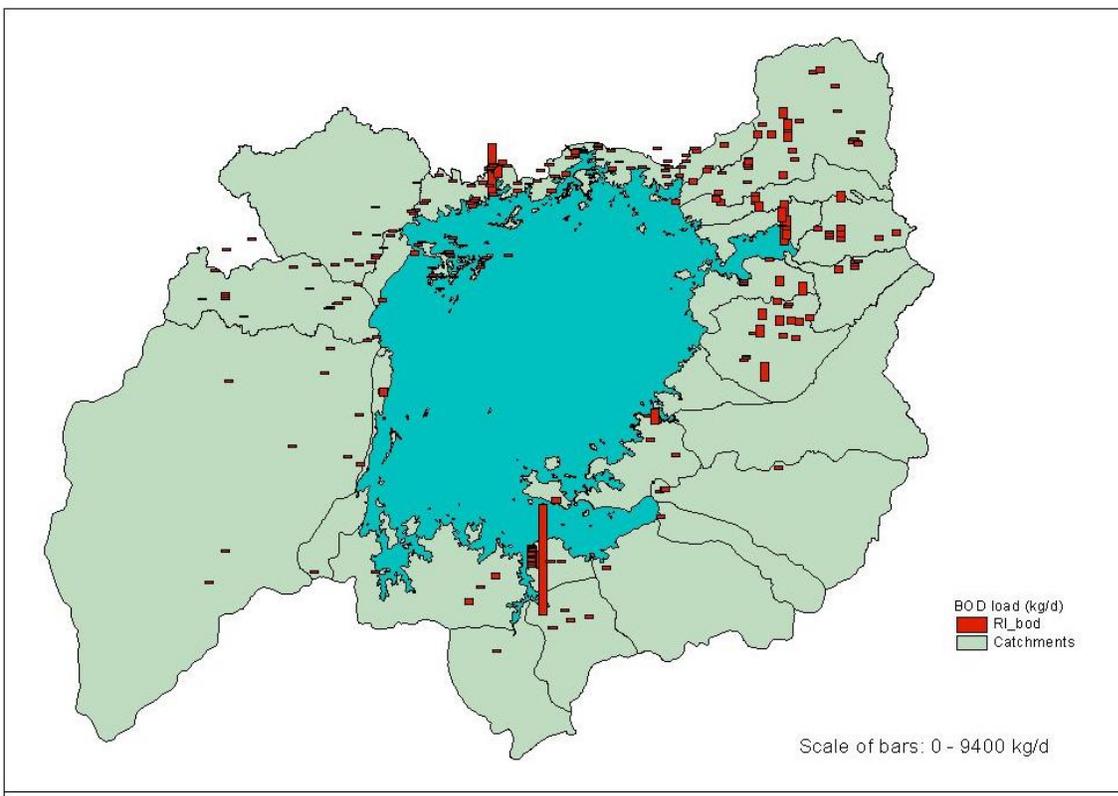
Figure 1.1. Map of Lake Victoria, showing point-sources of contamination

(BOD = Biological Oxygen Demand): *Source, UN-HABITAT (2005).*

In Homa Bay Kenya, the sewage treatment works constructed in 1982, has a design capacity of 750 m³/day. The current daily raw wastewater flow is in excess of 2,000 m³/day. The treatment works thus produces a final effluent which is of a very poor quality, and is discharged directly into the lake. In the town only 22% of the population is connected to the sewerage network. If this connection rate is increased, the capacity of the treatment works becomes even more limited. In addition, although the surface water drainage system is supposed to be separated from foul sewage, many of the peri-urban settlements dispose of blackwater directly to the drains. In periods of heavy rain, there is a huge pollution load to the Lake and local observations note severe eutrophocation in the vicinity of the sewer outfall.

Waste Water Treatment Plants (WWTPs) effluents have been implicated in the presence and persistence of emerging antibiotic resistant microbial populations (Ngumba *et al.*, 2015). Similarly, Methicillin-resistant *Staphylococcus aureus* (MRSA) has gained recent attention as an emerging contaminant of particular concern for the wastewater industry. In a study of hospital wastewaters, Thompson *et al. (*2012) identified numerous MRSA strains in hospital wastewater that were able to survive transport to the WWTPs. However, only three isolates originating from the hospital waste were found post treatment, indicating treatment effectiveness against these types of bacteria. Nonetheless, this research raises questions regarding Antibiotic Resistant Bacteria (ARB) in waste streams from hospitals (Thompson *et al.,* 2012).

To screen for antibiotic resistant bacteria in wastewater, Sigala and Unc (2013) exposed residential, hospital, residential/industrial, WWTPs influent and WWTP effluent wastewater sources to the antibiotics cefaclor, ciprofloxacin, doxycycline, or erythromycin. Arcobacter spp. or *E. coli* dominated bacterial communities exposed to ciprofloxacin or doxycycline, respectively. Petit *et al.* (2013) suggests that while genes responsible for resistance were detected in the isolates, antibiotic occurrence in treated waters was below detection limit. Korzeniewska and Harnisz (2013) demonstrated in their study that despite treatment, municipal wastewater is a pool of antibiotic resistant microorganisms and plasmid-mediated resistant genes. The plasmid-mediated genes were detected in about 10% of the WWTPs final effluent and about

32% in the air at WWTPs. Presence of these genes in the environment facilitates dissemination among environmental bacteria. Additionally, genes encoding antibiotic resistance were shown to be transferrable to an *E. coli* recipient strain. Preliminary disinfection of hospital wastewater onsite before its release into the wastewater piping and treatment system might minimize the spread of ARB to the environment. Nonetheless, these studies raise questions and concerns regarding research on ARB in waste streams and rivers from hospitals within the Lake Victoria basin as well.

Results from studies in the past several years across the globe provide evidence that many emerging pollutants enter aquatic systems because they persist through wastewater treatment processes and are subsequently discharged from wastewater treatment plants into surface water or groundwater and may cause harm to humans and the environment (Seehausen, 1997). However, despite recent advances in research, the full extent, magnitude and consequences of emerging pollutants in aquatic environments are still largely unexplored. Furthermore, even the paltry available documented evidence of these pollutants remains scattered and unavailable for review, especially for the major rivers and Lakes of Africa (including the Lake Victoria basin). Emerging pollutants pose a growing threat to both surface and groundwater quality. Current concerns associated with transport and fate of emerging pollutants within Lake Victoria basin mainly revolve around increase in antibiotics resistance and disruption of the endocrine system among others. There is an urgent need to better understand their occurrence and environmental behaviour.

This report seeks to present a systematic and comprehensive review that will provide updated information on emerging pollutants based on previous studies conducted in five (5) major river basins on the Kenyan side of the LVB. The review will focus on understanding the five river basins' potential contribution to emerging pollutants into the Lake Victoria. The review also provides updates on the sources, transport and fate of emerging pollutants on the LVB and its impacts on the inhabitants' health and livelihoods as well as on the ecosystem health.

2.0. OBJECTIVES OF THE REVIEW

2.1. Main Objective

To collect, review and analyze secondary data on effects of emerging pollutants on human health and livelihoods of populations living along Lake Victoria Basin of Kenyan

2.2. Specific Objectives

(i)   To identify the main sources of wastewater discharged into the major rivers within Lake Victoria basin, Kenya.

(ii)   To determine from already quantified data the emerging pollutants in major rivers within Lake Victoria basin, Kenya

(iii)   To assess the contribution of emerging pollutants to health status of the surrounding population as well as the natural ecosystems in major rivers within the Lake Victoria basin, Kenya.

(iv)   To identify gaps and propose ways of enhancing policy implementation at river basin level within Lake Victoria basin, Kenya.

2.3 Conceptual Framework

Wastewater / pollutants
♦ Industrial effluents
♦ Human settlements
♦ Land use systems
♦ Untreated sewage

Water Quality
♦ Physical parameters
♦ Chemical water quality
♦ Biological water quality

Impacts
♦ Ecosystem health
♦ Human health

Outcome
Effects on Livelihoods
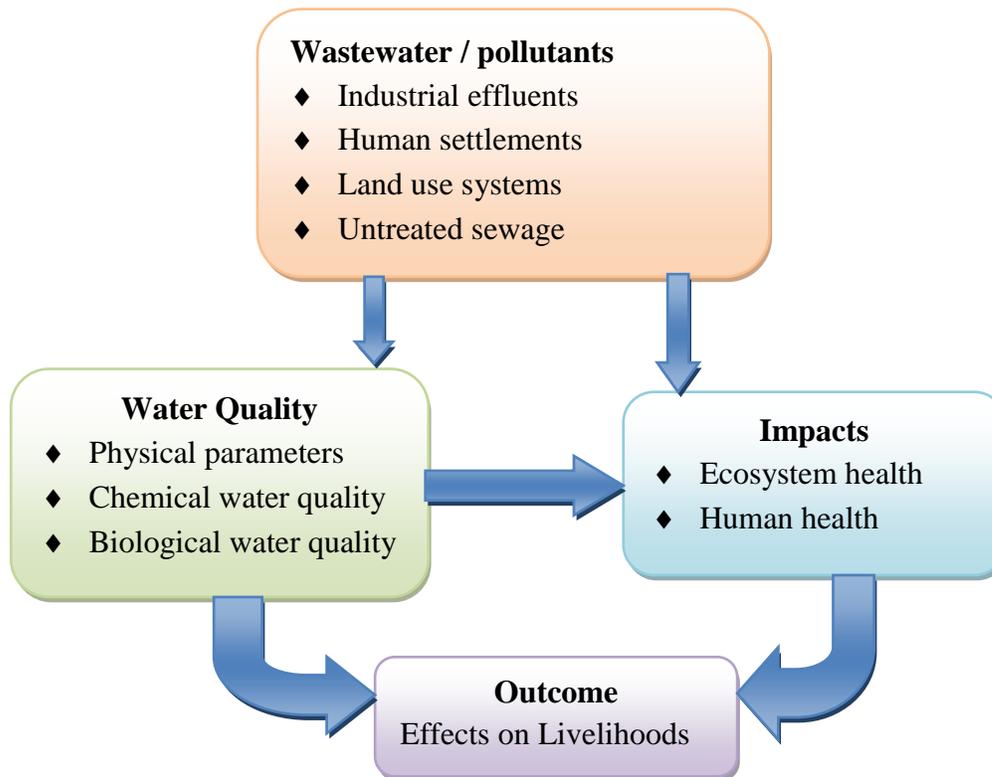
Figure 2.1. Conceptual Framework

3.0 METHODOLOGY

3.1. The Lake Victoria Basin

Geographically, the lake surface is shared between Kenya (6%), Uganda (43%) and Tanzania (51%), while its basin includes parts of Burundi and Rwanda. The largest proportion of the LVB lies in Tanzania (44%), followed by Kenya (21.5%), Uganda (15.9%), Rwanda (11.4%) and Burundi (7.2%) (LVEMP II Report, 2007). Lake Victoria stretches 412 km from North to South between latitude $0^030'$ N and $3^012'$ S and 355 Km from West to East between longitude $31^037'$ and $34^053'$. It is situated at an altitude of 1,134 m.a.s.l, but is characterized by a series of stepped plateaus with an average elevation of 2,700 m but rising to 4,000 m or more in the highland areas. Lake Victoria has a volume of 2,760km^3, with an indented shoreline estimated to be about 3,460 km long. The lake basin area is 194,000 km^2 and the lake surface area is about 68,800 km^2 or 35% of the basin. The Lake Victoria is located in continental sag between the two arms of the Great Rift Valley system, with high mountain ranges on the east and west (Kilimanjaro, Kenya and Rwenzori).

The general climate of the lake basin ranges from a modified equatorial type with substantial rainfall occurring throughout the year, especially over the lake and its vicinity to a semiarid type characterized by intermittent droughts over some areas some of which are even located within short distances from the lake shore. The mean annual rainfall based on rainfall data from 1950-2000, ranges between 886-2,609 mm (COWI, 2002). Land use within the basin has intensified and human and livestock population increased, especially along the lakeshores and on the islands in the lake. Increased pollution from municipal and industrial discharges is visible in some of the rivers feeding the lake and in urban areas around the lake. Some of the key pollution sources to the lake include a number of basic industries (breweries, tanning, fish processing, agro-processing, abattoirs among others). A study by LVEMP on pollutant loads into Lake Victoria indicates that there are 87 large towns within the Lake Victoria Basin (51 in Kenya, 30 in Tanzania and 6 in Uganda) (COWI, 2002). The same study puts the total number of industries in the catchment area at 68 (16 in Kenya, 34 in Tanzania, 18 in Uganda) and is reported to provide employment for up to 30 million people.

Increased nutrient flows from eroded sediments, burning of wood fuels and other anthropogenic factors are also contributing to increased pollution load into Lake Victoria. The causes of rising pollution levels in the Lake are as many as they are diverse and each of the East African nations within the basin is culpable. Pollutant loading from various sources was reported based on data generated by LVEMP from a total of 56 monitoring stations (9 stations in Kenya, 19 in Uganda and 28 in Tanzania) established within the lake to determine in-lake pollution concentrations and 18 monitoring stations established on rivers draining into Lake Victoria. Currently, the catchment area of Lake Victoria is slowly being degraded due to deforestation, poor agricultural practices, industries and domestic effluents spillages into aquatic ecosystem, urbanization among other destructive human activities. As a result the lake has for a long time been a sink to excessive nutrients and untreated effluents that are now threatening not only the ecosystem itself but also the humans and organisms dependent on the ecosystem.

3.1.2. Lake Victoria Drainage Basin

The main rivers flowing into Lake Victoria from the Kenyan catchment are Nzoia, Sio, Yala, Nyando, Kibos, Sondu Miriu, Kuja/Gucha, Migori, Riaria and Mawa (LVEMP, 2003). While the Kagera River which drains Burundi, Rwanda and part of Uganda is the single largest river flowing into the lake.
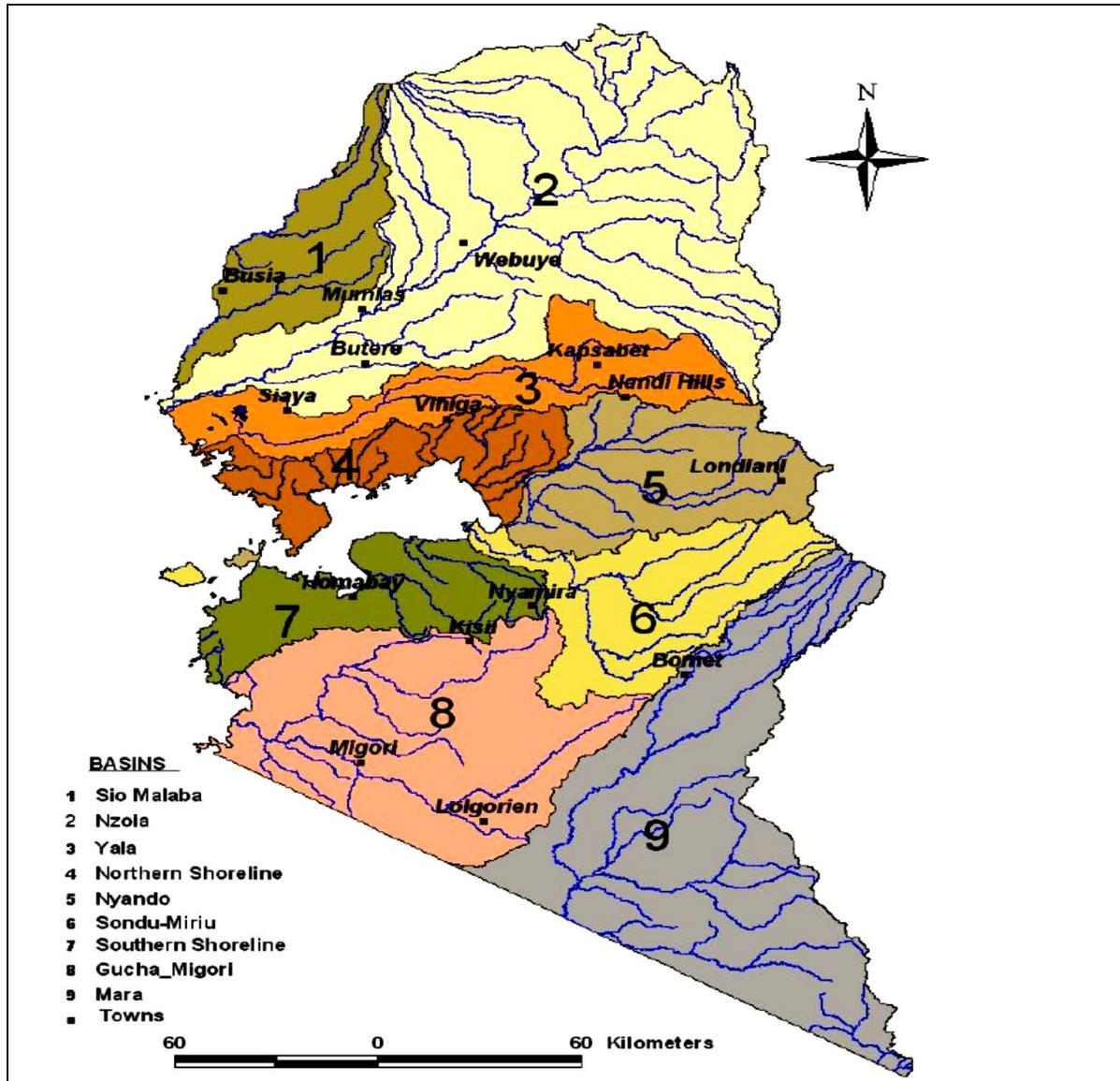
Figure 3.1. Map of the Lake Victoria Basin of Kenya showing major river basins

The rivers discharging their waters into the lake from the Kenyan side of the catchment contribute over 37.5% of the lake surface inflows (COWI, 2002). However about 87% of the total water input into Lake Victoria falls as rain, while evaporation accounts for about 80% (LVEMP II Report, 2007). This review focused on some of the key rivers which originate from the Kenyan side of the basin and drain into Lake Victoria. These include rivers: Nzoia, Yala, Nyando, Gucha and Mara.

3.2. Description of Case Study Rivers within the Lake Victoria Drainage Basin of Kenya

3.2.1. The Nzoia/Yala Rivers

Nzoia river system is the largest river basin in Kenya's Lake Victoria basin and has its source in the forested highlands (Mt. Elgon, Cherangani hills, Nandi Hills and Kakamega forest). The river traverses Trans Nzoia, Bungoma, Butere-Mumias, Siaya and Busia counties in the western part of the country - a region estimated to be populated by over 3.5 million people. Geographically, the River Nzoia basin is situated between latitudes 1^0 30'N and 0^0 05'S and between longitudes 34^0E and 35^0 45'E with an area of 12,709km^2 and a length of 334km up to its outfall into the Lake Victoria. The river experiences perennial flooding in its lower reaches especially the Budalangi area of Busia district. Mean annual discharge of River Nzoia is estimated at 1777x10^{6}m^3/year by ADCL (2006), accounting for 14.8% of the surface inflow into Lake Victoria.

From physiographic and land use point of view, the Nzoia basin has four distinct zones: i.e. mountain zone, plateau zone, transition zone and lowland zone. Mountain zone is forested but suffers severe land degradation; plateau zone is the major farming zone and is characterized by small-scale farming activities which extend through to the transition and the flood prone lowland zones. Major pollutants to the river emanate from the industrial region centred at Webuye, where the river absorbs a lot of effluent from the paper and sugar factories in the area. The Yala River whose basin covers 3,351 km^2 is also one of the main Kenyan rivers draining into Lake Victoria. Its long-term average annual discharge (based on data from 1950 to 2000) is 37.6m^3/s, which accounts for 4.8% of the surface inflow into Lake Victoria (Otiende, 2009).

3.2.2. The Nyando River

The Nyando River basin covers 3,587 Km^2, and varies in altitude from about 3,000 m.a.s.l at the headwaters to 1,184 m.a.s.l at the point of drainage into Lake Victoria. The Nyando River flows from the Mau forest complex into the Winam Gulf of Lake Victoria. It has a long-term average annual discharge (based on data from 1950 to 2000) of 18.0m^3/s, accounting for 2.3% of the surface inflow into Lake Victoria. The river is a major contributor of sediment and phosphorus

to Lake Victoria. The Nyando River basin has been reported to contain some of the most severe problems of environmental degradation and high rates of poverty among the inhabitants.

The River Nyando has been identified as among the most polluted drainage basin on the Kenyan side of the lake (Shepherd *et al.*, 2000). The drainage system traverses formerly three districts (Kericho, Nandi, and Nyando), which are major agricultural and industrial zones in Western Kenya. It serves as a recipient of effluents from tea, coffee, lime and sugar factories. Farming is intense and a wide range of pesticides are used in the drainage basin. In addition, it has the highest slope and rate of sediment transport of all the rivers draining into Lake Victoria. Arguably, poor land-use management practices (e.g., cultivating on slopes adjacent to rivers and on river banks, draining of wetlands and clearance of forest cover to give additional arable land) and intensive use of agrochemicals have resulted in a high flow of nutrients and sediments that have negative impacts on River Nyando and Lake Victoria ecosystems (Peters and Meyback, 2000).

3.2.3. The Gucha-Migori Rivers

Gucha River also known as Kuja is located between 0°55'60" S and 34°7'60" E at an elevation of 1,133 m.a.s.l. It has its headwaters in the highlands around Keroka area, which rise up-to nearly 3000 m.a.s.l at Kiabonyoru peak in Nyamira County and flows through the heart of Gucha district and runs west through Migori town where it forms a confluence with Migori river on the southwestern part of Lake Victoria drainage area in western Kenya. Gucha River is among the tributaries of the greater Gucha - Migori River whose total drainage area is 5,180 km². The total area of the catchment is 2,196 km² (Ojany and Ogendo, 1986).

The Migori River is also located in the south-western corner of the Lake Victoria drainage basin in western Kenya. The Migori River has its headwaters in Chepalungu forest, at altitudes around 2,000 m.a.s.l, and drains a large area west of the Sirian Escarpment which shields the Maasai Mara to the east. The two rivers together have a catchment area which spans over 6,900 km² (Karani, 2005) in Nyamira, Kisii, Migori and a section in the western-most Narok Counties. Considering the Gucha-Migori River system as a whole, the Gucha catchment constitutes

approximately 42% of the total catchment area of the Gucha- Migori River system (Ojany and Ogendo, 1986). The catchment covers large parts of Kisii and Nyamira counties with only a small portion occurring in Migori district in the South Nyanza region. They have a confluence at MaCalder Mines, about 30 km from their mouth on Lake Victoria. The two rivers combined have a long-term average annual discharge (based on data from 1950 to 2000) of $58.0 m^3/s$, accounting for 7.3% of the surface inflow into Lake Victoria. Population growth rate in the catchment is among the highest in the country, being 2.75% per annum and poverty level of 51% (Kenya Bureau of Statistics, 2009).

3.2.4. The Mara River

The Mara River basin covers a surface area of 13,504 km^2, of which approximately 65% is located in Kenya and 35% in Tanzania. The river originates from the Mau Escarpment in the Kenyan highlands, and flows for about 395 km into Lake Victoria at Kirumi swamp in Tanzania. Therefore, though the Mara River drains into Lake Victoria through Tanzania, it originates and traverses large sections of the Kenyan side and in the process is heavily impacted by the various human activities, hence the reason for its inclusion in this review. The Mara river basin experiences extensive degradation resulting from excessive nutrient and agrochemical pollution from agricultural farms; untreated effluent discharges from industry and sewage outfalls; pollution from poorly disposed human excreta and other solid wastes (Anyona *et al.*, 2014); soil erosion due to unsustainable land use and farming practices; encroachment of fragile ecosystems (e.g., wetlands, forests, etc.) in search of new farming land; and siltation of water courses and water storage facilities due to increased sediment loads; among others (Matano *et al.*, 2015).

3.3 Eligibility (Inclusion and Exclusion Criteria)

3.3.1. Inclusion criteria

Studies included in this research describe findings on emerging pollutants and their consequences on health status of the surrounding population and natural ecosystems, with particular emphasis on the five main river basins within the LVB of Kenya.

3.3.2. Exclusion criteria

All non-verified sources of information and information on other river basins besides the five selected rivers were excluded from the review. In addition, articles on other forms of contaminants which are not classified as emerging pollutants were also excluded.

3.4. Study Design

3.4.1. Description of the case study

This case study sought to explore pollution sources, taking into account emergent pollutants such as endocrine disruptors, veterinary, pharmaceutical and personal care products, antibiotic resistant microorganisms and antibiotic resistance genes (ARGs) as well as nanoparticles (NPs) and nanomaterials (NMs) among others under the broad category of emerging pollutants, and their impacts on ecosystems, human health and livelihoods of inhabitants of the Lake Victoria Basin of Kenya. Specifically, this work explored five major rivers draining into the Lake Victoria from the Kenyan catchment, namely: River Nzoia and Yala, River Nyando, River Sondu Miriu, Mara River and River Gucha and Migori. In this review, the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA system) and guidelines proposed by Arksey and O'Malley (2005) was used in the systematic review of the articles on emerging pollutants.

3.5. Development of the PRISMA network meta-analysis extension statement

Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) is an evidence-based minimum set of items aimed at guiding authors to report a wide array of systematic reviews and meta-analyses. The PRISMA statement is a reporting guideline designed to improve the completeness of reporting of systematic reviews and meta-analyses. The main aim of the PRISMA statement is therefore, to help authors improve the reporting of systematic reviews and meta-analyses (Moher *et al.*, 2010). The PRISMA standard supersedes the Quality of Reporting of Meta-Analyses (QUOROM) standard. It is however important to remember that PRISMA is not a quality assessment instrument for systematic reviews but may be useful for critical appraisal purposes.

3.5.1. Search strategy using PRISMA system

Preferred Reporting Items for Systematic reviews and Meta-Analyses guidelines (Dias *et al*., 2013) were used to systematically search for published literature from January 2000 to December 2015 in PubMed, SpringerLink, SCOPUS, Web of Science, WHOLIS, Food and Agricultural Organization (FAO), and U.S Center for Disease Control and Prevention (CDC) databases. To maximize the completeness of the search and reduce selection bias, the search was restricted to English articles using the key teams: emerging pollutants in the LVB. Other search terms used include ''pollution in LVB, wastewater pollutants, among others. During the initial search, studies were selected based on a review of titles and abstracts. All abstracts identified from the indexed databases were screened for eligibility, and the full text of relevant articles was reviewed.

4.0. FINDINGS FROM THE REVIEW

4.1. The Data Sources

This section presents an extended review of available studies and datasets relating to emerging pollutants in five selected river basins within the Lake Victoria Basin of Kenya. All relevant articles with regard to emerging pollutants in the select river basins were fully reviewed and their findings presented herein. Using the key search terms such as: "emerging pollutants, pollution in LVB and Emerging contaminants" a total of 4,010, articles were retrieved through internet search. A total of 2,340 of the articles were sourced from indexed scientific databases [PubMed, SpringerLink and SCOPUS], while 1,670 were sourced from generalized searches in Google Scholar, Web of Science, WHOLIS, FAO and CDC databases.

The 4,010 articles were imported to MS Excel, and 56 articles presenting duplicate titles removed to obtain 3,954 articles. Further screening was done by title and relevance and a total of 3,746 articles excluded from the review leaving a sub-set of 208 articles. The 208 articles were assessed for eligibility by reading through the abstract. One thirty five (135) articles were excluded at this point based on the general exclusion criteria. A Full-text assessment was conducted on the 73 remaining articles and a further 56 articles excluded following the subject matter of exclusion criteria. This resulted in 15 eligible review articles; 14 of which were quantitative studies while one was a qualitative study (**Figure 4.1**).

| 2340 records identified through database searching
Pubmed = 44
SpringerLink/SCOPUS = 2296 | 1670 records identified through other sources (Google Scholar, WHOLIS, Web of Science, FAO & CDC) |

56 duplicate records removed

| 3,954 records screened by title | 3746 articles excluded |

| 208 records screened by title and abstract for relevance | 135 records excluded |

| 73 full-text articles assessed for eligibility | 57 Full-text articles excluded based on exclusion criteria |

1 study included in qualitative synthesis

14 studies included in quantitative synthesis

Figure 4.1. The PRISMA flow chart diagram describing the articles analysis process for inclusion in the review [Adapted and modified from Moher *et al.,* (2009)]

In the present report, a review of the literature data on the occurrence of emerging pollutants in five selected river basins within the Lake Victoria Basin of Kenya between the years 2000 and 2015 is provided. In the review, we refer mainly to the academic journals and peer-reviewed published papers, including working papers and books on emerging pollutants from five selected river basins within the Lake Victoria Basin of Kenya. **Table 4.1** below gives a summary of all available studies that have been documented on emerging pollutants in selected river basins within the Lake Victoria basin of Kenya between the year 2000 and 2015.

Table 4.1. Summary of Emerging Pollutants Studied in the Lake Victoria Basin of Kenya

	Publication Year	Emerging pollutants studied	Instrumental techniques used	Sampling site	Author
1	2015	Carbofuran (2,3-dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate)	HPLC analysis of carbofuran and metabolites on soil bacteria extracted from soil samples.	Bunyala Irrigation Scheme within Nzoia River basin	Onunga *et al.*, 2015
2	2015	Dioxin – like PCBs and PCDD/Fs	Sediment core samples analysed in a high resolution Agilent Technologies 6890 gas chromatography coupled with a MAT 955 mass spectrometer, using isotope dilution technique.	Winam Gulf of Lake Victoria (Kisumu, Homabay and Mbita)	Omwoma *et al.*, 2015
3	2015	Halogenated and non-halogenated hydrocarbons, residual hydrocarbons (bendiocarb, benzene hexachloride (BHC), carbaryl, cypermethrin, decis, deltamethrin, diazinon, dieldrin, DDT, DDD, DDE, malathion, propoxur, sumithion, 5-phenylrhodanine, 1,3,5-trichlorobenzene, 1-(2-phenoxybenzyl)hydrazine)	Water, sediments and papyrus reed plant materials analyzed using validated Gas Chromatography - Mass Spectrometer (GC-MS) method.	Kigwal/Kimondi wetland along River Yala, Nyando and Nzoia wetland ecosystems	Mule *et al.*, 2015
4	2003	Chloroacetanilide herbicides alachlor, metolachlor, and their environmentally stable aniline degradation products 2,6-diethylaniline, and 2-ethyl-6-methylaniline	Analysis of the pesticides in water and sediment samples was performed using a Varian® Gas Chromatograph, model 3400CX	River Nzoia, Kenya	Osano *et al.*, 2003
5	2015	Organochlorine pesticides (DDT, lindane, aldrin, dieldrin, heptachlor, endrin, endosulfan (both α- and β- isomers and endosulfan sulphate), and methoxychlor)	Analysis of levels of residue levels of pesticide in soil samples using gas chromatography	Nyando River Catchment	Abongo *et al.*, 2015

6	2014	Organophosphates and other banned organochlorine pesticides such as lindane, aldrin and dieldrin	Qualitative study in which questionnaire with both open and closed end questions, field observation checklist and measurements of areas of some farms were used.	Nyando River Catchment (Qualitative study)	Abongo *et al*, 2014
7	n.d	Organochlorine pesticide residue: p,p-DDT, o,p'-DDE, p,p-DDD, g-HCH, D-HCH, α-HCH, Aldrin, and Dieldrin	Water samples analyzed using gas chromatography equipped with electron capture detector	Lake Victoria catchment (Rivers Nzoia and Sio)	Madadi *et al*, (2005)
8	2011	Perfluorinated Compounds	Perfluorooctanoic acid and perfluorooctane sulfonate were determined in the sediments using SPE and HPLC-MS-MS analytical methodology	Lake Victoria Gulf Basin	Orata *et al.*, 2011
9	2015 Jan – March 2013	Perfluoroalkyl acids (PFAAs) and their homologues (perfluorooctanoic acid [PFOA] and perfluorooctane sulfonate [PFOS]).	Wastewater and sewage sludge samples from hospital and WWTPs were extracted and separated using solid-phase extraction and ultraperformance liquid chromatography (UPLC)-MS/MS or LC-MS/MS methodology.	Lake Victoria Basin (WWTP in Bungoma, Busia, Kakamega, Kisii and Mumias)	Chirikona *et al.*, 2015
10	2011	Organochlorine and Organophosphorus pesticide residues	Analysis of organochlorine pesticide residues carried gas chromatography equipped with electron capture detector.	Yala/Nzoia River in the Lake Victoria Basin	Musa *et al.*, 2011
11	n.d.	Organochlorine compounds among them (α-BHC, β-BHC, Lindane, Heptachlor, Aldrin, Heptachlore, Endosulfan, Dieldrin, Endrin and Methoxychlor)	Sediment samples analyzed for presence of organochlorine compounds suing gas chromatography equipped with electron capture detector.	River Nyando – Lake Victoria Basin	Maturwe *et al.*, (n,d,)

12	2005	Organochlorines (p,p-DDT, o,p'-DDE, p,p-DDD, δ-HCH, D-HCH, α -HCH, Aldrin, and Dieldrin),	Residue levels of organochlorine pesticides in water samples using gas chromatography equipped with electron capture detector.	Lake Victoria Catchment (River Nzoia, River Sio, Sio Port and Lake Victoria – Marenga Beach)	Madadi *et al* (2005)
13	2008	Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA) in fish muscles and liver	HPLC-MS/MS analysis were carried out with HPLC (HP 1090) interfaced with an Ion Trap MS (Thermo LCQ-Duo).	Winam gulf of Lake Victoria, Kenya	Orata *et al.,* 2008
14	2014	Intestinal *enterococci* and *Clostridium perfringens*	Membrane Filtration Technique (MFT) was used to determine the densities of total coliforms, *Escherichia coli*, intestinal *enterococci* and *Clostridium perfringens*	Nyangores River of Mara catchment, Kenya	Kipsang *et al.,* 2014
15	2015	Chlorsulfuron in Five Wheat Growing Regions Within the Mara River Basin, Kenya	Chlorsulfuron in soil sample analyzed using ultra-high performance liquid chromatography (UHPLC) grade.	Mara River Basin, Kenya	Oguna *et al.,* 2015

4.2. Emerging Pollutants in the Five Selected River Basins

Majority of the reviewed articles on emerging pollutants within the Lake Victoria Basin were done in the Nzoia River Basin and the greater Winam Gulf/ Lake Victoria Catchment, followed by Nyando, then Mara River basin and finally Yala River. No single study was conducted on emerging pollutants within the Gucha/Migori river basin. Some studies encompassed more than one river basin of interest and were included in this review.

Most (73.3%) of the articles reviewed reported on pesticides such as organochlorines, DDT and Aldrin in three river basins (Nzoia, Yala, Mara and Nyando river basins). Other articles reviewed on emerging pollutants included three on perflorinated compounds; two of them within the LVB gulf and the other in the western part of LVB (Bungoma, Busia and Kakamega – Nzoia basin). One study in the Mara River focused on bacterial of interest, intestinal enterococci and *Clostridium perfringens*. The available studies on emerging pollutants that were reviewed are presented in sub-sections that follow.

4.2.1. Pesticides – (herbicides, insecticides and fungicides)

Pesticides, including herbicides, insecticides and fungicides are commonly used in agricultural activities to prevent, destroy or mitigate pests. However, they are considered as priority pollutants due to their adverse effects on the aquatic/ terrestrial organisms and human health. Many pesticides are suspected of being endocrine disruptors with the ability to cause sexual abnormalities and reproductive failure. Despite their ban or restricted use, pesticides are still present in different environmental compartments. This review established that a number of studies (Abongo *et al.*, 2015; Madadi *et al.* 2005; Osano *et al.*, 2003; Maturwe *et al.*, n.d.; Mule *et al.*, 2015) have been conducted to evaluate pesticide residues in surface waters meant for domestic use, some of them recently in various river basins (Nyando, Nzoia and Yala) within the Lake Victoria Basin of Kenya.

For instance, Abongo *et al.* (2015), carried out a study on organochlorine pesticide (DDT, lindane, aldrin, dieldrin, heptachlor, endrin, endosulfan (both α- and β- isomers and endosulfan sulphate), the sum is called "total" or Σendosulfan and methoxychlor) residue levels and

distribution in soils from the Nyando River Catchment, of Kenya. These pesticides have either been banned or restricted for use in Kenya. Their findings revealed the presence of all the targeted pesticides with the highest mean concentrations reported for methoxychlor (138.97±1.517 µg/kg), Σendosulfan (30.267±2.098µg/kg) and aldrin (18.317±0.276 µg/kg), respectively. The wet seasons had percentage higher detection levels than the dry seasons. The findings further showed that the pesticide residue levels leached much more in the wet season than in the dry season due to agricultural run-off. All the pesticide analyzed in this study were banned in Kenya in 1986 except for aldrin, dieldrin, lindane, and DDT, the use of which at the time were restricted to the control of termites in the building industry and in the public health for vector control (Pest Control and Product Board, 1992). Methoxychlor which is not banned or restricted was the most commonly used. The pesticide residue levels detected in the samples were however within the acceptable range of 70-120% (Hill, 2000).

The findings by Abongo (2015) were of importance as increased run-off laden with pesticides and fertilizers from farmlands within the Lake Victoria basin often find their way into the Lake Victoria through the rivers such as Nyando River that drains the basin. The authors further reported that soil samples from the Nandi-Lower Nyando sub-catchment area had more pesticides concentrations than the Kericho-Upper Nyando section. The authors concluded that the presence of these pesticides in soils in the basin could be impacting negatively on the ecosystem health of the area.

Based on the above findings and those from studies conducted by Getenga *et al*. (2004), Abongo *et al*. (2015) in other parts of the Lake Victoria basin, the authors recommended the need to monitor and ascertain the minimum residue levels of organophosphates, and institute a ban or restriction on organochlorine pesticides in soil and aquatic environments within the Lake Victoria. A qualitative study by Abongo *et al*. (2014) using questionnaires administered on farmers in the River Nyando catchment to establish the impacts of pesticides on human health and environment, established that organophosphates and other banned organochlorine pesticides such as lindane, aldrin and dieldrin were still being used by farmers in the

region. A total of fourteen pesticides were identified as commonly used, of which four were toxic to bees and five to birds. Out of the fourteen commonly used pesticides in the Nyando catchment, 14.3% are classified by World Health Organization (WHO 2002) as highly hazardous, 50% as moderately hazardous and 35.7% as slightly hazardous. Agro-chemicals and pesticides reportedly used in the River Nyando Basin are listed in **Tables 4.2 and 4.3** below.

Table 4.1. **Agrochemicals Used in River Nyando Basin and their Recommended Rates**

Trade Name	Active Ingredients	Types of pesticides	Crops	Recommended rate
Actellic	Pirimiphos – methyl	Insecticide	Cereals-maize and sorghum	100 g a.i. per 90 kg sack against storage pests
Dipterex	Triclorfon	Insecticide	Maize and sorghum	1000 g a.i. ha^{-1}
Dithane	Mancozeb	Fungicides	Tomatoes	300 – 500 g a.i. ha^{-1}
Fenthion	O,O-Dimethyl O-[3-methyl-4-(methylthio) phenyl] phosphorothioate	Insecticide	Coffee	983 g a.i. ha^{-1}
Furadan 5G	Carbofuran	Insecticide	Rice and horticulture nursery beds	1000 – 1500 g a.i. ha^{-1}
Karate	Lambdacyhalothrin	Fungicide	Tomatoes, kales, cotton	1kg a. ha^{-1}
Kocide	Copper hydroxide		Coffee	2000 – 2500 g a.i. ha^{-1}
Linulon		Herbicide	Sugarcane	5000 g a.i. ha^{-1}
Milraz	Cymoxanil (ethyl urea) and Propineb (dithiocarbamate)	Fungicide	Tomatoes	300 – 500 g a.i. ha^{-1}
Milthane	Mancozeb	Fungicide	Tomatoes	500 – 1000 g a.i. ha^{-1}
Neocidal	Diazinon	Insecticide	Tea, coffee	1000 g a.i. ha^{-1}
Perfekthion	Dimetoate	Insecticide	Vegetables, fruits trees, tobacco	750 – 1500 ml a.i. ha^{-1}
Ridomil	Mefenoxam and Mancozeb	Fungicide	Tomatoes	500 – 1000 g a.i. ha^{-1}
Round up	Glyphosate Acid	Herbicide	Sugarcane	360 g a.i. ha^{-1}
Sumithin	Fenitrothion	Insecticide	Tea, coffee	500 g a.i. ha^{-1}

g = grams; a.i. – active ingredients; ha = hectare; kg = kilograms

Source: PCPB, 2008

Table 4.3. Pesticides Used in River Nyando Basin their Classifications and Toxicity to Bees and Birds

Product Name	Active Ingredients	Types of Pesticides	Toxic classification	Active Ingredient Toxicity Towards Bees and Birds**	Use by % household
Dursban	Chroropyrifos	Insecticides	WHO II	Toxic to bees, LD_{50} (oral) $0.36\mu g$ bee^{-1}, LD_{50} (contact) $0.07\mu g$ bee^{-1}; toxicity to birds. 32-102 mg kg,$^{-1}$ body mass (chicken), Dietary LC_{50} (8d), 423 mg kg $^{-1}$ body mass bobwhite quail	56
Dithane/Sancozab	Mancozeb	Fungicides	WHO III	Acute, 48 hour LD_{50} 140.6 μg bee-1	60
Sumithin	Fenitrothion	Insecticide	WHO II	Acute, 48 hour LD_{50} $0.16\mu g$ bee^{-1}	78
Neocidal	Diazinon	Insecticide	WHO II	Acute, 48 hour LD_{50} 0.09 μg bee^{-1}	47
Antracol	Propinab	Fungicide	WHO III	-	12
Furadan	Carbofuran	Insecticide	WHO II	Acute, 48 hour LD_{50} 0.036 μg bee^{-1}	36
Caprado 50 WP	Copper Oxychloride	Fungicide	WHO II	-	9
Karate	Λ- cyhalothrin	Fungicide	WHO II	Highly toxic to bees, LD_{50} (oral) $0.038\mu g$ bee-1, LD_{50} (contact) 0.9 μg/bee $^{-1}$	9
Round Up	Glyphosphate	Herbicides	WHO II	-	48
Gramoxone	Paraquat	Herbicides	WHO II	-	33
Ambush CY	Cypermenthrin	Insecticide	WHO III	Acute, 48 hour LD_{50} 0.02 μg bee^{-1}	49
Thiodan EC	Endosulfan	Insecticide	WHO II	Acute, 48 hour LD_{50} 7.81 μg bee^{-1}, acuteoral 205-245 mg kg^{-1} body mass(mallard ducks); 620-1000 mg kg^{-1}bodymass (ring-necked pheasant)	13
Stalladone	Chlorfenviphos	Insecticide	WHO I	LD_{50} (24h, oral) 0.55 μg bee^{-1},(tropical); 4.1 μg bee^{-1}, acute oral LC_{50}pheasant 107 mg kg^{-1} body mass ; LC_{50}pigeons 16 mg kg^{-1} body mass, ; LC_{50}mallard ducks 490 mg kg^{-1} body massLC_{50} house sparrow 122 mg kg^{-1} body mass.	64
Tactic/Tixfix	Amitraz	Acaricide	WHO III	Low toxicity to bees LD_{50} (contact) 50μg bee^{-1}; LD_{50} bobwhite quail 788 mgkg^{-1} body mass; LC_{50} (8d) mallard ducks7000 mg kg^{-1} body mass, Japanese quail1800 mg kg^{-1} body mass.	40

The dosage of most commonly used pesticides according to the households interviewed ranged between 750-1,500 mL a.i ha^{-1} (a.i, active ingredient) to 3,000-5,000 mL a.i ha^{-1} in some areas, while round up (Glyphosate), with application rate of 3,000-5,000 mL a.i ha^{-1}was reported as the most commonly used herbicide. The findings by Abongo *et al.* (2014) further showed that up to 44% of the farmers in river Nyando catchment area were not aware of the existence of a ban or restrictions imposed on some pesticides in Kenya (PCPB, 2008). The authors however, observed that some of the pesticides present within the Nyando catchment could have easily found their way into the region from other districts such as Nakuru where obsolete stock piles have been reported in the past (NES, 2006).

According to the farmers the most significant environmental impact of pesticides usage observed were the decline in abundance of pollinating bees (40%) and butterflies (18%), the disappearance of the red-billed oxpecker bird (*Buphagus erythrorthynchus*) (20%) and the death of other non-target insects when or after spraying (12%) and wildlife mortalities (10%). Chlopyrifos, a systematic insecticide used against a wide range of pests such as thrips, caterpillars and leaf miners was reported to be responsible for the highest number (15%) of symptoms of ill health in the study area followed by fenitrothion (*O,O*-Dimethyl *O*-[3-methyl-4-nitrophenyl] phosphorothioate) (10%) and diazinon (*O,O*-Diethyl *O*- [4-methyl-6-(propan-2-yl)pyrimidin-2-yl] phosphorothioate) (8%). Over 9% of the farmers also reported feeling ill after exposure to pesticides but could not attribute their sickness to any specific pesticide.

Another study in the Lake Victoria catchment by Madadi *et al.* (2005) on the status of persistent organic pollutants in Lake Victoria catchment sought to investigate the residues levels of p,p-DDT, o,p'- DDE, p,p-DDD, g-HCH, D-HCH, a-HCH, Aldrin, and Dieldrin, in water samples from River Nzoia, River Sio and Lake Victoria during the short rain, dry, and wet seasons. The authors reported concentration for the analyzed pesticides ranged from below detection limit (BDL) - 0.044 µg/l in River Nzoia water, between BDL - 0.34 µg/l in river Sio water, BDL - 0.26 µg/l in water from Sio Port, and between BDL - 0.31 µg/l in water from Lake Victoria at Marenga Beach. Organochlorine pesticide residues detected in water collected during the short

rain season were higher in river samples compared to the levels detected in the lake water samples. p,p'-DDT, o,p'-DDE, p,p'-DDD and dieldrin constituted the highest residues detected during the short rain season, whereas -HCH was the least.

The residue levels of DDT and HCH detected during the wet season were, however, below the World Health Organization (WHO) recommended guidelines except for aldrin and dieldrin. The fact that the detected residues of dieldrin were higher than those for aldrin signified previous use of aldrin in the region or direct application of dieldrin in efforts to eliminate locusts. Analysis of seasonal variations of the residue levels across the three seasons indicated that samples collected from river Nzoia during the short rain season contained the highest amount of pesticide residues except for aldrin while the dry and wet seasons had higher aldrin concentrations. The authors attributed the high levels of residues detected during the short rain season compared to the dry season to contributions through runoff from fields where those compounds were previously applied. On the other hand the low residue levels detected during the wet season compared to the short rain season were attributed to dilution effects based on large volumes of rainwater.

A study on the fate of chloroacetanilide herbicides and their degradation products in the Nzoia Basin, Kenya by Osano *et al*. (2003) sought to analyze Alachlor, Metolachlor and their respective environmentally stable aniline degradation products, 2,6-diethylaniline and 2-ethyl-6-methylaniline in water and sediment samples from 9 sites along River Nzoia, using gas chromatography. The degradation products were detected in > 90% of the sediment and water samples, while the parent compounds occurred in < 14% of the water samples. Higher concentrations of pesticides were detected in soil sediments than in the water of up to 800-fold, indicating a high accumulation of the compounds in the sediments.

The authors also observed constant occurrence of the degradation products in the sediment during the study period denoting persistence of these compounds. They further presupposed that the prevailing tropical climatic conditions favored a quick breakdown of the pesticides to

their environmentally stable degradation products, thereby making the latter a more important pollutant than their parent products in the study area. Potential major sources of pollution for the River Nzoia as reported by the authors included agricultural chemicals, urban effluents from various towns including Eldoret (population 234,000), Kitale (pop. 88,100), Bungoma (pop. 32,900), Webuye (pop. 45,100), Kakamega (pop. 86,500), Mumias (pop. 36,200); and industrial wastes from the Panpaper pulp mills at Webuye; textile factories in Eldoret; coffee factories scattered in the higher regions; and sugar industries mainly at Mumias, Kakamega, and Bungoma districts.

Musa *et al.* (2011) studied organochlorine and organophosphorus pesticide residues in water and sediment samples from Yala/Nzoia River within Lake Victoria Basin, Kenya through a study in which they employed both qualitative and quantitative design. The authors sought to make an inventory of the types of pesticides used in Yala/Nzoia catchment using a structured questionnaire, observation and focused group discussions (FGD) among large-scale and small-scale farmers, and stockist shops. More information was also gathered from offices of the Ministry of Agriculture, Livestock and Ministry of Health. To complement this, field sampling of water and sediment samples from nine selected sites at the Yala/Nzoia basin were also conducted. The study established that the banned organochlorines were still in use in the Yala/Nzoia catchment, with the most commonly used pesticides being organophosphates, and organochlorines as well as a few pyrethroids (Table 4.4).

Table 4.2. **Pesticides most commonly used in Yala/Nzoia catchment area during the study period**

Agricultural farms		
Family	Trade Name	Active Ingredient
Organophosphates	Diagran (I)	Diazinon(II)
	Basudin (I)	Diazinon (II)
	Diazole (I)	Diazinon (II)
	Fenom (I)	Diazinon (II)
	Perfekthion (I)	Dimethoate (II)
	Attain (F)	Malathion (III)
	Lysol (I)	Malathion(III)
	Roundup (H)	Glyphosate Acid(II)

	Steladone (A)	Chloropyrifos(II)
	Dursban (A, I)	Chloropyrifos(II)
	Actelic Super (I)	Primiphos-methyl(IV)
	Mboga dust (I)	Fenitrothion(III)
	Sumithion (I)	Fenitrothion(III)
	Skanar Super (I)	Malathion(III)
	Sulban (I)	Chloropyrifos(II)
	Kelthane (I)	Pirimiphos-methyl(IV)
	Velpar (H)	Hexazinone(IV)
	Diazole (H)	Diazinon(II)
	Gesapak Combi (H)	Ametryn + Atrazine(IV)
	Dual gold (I)	Pirimiphos-methyl(IV)
Organochlorines	Alanex (H)	Alachlor(IV)
	Akarint (I)	Dicofol(II)
	Pentac (I)	Dienochlor(IV)
	Mitigan(I)	Dicofol(II)
	Chlortox (I)	Chlordane(III)
	Velsicol (I)	Heptachlor(II)
	Novadrin (I)	Aldrin(II)
	Murtano (I)	Lindane(I)
	Nendrin (I)	Endrin(II)
Pyrethroids	Karate (I)	Lambdacyhalothrin(III)
	Brigade (I)	Bifenthrin(II)
	Bulldock (I)	Niclosamide(IV)
Small-scale shops in catchments		
Family	**Trade Name**	**Active Ingredient**
Organophosphates	Diazole (I)	Diazinon(II)
	Diagran(I)	Diazinon(II)
	Basudin(I)	Diazinon(II)
	Fenom (I)	Diazinnon(II)
	Attain (F)	Malathion(III)
	Skanar Super (I)	Malathion(III)
	Roundup (H)	Glyphosate Acid(II)
	Dursban (I)	Chloropyrifos(II)
	Steladone (A)	Chloropyrifos(II)
	Actelic Super (I)	Primiphos-methyl(IV)
	Sulban (I)	Chlorophyrifos(II)
	Mboga dust (I)	Fenitrothion(III)
	Sumithion(I)	Fenitrothion(II)
	Velpar (H)	Hexazinone(IV)
	Kelthane (I)	Pirimiphos-methyl(IV)
	Hostathion (A, I, N)	Triazophos(II)

	Folimat (A, I)	Omethoate(II)
	Nemacur (N)	Fenamiphos(II)
	Miratex(I)	Bromadiolone(II)
	Orthene (A, I)	Acephate(IV)
	Diazole (H)	Diazinon(II)
	Dual gold (I)	Pirimiphos-methyl(IV)
	Gesapak Combi (H)	Ametryn + Atrazine(IV)
	Lysol (I)	Malathion(III)
Organochlorines	Alanex (H)	Alachlor(IV)
	Pentac (I)	Dienochlor(IV)
	Akarint (I)	Dicofol(II)
	Mitigan (I)	Dicofol(II)
	Chlortox (I)	Chlordane(III)
	Velsicol (I)	Heptachlor(II)
	Nendrin (I)	Endrin(II)
	Murtano (I)	Lindane(I)
	Novadrin (I)	Aldrin(II)
Pyrethroids	Karate (I)	Lambdacyhalothrin(III)
	Brigade (I)	Bifenthrin(II)
	Bulldock (I)	Beta-cyfluthrin(IV)
	Krismat (I)	Lambdacyhalothrin(III)

*I = Insecticide, A = acaricide, H = herbicide, N = nematicide, R = rodenticide. I, II, III and IV= WHO category.

Once pesticides are applied in an area, some are likely to remain in the environment for many years, though others are readily degraded. In the above scenario, the residue levels detected in sediment samples collected during the rainy season ranged from 0.05 to 59.01 μgkg^{-1}, whereas during the dry season, they ranged from below detection limit (BDL) to 24.54 μgkg^{-1}. The concentrations of dieldrin and p,p'-DDD were notably higher than aldrin and p,p'DDT, respectively, in most of the samples. No organophosphates were detected (or were below detection limit) in any of the water and sediment samples. Pesticide residue levels of organochlorines in water samples from Yala/Nzoia river basins were BDL both during the rainy and dry seasons (**Table 4.5**) [PCPB, 2009].

Since then, the debate for or against the use of DDT in Kenya with the Kenya's premier research institute, Kenya Medical Research Institute (KEMRI), taking a strong stand for its re-

introduction, while another research institute, the International Center of Insect Physiology and Ecology (ICIPE), taking the anti-DDT view. Currently, the use of alternatives such pyrethroids are strongly recommended, while DDT use is banned, except for emergency control of mosquitoes under incidences of malaria epidemics.

Table 4.3. **Mean concentration (± SE) of organochlorine pesticide residues in water and sediment samples from Yala/Nzoia Basin during rainy and dry season.**

Pesticide name	Rainy season		Dry season	
	Water (μgL^{-1})	Sediment (μgkg^{-1})	Water (μgL^{-1})	Sediment (μgkg^{-1})
α-HCH	BDL	1.81±0.006	BDL	4.41
β-HCH	BDL	0.92±0.017	BDL	2.76
Υ-HCH	BDL	6.43±0.012	BDL	16.03
p,p'-DDT	BDL	7.16±0.012	BDL	9.48
o,p-DDE	BDL	6.21±0.006	BDL	4.21
p,p'-DDD	BDL	15.66±0.035	BDL	13.16
α-Endosulfan	BDL	5.96±0.023	BDL	13.2
Endosulfan sulfate	BDL	2.88±0.012	BDL	5.35
β-Endosulfan	BDL	0.05±0.006	BDL	BDL
Aldrin	BDL	12.67±0.023	BDL	12.71
Dieldrin	BDL	59.01±2.121	BDL	24.54
Endrin	BDL	18.13±0.012	BDL	8.64
Heptachlor	BDL	9.58±0.046	BDL	10
Heptachlor epoxide	BDL	3.44±0.023	BDL	8.76
Methoxychlor	BDL	14.78±0.040	BDL	2.52

*BDL = Below Detection Limit

The concentration of dieldrin and p,p'-DDD were notably higher than aldrin and p,p'DDT, respectively, in most of the samples. Since the former are their degradation products, this indicated possible transformation process taking place on p,p'-DDT and aldrin previously used in the region. This is because dieldrin is a degradation product of aldrin. Sunlight and bacteria changed aldrin to dieldrin which in soil and water degrades slowly (ATSDR, 2002). The dieldrin concentrations were relatively higher compared to the p,p'-DDT concentrations. This is an indication that dieldrin is probably still in use within the basin. High residues of lindane, endosulfan and heptachlor in the environment indicates that some farmers are still applying

them illegally, and hence more strict control measures against the use of these compounds needs to be put in place. The organochlorine residues detected in sediment in both seasons were however below the World Health Organization recommended guidelines.

The survey by Musa *et al.* (2011) further established that a number of organophosphates including diazinon and malathion were present in the stockiest shop and were being used in the farms. The seasonal changes were observed to influence the concentration of pesticides in the field samples. The pesticide residues in various samples depicted a general trend of concentration levels in rainy season higher than in dry season. Since the major aspect of seasonal changes was rainfall, it would imply that most residues were washed off from agricultural fields by the storm water into the rivers and the lakes. The study also showed that the banned organochlorine pesticide compounds were still in use in the Yala/Nzoia basin even though their concentrations were below the minimum levels and may not pose environmental and human risks to consumers. Regardless, there is an increasing need for constant monitoring of these compounds in the aquatic ecosystem to ensure the protection of the aquatic ecosystem. There is also the need to establish maximum permissible levels of toxic substances for protection of aquatic biota.

Onunga *et al.* (2015), on the other hand focused on carbofuran pesticide in the River Nzoia Basin in attempts to establish the capacity of native bacteria to degrade carbofuran in soils. Carbofuran (2, 3-dihydro-2, 2 dimethyl-7-benzofuranoyl N-methylcarbamate) is a broad-spectrum carbamate insecticide, acaricide and nematicide which belongs to the Nmethylcarbamate class that is extensively used in pest control. It is widely used in the control of pests such as corn root worm, wire worms, boll weevils, mosquitoes, alfalfa weevils and white grubs. It has been also used worldwide for the control of rice pests such as green leafhoppers, brown planthoppers, stem-borers and whorl maggots. Carbofuran has rapid action against both nymphs and adults, killing them within 20 min. However, accidental exposure of carbofuran can result in acute toxicities and fatalities even to wildlife and human beings, thereby making it highly hazardous.

The study by Onungo *et al.* (2015) established that carbofuran has been used in Nzoia River drainage basin, especially in Bunyala Rice Irrigation Scheme's nuclear estates for the control of pests (Mohanty *et al.*, 2009). A study done by Kimosop *et al*. (2011) in the same area on the dissipation behavior of carbofuran in the soil established that residual levels of carbofuran ranged from 0.01 – 1.08 mg kg^{-1} in the soils, indicating environmental contamination. Therefore, the detoxifications of the contaminated sites are necessary. Wetland birds have also not been spared by the poisoning of the riverine zone. For instance, storks, egrets and other wetland wading birds have been reported extinct as a result of poisoning (Odino and Ogada, 2008). Grassland birds and raptors are often affected by poisonous pesticides because they are seedeaters and predators, respectively, which are often attracted by the food resources concentrated at rice irrigation plantations. Odino and Ogada (2008), sought to conduct a minor, random survey on the availability, use and regulation of Furadan in Kenya from the end of 2007 into 2008. He surveyed on pastoralist and plantation farming sites for Furadan availability and use as a poison (Figure 4.3).
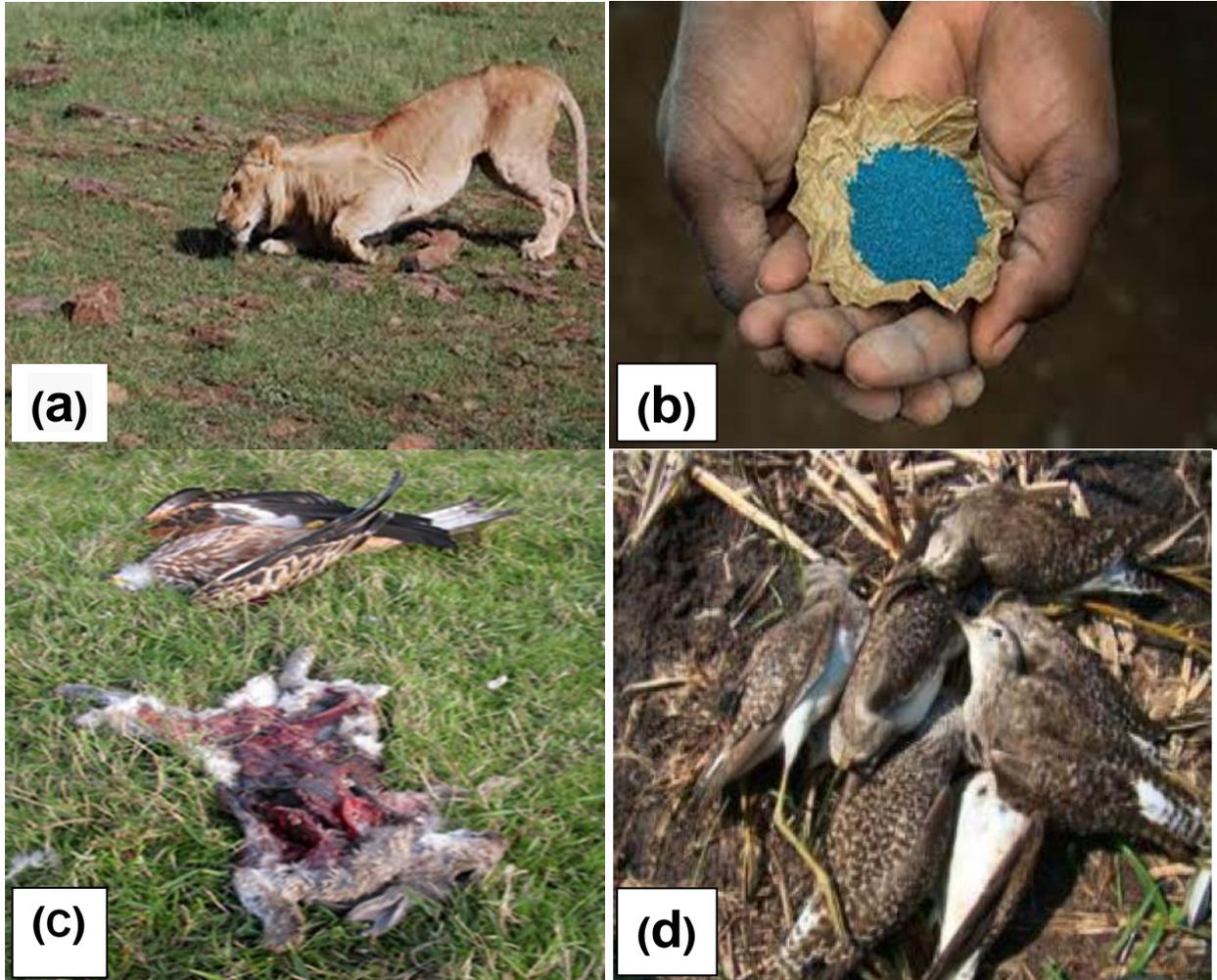
Figure 2.3. (a) Wild lioness immobilized by illegal poison bait along the Mara River, (b) Carbofuran pellets; (c) the brown hare and, (d) Wood sandpipers carcass that were laced with the highly toxic agricultural pesticide Furadin along Nzoia River (Source: Odino, and Ogada, 2008)

Maturwe *et al*. (n.d) in a book chapter on pesticides and heavy metals contamination in the Lake Victoria Basin, Kenya sought to generate information on the levels of pesticide residue levels in soil, sediments and water from river Nyando catchment area, where various pesticides are used for agricultural production. Their findings showed the presence of organochlorine compounds among them (α-BHC, β-BHC, Lindane, Heptachlor, Aldrin, Heptachlore, Endosulfan, Dieldrin, Endrin and Methoxychlor) in different concentrations in soils from fields and in water collected from various sampling points (Table 4.6 & 4.7).

Table 4.4. Concentration (μg/g) of organochlorine compounds in the soil from fields applied at different times (2, 6, 12 and 60 months) before May 2002

Pesticide	2 months	6 months	12 months	60 months
α-BHC	3.758	0.939	0.681	0.434
β-BHC	5.022	0.308	0.273	0.25
Lindane	2.579	1.283	1.27	1.294
Heptachlor	7.924	0.396	0.482	0.317
Aldrin	4.088	0.861	0,811	0.534
Heptachore	3.522	0.283	0.25	0.243
Endosulfan	1.242	0.513	0.891	1.552
Dieldrin	3.512	0.542	0.568	0.473
Endrin	4.693	0.142	0.052	0.31
Methoxychlor	1.026	0.049	0.022	0.475

Table 4.5. Concentrations (ppm) of organochlorine compounds in water from different sampling points along Nyando River

Pesticide	Mbogo	Nyando 1GD7	Nyando 1GD3	Nyando 1GD2	Kedowa	Ahero channel	Ainamotua 1GDB3
α-BHC	0.379	0.211	0.182	0.176	0.691	0.251	0.113
β-BHC	0.046	0.0112	0.0095	0.0091	0.035	0.014	0.0073
Lindane	1.24	0.0433	0.039	0.034	0.095	0.104	0.027
Heptachlor	0.07	0.0102	0.0086	0.0062	0.07	0.011	0.0063
Aldrin	0.089	0.0083	0.0046	0.0033	0.089	0.0055	0.0034
Heptachore	0.0048	0.0029	0.0034	0.0024	0.0048	0.0036	0.0027
Endosulfan	BDL	0.0101	BDL	BDL	BDL	BDL	BDL
Dieldrin	0.096	0.0052	0.0018	0.0011	0.096	0.096	0.0024
Endrin	0.031	0.0011	0.0011	BDL	0.031	0.031	0.0004
Methoxychlor	0.022	BDL	BDL	BDL	BDL	0.0404	BDL

BDL = Below Detection Limit

A different study on retention efficiencies of halogenated and non-halogenated hydrocarbons in selected wetland ecosystem of Nyando, Nzoia and Kigwal/Kimondi wetland along River Yala in the Lake Victoria basin by Mule *et al.* (2015) reported the presence of residual

organochlorines, organophosphorus, carbamates and synthetic pyrethroid hydrocarbons in water, sediment and plant materials.

From the analysis, several residual hydrocarbons were detected and quantified. River Nyando wetland recorded mean percentage retention efficiencies of 76 and 94% for dry and rainy seasons, respectively; Kigwal/Kimondi wetland had seasonal mean percentage retention efficiencies of 63 to 78%, while River Nzoia had percentage retention efficiencies of between 56 to 88%.

Mule *et al.* (2015) established that generally the dry season had lower mean percentages retention efficiencies of the organophosphates compared to the rainy season across the three wetlands probably due to inadequate soil moisture during dry seasosn. The authors observed that retention efficiencies of tropical wetland ecosystems were greatly affected by anthropogenic activities, physical properties of the hydrocarbon, and environmental conditions among others. Several anthropogenic activities have been mentioned as possible contributors to the presence and levels of hydrocarbons in the wetlands, including agricultural, municipal, industrial and public health activities.

Organochlorine pesticides have been extensively used for agriculture and vector control purposes in Kenya (Gitahi *et al.,* 2002). Pesticides are transported to aquatic bodies by surface runoff into rivers and streams thus impacting associate with biotic and abiotic macro-particles (Wandiga *et al.,* 2002; Getenga *et al.,* 2004). They are removed from the water surface to benthic layers by settling of particles (Wandiga *et al.,* 2002). The hydrophobicity, low chemical and biological degradation rates and lipophilic nature of Organochlorine pesticides have led to their accumulation in biological tissues and the subsequent magnification of concentrations in organisms progressing up the food chain (Mavura and Wangila, 2004).

Getenga *et al.,* (2004) found lindane, endosulfan, heptachlor, aldrin, heptachlor epoxide, dieldrin, endrin and methoxychlor residues in water samples collected from rivers draining the

sugarcane fields, and in soils from sugarcane fields that constitute Lake Victoria basin. They found residues levels of lindane to be the highest, at an average concentration of 0.219 ± 0.091 mg/l for sediment from six points, except one point that showed concentration as high as 0.691 mg/l. The same study reported the highest concentration of lindane in water to be 1.240 mg/l. The study concluded that the greatest development challenges currently facing Lake Victoria and its basin is increasing pollution sources, subsequently leading to decline in food security which contributes to the perpetuated poverty in the region. The basin can therefore no longer support the over 40 million people who depended on it directly or indirectly.

A study by Twesigye *et al.,* (2011) in three selected sub-basins within the Lake Victoria Basin among them Nzoia River basin aimed to establish the impact of land use activities on vegetation cover and water quality in the Lake Victoria watershed using remote sensing technology and water quality analysis techniques. The remote sensing technologies were applied in tracking land degradation status and its impacts on the aquatic ecosystem, and its potential for accurate remote sensing assessment of the changes in land use patterns of the watersheds as the primary sources of pollution to Lake Victoria. The findings showed that soils from some selected fields in Nzoia River basin showed high levels of compounds such as aldrin, dieldrin, endosulfan, DDT, and endrin. The researchers observed that the results from effluent analysis from Nzoia area clearly showed that the effluents from the industries are not adequately treated and therefore, impact negatively on the quality of the receiving waters.

4.2.2. Pesticides as Emerging Pollutants

Kenya, like many other developing countries, is at the crossroads of environmentally sustainable agricultural practices and ostensibly economically sustainable practices, characterized by high usage of agricultural chemicals. Most of the agricultural production in Kenya comprises mixed farming, *i.e.*, crop and livestock farming. Hence there is a tendency towards the use of chemicals especially fertilizers, veterinary chemicals and pesticides. Rapid expansion of the agriculture due to increasing population has resulted in increased demand for agro-chemicals in Kenya and recently pesticides have become an integral part of plant, livestock

and public health (NES, 2006). Besides, pesticide use in Kenya is already one of the highest in sub-Saharan Africa with a market share of approximately USD 40.4 million since 1992. This was projected to increase by about 10% annually. The official ban or restriction on these pesticides in Kenya notwithstanding, several studies have so far indicated that pesticides are still being detected in the environment in varying quantities (Wandiga *et al.*, 2001; Abong'o, 2009; Musa *et al.*, 2011. The continued use of pesticides in vector control (e.g. use of DDT which is authorized by the WHO) or in the sanitary fight against pests contributes to some of the pesticides detected in the environment.

According to the regional transboundary diagnostic analysis of the Lake Victoria basin (2007), there is gap in sustainable agricultural activities with respect to pesticide, herbicide or fertilizer use, bush burning, deforestation, over-cultivation, poor human waste management, farming along the lake, mono cropping, and/or over-grazing.

4.2.3. Emerging Pollutant (Organochlorines) Levels in Biota within Lake Victoria basin

Within the Kenyan Lake Victoria basin, pesticides and fertilizers have been increasingly used to boost agricultural production in large-scale farms within the vast catchment (Abongo *et al.*, 2015; Abong'o, 2009; Onywere *et al.*, 2007). Increased run-off laden with pesticides and fertilizers from these farms is inevitably finding its way into the lake through the rivers draining the basin. Earlier studies in Lake Victoria on organic pollutants by Mitema and Gitau (1990) on eighty-two samples of either fat or muscle of the Nile perch fish collected from the Kenyan region of Lake Victoria reported a total of nine organochlorine residues.

Studies by Mbabazi (1998) and Kasozi (2001) which aimed at providing baseline information on the levels of organochlorine pesticide residues in aquatic system of Lake Victoria at the time showed high DDE:DDT ratios and claimed that widespread use of DDT had ceased and significant use of lindane and endosulfan within the Lake Victoria basin in Uganda was on the increase. This implies that the organic pollutants that were present in the 1990s were still in use

within the Lake Victoria basin in general. Meanwhile, despite the reported rapid degradation of some pesticides in the Kenyan soil (Wandiga and Natwaluma, 1984) and the evidence of bioaccumulation and bio-concentration of these pesticides, their use still goes on unabated posing a serious ecological and health challenge for the inhabitants of the LVB (Wandiga, 1996).

Pesticide leaching from agricultural land into the surface and ground water are a source of pollution particularly due to their mobility and persistence. Similarly, pesticide residues and their breakdown products have also been found in increasing amounts in water, fish, weeds, soil sediments from Lake Victoria basin in Kenya (Madadi, 2005; Getenga, *et al.*, 2004).

4.3. Polychlorinated dibenzo-p-dioxins, polychlorinated dibenzofurans and dioxin-like polychlorinated biphenyls

A study by Omwoma *et al.* (2015) sought out to generate baseline concentrations of polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and dioxin-like polychlorinated biphenyls (dl-PCBs) in surface sediment from selected sites (Kisumu, Homa Bay and Mbita (control) towns) in the Winam Gulf of Lake Victoria, Kenya to determine the influence of human activities on their concentrations and potential risks to fish-eating birds living near the lake. The study reported a total mean concentrations (in pg g^{-1} dry wt) ranging from 17.4–812 ($\sum$dl-PCBs), 36.6–813 ($\sum$PCDDs) and 1.45–46.4 ($\sum$PCDFs). The calculated Toxic Equivalents (TEQWHO) ranged from 0.001–0.43 ($\sum$dl-PCBs) and 0.09–31 ($\sum$PCDD/Fs).

With the toxic chemicals emanating from anthropogenic activities, especially near large industrial towns such as Kisumu, Nzoia and Bugoma. The fish landing beaches at Kisumu city were found to be contaminated with respect to dl-PCBs and dioxins, followed by Homa Bay and Mbita. The Relatively high levels of octachlorodibenzo-p-dioxin (OCDD) and octachlorodibenzofuran (OCDF) influenced the TEQ and the $\sum$PCDFs/$\sum$PCDDs ratios implicating chemical processes as partial sources of the dioxins. Mono-ortho dl-PCB congeners

such as Nos. 105 and 108 have also previously been reported to be present at higher concentrations in commercial PCB mixtures and to persist in higher concentrations in the environment due to their slow desorption (Zhou *et al.*, 2012) and this could have justified their presence in surface sediment as reported in Omwoma *et al*. (2015) study. The authors concluded that the levels of contaminants obtained in the study showed potential exposure to aquatic organisms and fish eating birds through food chain transfer. Pollution and overfishing were thought to have contributed to stock reduction, specifically Nile perch (*Lates niloticus*), tilapia (*Oreochromis niloticus*) and Dagaa (*Rastrineobola argentea*) in the Lake Victoria.

It is apparent from the comparison between the respective concentration levels obtained in the three sites in Winam Gulf in the study by Omwona *et al.*, (2015) that the levels varied and were slightly higher ranging from 17.4–812 pg g^{-1} (Rdl-PCBs) and 38–860 pg g_1 ($\sum$PCDD/Fs) and WHO TEQ ranging from 0.001–0.43 pg g_1 (Rdl-PCBs) and 0.09–3.1 pg g_1 ($\sum$PCDD/Fs) to the rates reported in a European site in Istanbul Strait in Turkey which was considered to be polluted had $\sum$dl-PCBs and $\sum$PCDD/Fs in surface sediment ranging from 17.9–746 pg g_1 and 2.04–60.5 pg g_1 while the WHO TEQ ranged from 0.01–17.8 pg g_1 and 0.98–1.01 pg g_1, respectively (Okay *et al.*, 2009). Omwona *et al* (2015) concluded that the Winam Gulf which receives discharges from river Nyando and other rivers/streams was polluted with respect to dioxins and dl-like PCBs. The reported sources of PCBs and dioxins to surface sediments near the shore of Winam Gulf, Lake Victoria were leakage from landfills, municipal solid waste incineration, industrial effluent discharges, home and hospital waste incinerations and industrial products such as paints, coatings, plastics and transformer oils that are discharged into the aquatic ecosystem. The lake's ability to support the millions who live near it is therefore currently under threat (**Figure 4.4**).

Figure 4.4. **Fishermen use a mosquito net to catch juvenile catfish in the shallows of Lake Victoria, Kenya**

4.4. Perfluoroalkyl Acids

A study by Chirikona *et al.* (2015) on perfluoroalkyl acids in selected wastewater treatment plants and their discharge load in the Lake Victoria focused on wastewater and sewage sludge samples emanating from domestic, hospital and industrial waste within the Lake Victoria basin of Kenya. The researchers determined levels of perfluoroalkyl acids (PFAAs) in wastewater and sludge from selected wastewater treatment plants (WWTPs) in Kenya and presented their daily discharge loads. The findings showed that all sewage sludge and wastewater samples obtained from the WWTPs contained detectable levels of PFAAs in picogram per gram dry weight (d.w.) and in nanogram per litre, respectively. There was variability in distribution of PFAAs in domestic, hospital, and industrial waste with domestic WWTPs observed to contain higher levels. Almost all PFAA homologues of chain length C-6 and above were detected in samples analyzed, with long-chain PFAAs (C-8 and above chain length) being dominant. The authors concluded that varied sources other than WWTPs might contribute to the observed higher PFAAs.

Using an average output of wastewater from the five WWTPs, a mass load of 1,013 mg/day PFAAs per day discharge has been calculated, with the highest discharge obtained at Kisumu City (656 mg day−1) (Orata *et al.,* 2008). The concentration range of perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) in wastewater were 1.3–28 and 0.9–9.8 ng/l and in sludge samples were 117–673 and 98–683 pg/g, respectively. It was therefore reasonable to suggest that the discharge from hospital contributed significantly to the amounts of PFAAs released to the municipal water systems and the lake catchment.

Similarly, a study on levels of Perflurooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA) in muscles and liver of two different fish species (*Lates niloticus* (Nile perch) and *Oreochromis niloticus* (Nile tilapia) from the Winam gulf of Lake Victoria, Kenya by Orata *et al.* (2008) reported varying concentration values. The concentrations value of PFOS in Nile perch muscles was up to 10.50 ng/g while for liver samples it was 35.70 ng/g. On the other hand, Nile tilapia concentration values were of up to 12.40 ng/g and 23.70 ng/g for muscles and liver samples respectively.

Orata *et al*. (2008) further reported that slightly higher concentration of PFOS than PFOA were noted in both fish species analyzed in their study, indicating that PFOS accumulates more in fish muscles and liver than PFOA. They further observed that the per-fluorinated compounds concentration does not correlate significantly between the two fish species in this study, for both muscles and liver samples. This indicates that concentration does not depend on the trophic position for Nile perch and Nile tilapia which implies diet as the only source of PFOS and PFOA.

4.4.1. Sources of PFAA

Waste Water Treatment Plants (WWTPs) that receive effluent from industrial, domestic, and other sources contribute to PFAA levels in the environment (Guo *et al.,* 2010; Ma and Shih 2010). Due to their stability, perfluorinated compounds persist in WWTP conditions and, hence, their subsequent release into the environment (Kima *et al.,* 2012). Huset *et al.,* (2008) had earlier shown that WWTPs were inefficient in the removal of PFAAs in sewage, whose effluent was

then discharged into the Glatt River. Treated waste water released from local wastewater treatment plants (WWTPs) is a main source of PFOA and PFOS in rivers. Levels of PFCs present in the effluents of industrial or municipal wastewater treatment plants only reveal the potential for direct releases to receiving water bodies.

Following this discussion it is thus clear that sources of PFOA and PFOS into the Lake Victoria are many given the number of waste water treatment plants that discharges their effluents into the lake. It is therefore important to monitor the levels of PFAAs that can result to potential human and ecological risks. Previous studies have shown that PFAAs are distributed between water, suspended particulate matter, and sediment, and hence sludge, is a sink of PFASs (Prevedouros *et al.*, 2006). Sewage sludge is used as fertilizer, and significant concentrations of PFOA and other PFAAs have been found in agricultural soils (Renner, 2009). The use of untreated sewage sludge as fertilizers poses an unacceptable risk to rural communities especially within the Lake Victoria basin where policies on pollution regulation are rarely implemented.

Moses *et al.* (2011) while investigating effluent discharge from Mumias Sugar Company in Western Kenya concluded that the source of pollution of River Nzoia was largely contributed by effluents from sugar milling activities. He speculated that the company could be releasing wastewater contaminated with PFOs and PFAs with inconsistent loading levels into the adjacent River Nzoia. The authors emphasized on the need for the company to embrace cleaner production technologies to ensure an improvement of in-plant pollution prevention measures to minimize the volume and pollution loading in the wastewater before discharge into River Nzoia.

Increased nutrient and sediment loads in the River Nyando have been linked to both point and non-point sources of pollution. World Agro forestry Centre (ICRAF) scientists estimate that about 61% of the basins are sediment "source" areas with average net erosion rates of 43 tonnes

per hectare per year, while 39% of the basins' are sediment sink areas that accumulate about 45 tonnes per hectare per year (Abuom *et al.,* 2003).

4.5. Antibiotics and Microorganisms as Emerging Pollutants

The occurrence of pharmaceutical residues in water systems has generated a lot of interest in the last two decades and surmounting data on the environmental occurrence of pharmaceuticals in different environmental compartments has been published mainly in developed countries. Several studies have reported that a significant fraction of consumed pharmaceuticals are passed into the environment as excreta via the urine and faces (Al Aukidy *et al.,* 2012). Discharges from wastewater treatment plants (WWTPs) have also been identified as one of the primary sources of pharmaceuticals into the aquatic environment, and are far much of significant as compared to secondary sources such as hospital effluent and wastewater discharges from pharmaceutical companies (Leung *et al.,* 2013).

Municipal wastewater treatment plants contain a pool of antibiotic resistant microorganisms and plasmid-mediated resistant genes. Presence of these organisms and genes in the environment facilitates dissemination among environmental bacteria. Rop *et al.* (2014) investigated the effect of human settlement and development on the microbial water quality at various points along the channel of Nyangores River of Kenya and established that the intestinal enterococci had higher values ranging between 0.0 to 1400.0 cfu/100ml in the sampled water, while *Clostridium perfringens* showed significant variation with respect to sampling sites. The researchers concluded that the presence of anthropogenic activities along Nyangores River impacted negatively on Mara River water quality and proposed that appropriate corrective mechanisms should be taken to improve and restore the water quality and ecological integrity. Previous studies have demonstrated that these kinds of organisms have the ability to release all sorts of biogenic material into the environment. The biogenic categories are unique within CECs, as their compounds are produced by some combination of humans, animals, microorganisms and plants.

4.7. Sources of emerging pollutants into specific Rivers within the Lake Victoria Basin of Kenya

Many rivers in developing countries face almost similar challenges. They receive pollutants from household and industrial discharges as well as diffuse sources generated by agricultural and urban run-off within their catchment area. Dumping of wastes in rivers without treatment is the most likely source of pollutants. Major rivers feeding Lake Victoria such as Nzoia, Kuja, Nyando, Sondu Miriu, Migori and Yala traverses through industrial and agricultural zones, e.g. Nzoia river receives effluents from Webuye Paper Mills, Nyando river transports effluents from Muhoroni sugar company and Agro-Chemical and Food Company Limited, Kuja river receives coffee factory effluents from Kisii highlands, Sondu Miriu river receives effluents from tea factories in Kericho highlands etc. A summary of the main sources of pollution into the rivers draining into Lake Victoria are given in Table 4.8 below.

Table 4.6. **Summary of emerging pollutants reported in selected river basin and their probable sources**

	Sampling area	Emerging pollutant studied	Probable source/s
1	Nzoia river basin	Pesticide residues	Agricultural activities
		Dioxin and PCBs	Pulp and paper mill' Industrial/sewage discharges
2	Nyando River Basin	Pesticide residues	Agricultural activities
3	Yala River Basin	Pesticide residues	Agricultural activities
4	Mara River basin	Pesticide residues and antibiotic resistant microbial populations	Agricultural activities Sewage discharges

4.7.1. River Nzoia

The environmental challenges on Nzoia River is occasioned by pollution from discharge of poorly treated effluent from sugarcane, pulping, coffee processing factories and the agricultural chemical run-offs. Effluents from the major industries in the basin but from outside the district namely paper mills, tobacco leaf factories and cotton ginnery have degraded the environment of the basin due to improper management of industrial waste. The waste is discharged into the

river and the atmosphere. High concentrations of Cd and Pb in the Nzoia/Yala river basins were attributed to pollution sources from the factories along the Yala and Nzoia River courses and from the Webuye Pan Paper Mill as well. Some of the main sources of pollutants into the River Nzoia are given in Table 4.9 below, though a majority of factories/industries within the Lake Victoria basin of Kenya use primary treatment processes.

Table 4.9. Sources of pollutants including those of emerging concern into River Nzoia

	Pollutant source	Activity/nature of waste	Receiving aquatic system
1	Kitale Municipal Council		
	Conventional sewage plant	Domestic sewage	Kiminini stream
	Sewage oxidation ponds	Domestic sewage	Koitibos stream
2	Kenya cooperative creameries - Kitale	Milk processing	
3	Eldoret Municipal Council	Domestic sewage	
	Oxidation ponds	Domestic sewage	Sosiani
	Conventional sewage plant	Domestic sewage	Sosiani
4	Webuye Municipal Sewage Ponds	Domestic sewage	Nzoia river
5	Panafrican Paper Mills (E.A.) Ltd	Paper manufacture	Nzoia river
6	Bungoma Municipal Sewage Ponds	Domestic sewage	Khalaba
7	Nzoia Sugar Company effluent ponds	White sugar processing	Kuywa
8	Mumias Sugar Company	White sugar processing	Nzoia river
	Factory effluent ponds	White sugar processing	Nzoia river
	Domestic sewage ponds	Domestic sewage	Nzoia river
9	Mumias Municipal sewage works	Domestic sewage	Nzoia river
10	Kakamega Municipal Sewage	Domestic sewage	Isiukhu & Lusumu
11	West Kenya Sugar Co.	Sugar production	Lusumu
12	Mukangu Sugar Co. Ltd	White sugar production	Isiukhu
13	Moi University Chepkoilel	Domestic sewage	Sergoit
14	Siaya District Hospital sewage	Hospital & domestic waste	Huludhi
15	Webuye pulp and paper mill	Paper manufacture	Nzoia river
16	Ken – Knit textile mills	Textile manufacture	Nzoia River
17	Heritage garments (Rupa)	Textile manufacture	Nzoia river

Figure 4.5. **Disposal of solid wastes along River Nzoia which are contributing emerging pollutants**

4.7.2. Yala River and its basin

The Yala River which covers approximately 242 kilometres (150 mi) in length, and with a mean annual flow of 718 gigalitres discharges into Lake Victoria directly from its Yala catchment basin. Its importance lies on the volume of water contribution into Lake Victoria as well as the volume of pollutants into Lake Victoria. Nevertheless, the Yala River system supports major activities which include domestic water supplies to the towns within its catchments, minor industries and agricultural activities. These activities contribute pollutants into the river. Some of the major sources of emerging pollutants into Yala River are given in the Table 4.10 below.

Table 4.7. Major and Potential Sources of Emerging Pollutants into Yala River

	Pollution point source	Activity / Nature of waste	Receiving aquatic system
1	Moi University sewage treatment works	Domestic sewage	Kesses
2	Kapsabet municipal sewage works	Domestic sewage	Mokong'
3	KCC company Kapsabet	Milk processing	Kesses
4	Bondo TTC sewage works	Domestic sewage	Yala River
5	Dominion Farm	Sewage and agricultural waste disposal	Yala River
6	Savani Tea factory	Sewage and disposal	Mosombor river
7	Urban point sources	Sewage and disposal	Yala River
8	Urban point source	Wastewater	River Kisat
9	Agricultural practices	Pesticides, nutrients, sediment loads	River Yala

4.7.3. River Nyando and its basin

The Nyando River drains a catchment area of approximately 3,652 km². The river discharges its water directly into Lake Victoria from its Kenyan catchment area. While its importance lies in the volumes of water it contributes into Lake Victoria, it also acts as conduit of pollutants into Lake Victoria among them emerging pollutants. The river system supports major agro-based industrial development activities as well as being a source for domestic and livestock water supplies.

The development activities which are based in the river basin contribute to river water pollution through both non-point and point sources. The River Nyando has been identified as the most polluted drainage basin on the Kenyan side of the lake (Shepherd *et al.*, 2000). The drainage system traverses formerly three districts (Kericho, Nandi, and Nyando), which are major agricultural and industrial zones in Western Kenya. It serves as a recipient for effluents from tea, coffee, lime and sugar factories. Farming is intense and a wide range of pesticides are used in the drainage basin. In addition, it has the highest slope and rate of sediment transport of all the rivers draining into Lake Victoria.

Figure 4.6. Disposal of domestic solid waste along the Nyando River, resulting in pollution (Source: Masese 2011)

Arguably, poor land-use management practices (e.g. cultivating on slopes adjacent to rivers and on river banks, draining of wetlands and clearance of forest cover to give additional arable land) and intensive use of agrochemicals have resulted in a high flow of nutrients and sediments that have negative impacts on River Nyando and Lake Victoria ecosystems (Peters and Meyback, 2000). There are also chemical alterations arising from release of pollutants and toxic chemicals into wetlands resulting in change in nutrient balance. The agricultural activities in the River Nyando drainage basin, specifically the use of fertilizers and pesticides, are among the major sources of pollution loads on the Kenya's Lake Victoria (Peters and Meyback, 2000). Earlier studies showed that the Nyando and Kagera carry higher sediments, pesticides and nutrients loads into the lake than other rivers (Calamari *et al.*, 1995). These emanates from physical degradation through infilling, draining, dredging, stream channelization, peat mining, grazing, waste dumping and damming. Recreational activities that use toxic substances or pollutants e.g. the use of lead pellets in fishing, application of herbicides and fertilizers along river continuum all contribute emerging pollutants into the river. All these have created a significant pollution problem that threatens the use of the LVB's resources for both regional and national development.

Table 4.8. Major sources of emerging pollutants into River Nyando

	Pollution point source	Activity / Nature of waste	Receiving aquatic system
1	Agro chemical and food company	Alcohol and yeast manufacturer	Nyando River
2	Muhoroni sugar factory effluent	White sugar processing	Nyando River
3	Chemelil sugar factory effluent	White sugar processing	Mbogo
4	Chemelil sugar company sewage	Domestic sewage	Osengeteti
5	Food and chemical industries	Wastewater	River Nyando
6	Kibos sugar industry	Sewage and industrial pollutant	River Nyando
7	Rice mill	Wastewater	River Nyando

4.7.4. Gucha /Migori River basin

The Gucha-Migori River system has a catchment area which spans over 6,600 km². The river discharges into Lake Victoria from its Kenyan catchment area. Its transboundary importance lies on its volumetric water contribution into Lake Victoria and as an agent for carrying pollutants into the lake.

Figure 4.7. Fishing using bednet at a site along River Gucha in Kisii, and softstone harvesting and carving near the river (Pictures by Abuga Makori, 2015)

Nationally, the river system supports major farming activities as well as being important as a source of water for domestic and industrial water use. Due to the catchment based development activities, the system experiences pollution from both non-point and point sources. The spillage of saline ammonia from fertilizers applied in sugar farms, mercury and other chemicals used in soft-stones harvesting and other organics emanating from slaughter houses and agricultural effluents from coffee and tea factories in the area points to major point source pollution (Table 4.12). The Gucha catchment has high sediment loading and nutrient loading from nearby towns and markets indicative of high soil erosion.

Table 4.9. **Some of the probable sources of pollution into Gucha/Migori River**

	Pollution point source	Activity / Nature of waste	Receiving aquatic system
1	Kisii municipal sewage treatment works	Domestic sewage	Riana
2	St. Joseph mission hospital, Ombo	Domestic / hospital wastes	Migori
3	Prinsals Limited	Fish processing	Migori
4	Sony sugar company	White sugar processing	Sare
5	Sony sugar company sewage	Sewage waste	Sare
6	Hospitals/health centres	Hospital waste	Gucha/ Migori
7	Slaughter houses – in almost every town	Livestock slaughter	Gucha/Migori
8	Learning institutions	Municipal sewage	Gucha/ Migori
9	Tea and coffee factories	Effluents from tea and coffee	Gucha
10	Soft-stone harvesting	Mercury and waste water	Gucha

4.7.5. Mara River basin

The Mara River with a catchment area of 9,000 km^2 flows from Kenya through Tanzania and discharges into Lake Victoria at Mwanza. The Mara River is characterized by major pollution problems occasioned by extensive land degradation and inappropriate agricultural activities in the upper catchments and lack of adequate sanitation within the tourist establishments based in the Maasai Mara Game Camps. Sediment transport especially from the upper Mara River on the Kenyan part of the basin contributes nutrients, heavy metals and pesticides into aquatic ecosystems that adversely affect the water quality of the river.

Figure 4.8. Poor agricultural practices in the Mara River Basin have led to the washing away of Pesticides into the river system as seen in this image (Picture by Robert Makori, 2014)

People residing along the Mara River of Kenya catchment and its basin are faced by numerous challenges including water shortages, poor water quality and environmental degradation as a result of pollution from agricultural runoff, large-scale urban development, mining, domestic wastewater discharge among other activities. The Mara River Basin is facing serious environmental problems primarily created from wide spread encroachment on protected forests and other fragile ecosystems for settlement and cultivation (WREM, 2008). These specifically include soil erosion and high sediment loads, deforestation resulting from encroachment and human settlement in the Mau forest areas, wildlife human conflicts resulting from large-scale farming that has extended into wildlife territories, declining water quality and quantity due to poor agricultural practices and excessive water abstractions, pollution as a result of unregulated wastewater discharges, especially from mining activities, poor sanitation activities and excessive use of agrochemicals for pests and disease control in crops and animals.

The Mara River suffers impacts of agricultural pollutants in its upper course due to the intensive farming activities in this region coupled with other anthropogenic activities which

result into the production of various pollutants that finally find their way into this river. Recent studies and GIS-based hydrological models for Mara Basin have shown that there has been extensive deforestation in Mau Escarpment and increased land use change from forestry to agriculture in the watershed (Mutie, 2006).

Open burning of domestic waste is widely used by the residents of major towns along the Mara River, as a means of disposing solid waste. The incinerator at Mulot Hospital, which is situated just a few metres upwind from the residential homes of low cadre staff of the hospital and medical students' hostels, operates at temperatures between 350°C and 650°C and emits noxious fumes. The by-products are carried to the nearby Mara River, causing considerable pollution to the water course. Additional research needs to be undertaken in order to gather more detailed information regarding this pattern of practice. A summary of pollutant sources into the Mara River is given in the Table 4.13 below.

Table 4.10. Summary on pollutant sources along the Mara River basin of Kenya

	Pollution point source	Activity / Nature of waste	Receiving aquatic system
1	Discharge of waste water from hotels	Domestic/Industrial	Mara River
2	Wastewater discharges open point	Wastewater	Mara River
3	Urban centres disposal	Solid waste	Mara
4	Industrial centres	Effluent discharge	Mara River
5	Hospitals	Open disposal of wastes	Mara river
6	Agricultural activities,	Pesticides/ Acaricides	Mara River
7	Bomet Municipal stabilizing pond	Domestic/ Industrial wastes	Mara River
8	Bomet slaughter house	Effluent	Mara River
9	Constructed wetland at Olenana hotel	Effluent	Nyangores
10	Waste water from the KTDA	Wasteswater	Nyangores
11	Incineration at Olenana hotel	Domestic wastes	Nyangores
12	Stabilization pond at Tirgaga tea factory	Wastewater	Amala
13	Open burning at Mulot Town	Domestic wastes	Amala
14	Open burning at Bomet town	Domestic wastes	Mara River
15	Domestic solid waste	Storm drainage	Amala
16	Eroded land around water point	Tilimiet Spring	Amala/ Nyangores
17	Open defecation field next to Bomet water pan	Solid wastes	Mara River

4.7.6. Sources of emerging pollutants into Winam Gulf of Lake Victoria Basin Kenya

Although the Winam Gulf in Kisumu Bay receives water from several small tributaries within the basin, other major rivers also discharge their waters into the Lake Victoria Basin through the bay. Therefore it was necessary to include the Winam gulf in the study on emerging pollutants. Potential sources of PAHs exist in Kisumu Bay of Winam Gulf. The major point sources include petroleum fuel spillages, Kenya Pipeline Company depot runoff, car wash activities at the shore, oil spills from vessels at the Pier and Yatch Club, mechanical workshops (Jua Kali sheds) and petrol-station runoffs (Bowa *et al.,* 2009). Mobile sources include motor vehicle exhaust (Lalah and Kaigwara, 2005) and consumer products waste dumped into the lake. Diffuse sources include asphalt roads and road tar, fires of all types (municipal garbage incineration and burning of sugar cane from the surrounding sugar belt) and biomass energy combustion (Lisouza *et al.,* 2011), agricultural runoff, natural alteration of organic matter (Mitra and Bianchi, 2003) as a results of widespread infestation of the gulf by the hyacinth. All these sources contribute significantly to emerging pollutants into the Lake Victoria gulf, of which their potential impact to human, livestock and the entire lake ecosystem are neither well known nor periodically monitored.

4.8. Effects of Emerging Pollutants on Human and Ecosystem Health

The negative health impacts caused by some of the emerging pollutants are well documented in other studies particularly those done in developed world. The greatest threat may be that certain chemicals, when combined with others in the environment, may produce a greater effect than that of a single chemical. Humans and other organisms are exposed to a multitude of chemicals simultaneously, some of which may have similar mechanisms of action. When considered in combination, the concentration may be at a level that does cause an effect.

Perhaps the most comprehensive study to date on potential health effects of emerging pollutants in the Lake Victoria basin was conducted by the Maseno University Department of Chemistry and school of public health (Omwoma *et al.,* 2015). Overall the authors noted that a number of avenues exist for contamination and exposure to emerging pollutants. In their studies, contaminants of concern included volatile organic compounds (VOCs); diesel exhaust;

nitrogen and sulfuric oxides (NOx, SOx); ozone; particulate matter; polycyclic aromatic hydrocarbons (PAHs); hydrogen sulfide; and hazardous chemicals within the fracking fluids.

Polycyclic aromatic hydrocarbons (PAHs) contains a variety of human health hazards, including particulate matter, heavy metals, and other organic compounds, and is associated with cardiovascular disease, respiratory disease, allergies, genetic changes to chromosomes and DNA, and childhood illnesses. Polycyclic aromatic hydrocarbons (PAHs) are associated with immune dysfunction, reproductive harm, and low birth weight and other foetal problems. Heavy metal exposure can lead to a variety of health issues. Lead, for example, is a known neurotoxin and is associated with increased cancer risk. Arsenic is associated with DNA changes, cancer, renal dysfunction, and reproductive harm.

Pesticides, especially organophosphates, have been associated with respiratory disease, childhood asthma, cardiovascular disease, genetic changes in chromosomes and DNA, harm to fetal and neonatal health, and increased mortality. Particulate matter in particular is associated with a number of health effects, and is especially hazardous to children and the elderly. Hydrogen sulfide is fatal at high doses, and can cause neurological damage at lower doses. This is one of the few compounds in which research of long-term, low-dose effects have been conducted. Researchers have demonstrated neuropsychological effects, including depression and memory loss, and high levels of hospitalization due to respiratory effects (including asthma, pneumonia, and chronic obstructive pulmonary disorder) in communities exposed to chronic H_2S.

The effects of exposure to some emerging contaminants have caused concern for both people and wildlife. These include chemicals such as personal care products triclosan and triclocarban (Murray *et al.*,2010), both of which are suspected to be compounds that can disrupt the body's endocrine — or hormonal— system (Witorsch and Thomas, 2010) and are toxic to fish crustaceans, algae (Tatarazako *et al.* 2004) and fish embryos. The effects of exposure to some

emerging contaminants include endocrine disruption and cancers, and are thus a serious concern for people and wildlife.

PBDEs, commonly found in flame retardants, have been shown to affect the endocrine systems (Talsness, 2008). PBDE levels in breast milk are associated with lower birth weights and decreased body mass, as well as cryptorchidism (undescended testicles) in newborn boys (Chao *et al*., 2007). Extrapolating from animal studies and body burdens in humans, Costa and Giordano (2007) estimated that the levels of PBDE's that cause developmental neurotoxicity in animal model experiments were similar to the higher levels seen in humans, indicating it is possible these compounds could cause the same phenomenon in people. A recent publication hypothesized that there may be a link between autism and PBDE exposures due to their impacts on thyroid function and development, however this hypothesis remains to be tested (Messer, 2010).

Other studies not necessarily in the Lake Victoria Basin attest to the potential health effects of emerging pollutants. For instance, toxicity testing has predominantly been assessed on PFOA and PFOS, and potential effects have been intensively studied mainly in rodents. Some of the observed effect of PFOA and PFOS in rodents is carcinogenic potential, immune toxicity, hormonal effects, and heap toxicity (Lau *et al*., 2007). Wielsøe *et al.* (2014), in an *in vitro* study, observed that cell line representing the human liver showed oxidative stress including DNA damages when exposed to PFAAs in particular PFOA and PFOS. Perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) are the two most commonly used PFAAs and have been detected in a variety of environmental matrices from around the globe. Longer-chain PFAAs containing more than six fluorinated carbons are known to bioaccumulate and biomagnify in biota (Conder *et al.* 2008). Human toxicology for PFOA and PFOS has been reviewed recently (Kennedy *et al.*, 2004; Lau *et al.*, 2007). Dietary intake seems to be the main source of exposure of the general population to PFOS and PFOA (Fromme *et al.*, 2007).

In recent years perfluorinated alkylated substances (PFAS) have appeared as a new class of global pollutant. PFCs are used as water and oil repellants in the treatment of fabrics and leather, the paper industry, personal care products, and in many other industrial uses (Kissa, 2001). Besides being an industrially important group of compounds, PFAS are regarded as highly toxic and extraordinarily persistent chemicals that pervasively contaminate human blood (Olsen *et al.*, 2003) and wildlife throughout the world (González-Barreiro *et al.*, 2006; Abbott *et al.*, 2007).They are therefore regarded as PBT (persistent, bioaccumulative and toxic) chemicals (González-Barreiro *et al.*, 2006) and cause diverse toxic effects in laboratory animals including primates (Butebhoff *et al.,* 2002).

Studies in Germany documented contamination of agricultural fields and surface water reservoirs, with correspondingly elevated levels of PFAAs found in the blood of people drinking the reservoir water (Skutlarek *et al.,* 2006; Holzer *et al.*, 2008). Therefore, there is the possibility of PFAA occurrence in feed crops which are grown in farm lands where sewage sludge is used as fertilizer. This possess global risk from human uptake which depends on the type of compound and the length of fluorinated carbon chain (Houde *et al.,* 2006; Conder *et al.,* 2008; Fromme *et al.,* 2009; Van Asselt *et al.,* 2011; Domingo 2012).

4.8.1. Health effects of Polychlorinated biphenyls (PCBs)

Most polychlorinated biphenyl bio accumulates in animals due to their stability and are also toxic depending on the amount of chlorine they contain. Polychlorinated dibenzo-p-dioxins (PCDD) and Polychlorinated dibenzofurans (PCDF), Hexachlorobenzene (HCB) and Polychlorinated Biphenyls (PCBs) are unintentional persistent organic pollutants (U-POPs), formed and released from thermal processes involving organic matter and chlorine as a result of incomplete combustion or chemical reactions. Higher levels of PCBs and related compounds in human are associated with various health effects such as lowering intelligence quotient, disorder of thyroid gland, higher rate of endometriosis in women, declining thyroid hormone levels, higher rate of diabetes in pregnant women, lower in gage at menarche, and altering play behaviour in children at school age (Masuda, 2003). Stockholm Convention identified waste

incinerators, including co-incinerators of municipal, hazardous or medical waste or of sewage sludge, as source categories with high potential to release U-POPs into the environment.

4.8.2. Health effects of Dioxins and dioxin like PCBs

Dioxins and dioxin-like PCBs are a group of structurally related chemicals which persist in the environment, may bio accumulate in food and human tissues and are toxic. Dioxin is used to refer to polychlorinated dibenzo-*para*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). They are ubiquitous pollutants produced in small quantities in most combustion processes and as by-products in some industrial processes involving chlorine such as waste incineration, chemical and pesticide manufacturing and pulp and paper bleaching. Connett (1998) demonstrated how municipal waste incineration is a poor solution to the waste management problem. The overall goal of the study was to understand the (social, economic and technological) dynamics of the practice of waste burning in the city and to find out how this might contribute to the release of U-POPs into the environment. The author listed the toxic emissions of incineration and showed how dioxins, furans and other by-products of combustion impact human health and the environment. Dioxins are considered to have similar mechanisms of toxicity and so are grouped together when considering potential risks even though they originate from different sources. The most toxic of these compounds is 2,3,7,8-tetrachlorodibenzo-p-dioxin or TCDD and the toxicity of other dioxins and dioxin like PCBs are measured in relation to it (DEFRA, 2002).

There is a wide range of toxic effects of dioxins. The most sensitive are immune suppression, developmental and reproductive toxicity, as well as neurological behavioural effects. Cancerogenic effects are induced at higher exposure (Nau, 2006). Dioxin's hormone-like activities include decreased sperm count, immune suppression, increased genital malformation and neurobehavioral effects in the offspring of animals (Masuda, 2003).

4.8.3. Health effects of Pesticides

Increasing evidence suggests that pesticides have intrinsic public health and environmental risks during their production, import, use, storage and disposal (Stadlinger *et al.*, 2013). Many pesticides used in all societies have been associated with toxicity to human (Jacobs and Dinham, 2001) and others are suspected to be carcinogenic, mutagenic, and endocrine disruptors (Colborn, 2004). Recently, work by Sereda *et al.* (2009) indicated that pyrethroids found in human breast milk may come from agricultural use, while Bouwman and Kylin (2009) pointed out the need to include agricultural and other uses of pesticides when evaluating risks to infants from pesticides used for vector control. All types of land use in the Lake Victoria catchment in one way or another affects the quality of its water and that of the tributaries through pesticides leaching or draining from agricultural land into aquatic ecosystems (Shephard *et al.*, 2000). The parent (alachlor and metolachlor) and degradation products of the chloroacetanilides (2,6-diethylaniline and 2-ethyl-6-methylaniline) were found to be acutely toxic to *Vibrio fischeri*, genotoxic to *Vibrio fischeri* (Mutatox® test), teratogenic to *Xenopus laevis*, and promutagenic in the Ames test (Osano *et al.*, 2002). Therefore, both the parent and the degradation products are toxicologically important.

4.9. Effect of Emerging Pollutants on Livelihood Sources of Lake Victoria Basin Inhabitants

The relationships between water quality, ecosystem health and socio-economic implications and human health are manifold and complex. Water quality change in the LVB has adversely affected the beneficial uses of Lake Victoria basin waters by the riparian communities. A large proportion of these communities source their water directly from the lake without any treatment. Treatment of that water if necessary is an additional cost at the individual or urban level when distribution systems are developed.

Over the past four to five decades, the lake has come under increasing and considerable pressure from a variety of interlinked human activities related to population growth and in-migration to the lakeshore resulting in destructive activities such as urbanization, concentrations of populations along the lakeshore to partake in the growth of the fishing

industry, increasing area of land brought into agriculture, intensive fishing for commercial and domestic use, species introductions and industrial development. These activities are of concern because of poor agricultural practices, over grazing, deforestation and wetlands conversion. These activities also threaten the sustainability of the lake and the livelihood of the lake basin's inhabitants by acting as major sources of emerging pollutants into the Lake ecosystem.

5.0 CHALLENGES AND GAPS IDENTIFIED

Most of the studies on emerging pollutants within the Lake Victoria basin focused on the pesticides and a few other emerging pollutants, specifically on their residual levels in the environment. Not a single study focused on the effects of emerging pollutants on human health within the Lake Victoria basin of Kenya. This should not however be construed to mean that they do not have an effect on humans and organisms within the basin. On the contrary, the inhabitants might be facing serious health risks from these emerging pollutants. Various studies conducted elsewhere around the globe have outlined some of the health effects of emerging pollutants on human and ecosystem. Given that sources of these emerging pollutants are almost the same and these have been identified within the Lake Victoria Basin, then it only means that the Lake Victoria faces threats of pollution from emerging contaminants which subsequently pose serious health risk to unsuspecting inhabitants in the basin.

5.1.1. Challenges and gaps with respect to tools for modelling the fate of emerging pollutants

Modelling frameworks are poorly developed for emerging pollutants' fate, with the exception of pesticides. These tools are necessary in the soil–water environment and require further development. The challenge is to model transport and fate of various EPs from all possible sources (urban, industrial, agriculture), through catchments to their outlet (Figure 4.10). Emerging pollutants from diffuse sources are transported via the soil into water systems which act as a sink (McGuire & McDonnell, 2006). Depending on their properties, EPs can be transported by different processes, such as by runoff, erosion or leaching and enter into groundwater or surface water. They may be intercepted by the soil through adsorption or can

be degraded during the transport and never reach the water bodies. Once water bodies are reached, further transport downstream in solution or attached to suspended material may occur. As EPs are "emerging", little experimental evidence is available on their transport and partitioning in catchments and models to simulate this transport have not been parameterized for EPs. Figure 4.9 below represents the schematic model developed by the reviewers which can be applied for the assessment of emerging pollutants within the LVB.
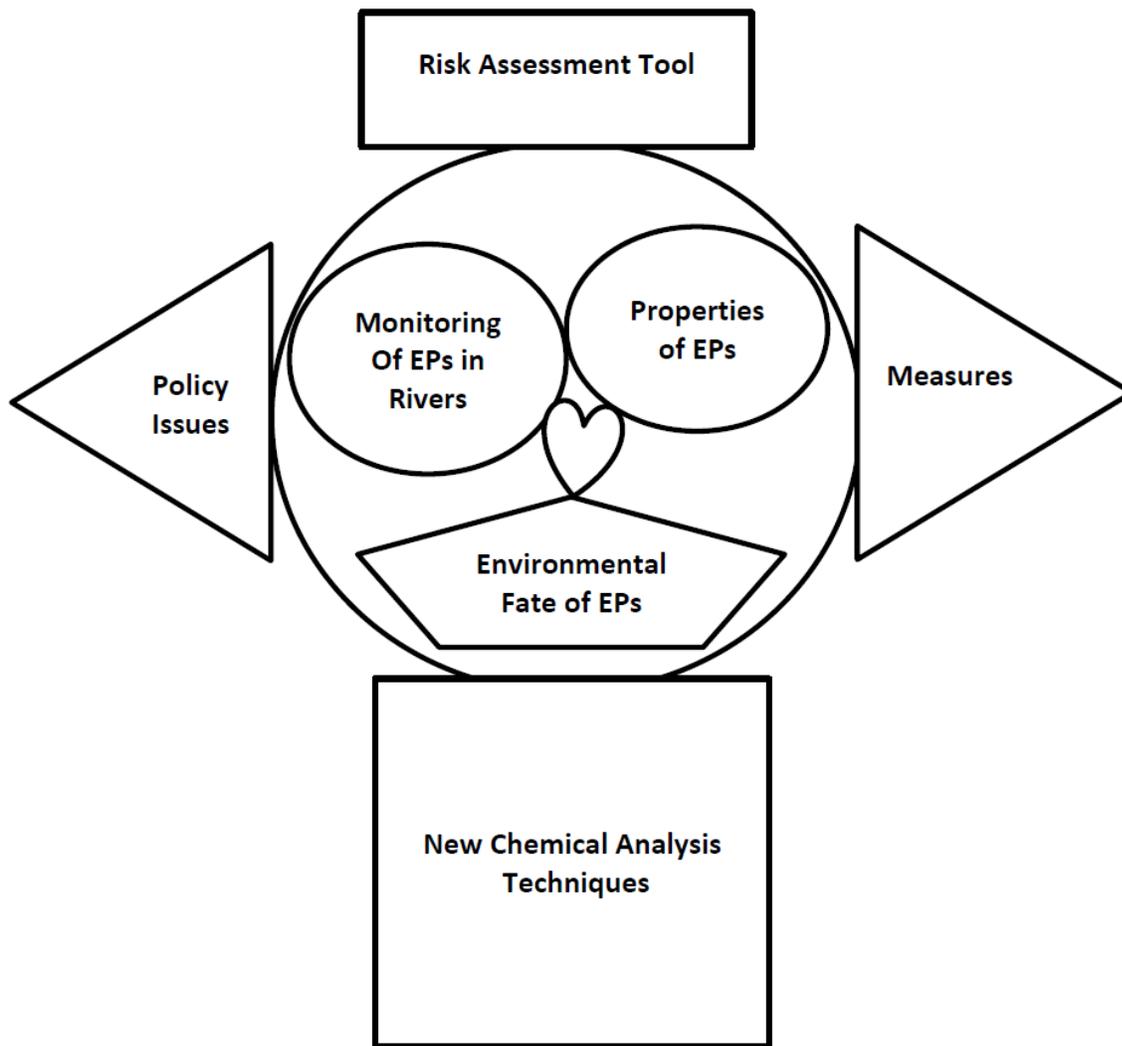

Figure 4.9. The proposed emerging pollutants assessment model for LVB rivers (Source: Authors).

There is a need for investigation of the emerging pollutants at different scales. Various models are available for calibration, validation, and process understanding, particularly in the context of pesticide fate screening, and that are all based on similar basic principles as one dimensional unsaturated water flow in soil and water, where the emerging pollutants behaves as an adsorbing and degrading agent (Schotanus *et al.,* 2013). As they derive from pesticide screening, specific processes that may occur for a certain class of emerging pollutants are usually not incorporated in such models. A major unknown part, in parameterization, is whether complex interactions should be considered to be time-dependent, or not.

Lack of analytical capacity to monitor most emerging pollutants poses a huge challenge (Stockholm convention, 2013), thus curtailing the collection of critical data that is required to understand the discharge load and fate of these compounds. Antibiotic resistance is an increasing concern because it eliminates the ability to control infections. Increased use of antibiotics has been known to increase the chance for bacteria to evolve to become resistant. Unfortunately, no single article was found focusing on antibiotic occurrence in the Lake Victoria Basin of Kenya despite the numerous probable sources such as hospitals and domestic sewage effluents, as well as from antibiotic use in agriculture and aquaculture. This in itself is a gap that needs to be filled.

Based on studies done in the developed world, it is apparent that most exposures to emerging pollutants are chronic yet only few studies around the globe and none in the Lake Victoria basin of Kenya were documenting effects from long-term exposures to emerging pollutants. There are also large gaps in understanding bioaccumulation, specific exposures in the Lake Victoria Basin region, sub-lethal effects and outcomes, and information regarding impacts on a variety of organisms. Most of these studies have, by and large, centred on emerging pollutants with regards to pesticides ignoring a multitude of breakdown products associated with these compounds that have not been measured in the Lake Victoria basin and, in some cases, not even identified. Beyond this, there are thousands of chemicals in production that have not been monitored. An estimated 23 million chemicals were indexed by the American Chemical

Society's Chemical Abstracts Service in 2004 (Daughton, 2004). More than 7 million of these chemicals were commercially available, with only 230,000 inventoried or regulated by governments worldwide at the time

5.1.2. Alternative technology gap in municipal wastes management

Due to gaps in the management of disposal wastes in the 5 river basins arising from technology gaps, the authors propose alternative technologies to treat the wastes and thus reduce sources of emerging pollutants into the Lake Victoria basin. Referred to as biological/chemical technologies, this technology operates at lower temperatures and slower reaction rates. This includes incineration method; however the wastes must be biodegradable. Solitude material must be separated and alternative processing initiated. Biological/chemical technologies can also produce electricity, fuels, and high-grade compost. Methods include composting, anaerobic digestion, and capture of pollution gases.
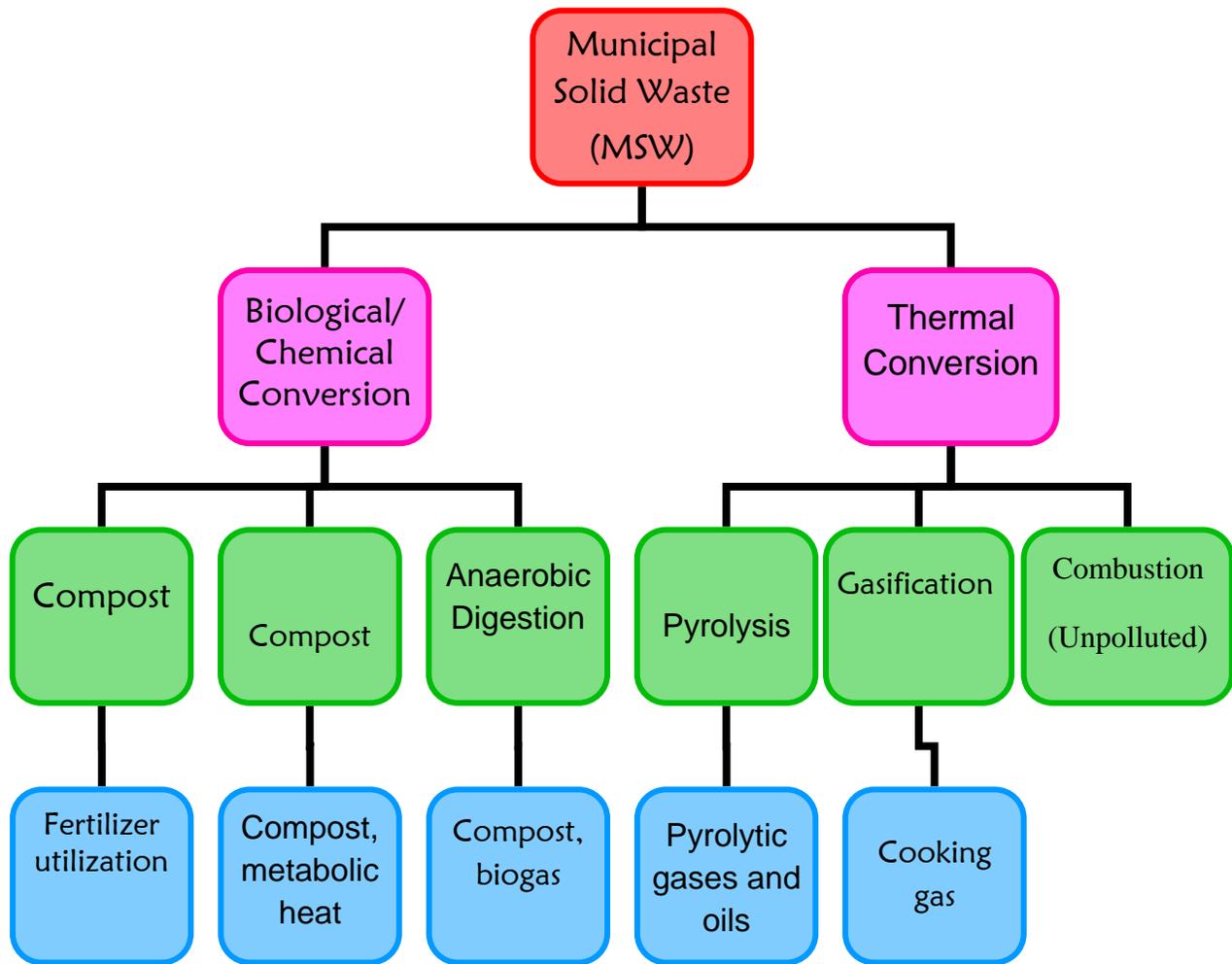
Figure 4.10. **Alternative model municipal wastes recycling and their outputs**

While most of this report focused on the traditional management approaches of recycling/composting and incineration, this review proposes alternative technologies that have a track record of commercial operation and could feasibly be appropriate in the future. Accordingly, two thermal technologies (pyrolysis and gasification) and one biological/chemical technology (anaerobic digestion) are some of the best alternative based on the gaps identified in the reviewed literature. These alternative technologies have been used in many countries, particularly in Europe and Japan, more than other emerging technologies.

Conventional thermal treatment of municipal wastes management, typically referred to as incineration, involves the combustion of wastes in an environment with a sufficient quantity of oxygen available to oxidize the waste stock. Incineration plant combustion temperatures are typically in excess of 1,500 degrees Fahrenheit. As explained further below, pyrolysis is the thermal degradation of wastes and, in contrast to incineration, requires the total absence of oxygen. The pyrolysis process requires an external heat source to maintain temperatures between 650 and 1,500 degrees Fahrenheit. Gasification can be seen as a treatment in between pyrolysis and incineration, in that it involves the partial oxidation of a substance.

5.1.3. Alternative technology gap in wastewater management, based on sustainable and suitable wastewater treatment technologies and the concept of circular economy

The integrated wastewater treatment technology is hereby proposed by the reviewers, as an economical technology process, comprising of anaerobic and aerobic processing factors (APFs) set up in a forward-backward flow regime to treat wastewater onsite. The reactor has the capacity to remove a considerable proportion of faecal coliforms and chemical oxygen demand in the process of an integrated anaerobic and aerobic APFs system. The anaerobic and aerobic APFs have the potential for treating abattoir wastewater highly recalcitrant in organic pollutants and faecal coliforms. The process is as illustrated in Figure 4.11 below. The aerobic oxidation of anaerobic processor leads to a reduction in organic and nutrient loading in the wastewater and generate nutrient-rich sludge, use of effluent from sequencing batch reactor and aerobic APFs for hydroponic systems and finally polishing of this effluent in constructed wetlands to achieve sustainable waste treatment and environmental clean-up. The cost of setting up the technology and operational costs are low as estimated from the proposed process for effluent treatment based on a project design for a methane recovery and utilization system at Kunak Oil Palm Mill in Sabah, Malaysia (UNFCCC 2013).
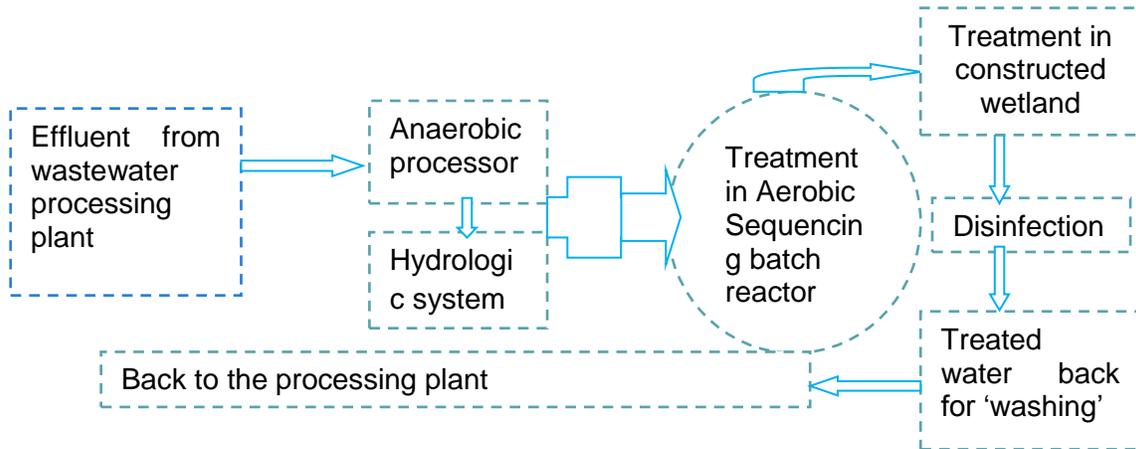
Figure 4.11. **The ischemic flow diagram showing proposed pathway in the process of wastewater treatment**

Source: Adapted from Njau et al. 2011

6.0. Relevant policy frameworks and policy options action needed in Kenya

In Kenya emphasis is on control of conventional pollutants. More recently, emphasis has been placed on control of toxics and the protection of rivers, lake water and oceans. Unlike air pollution where focus has shifted towards more cost effective approaches, the control of water still relies on municipal wastewater treatment and standard imposed on industrial sources. Similarly, non-point sources have been ignored and technology progress is not stimulated by the current approach. There is too much emphasis on direct regulation rather than on permits or taxes.

In 2016, over 50,000 residents of Nyanza, Eastern, North Eastern and Central Kenya became ill from water-borne diseases. More than 60 individuals lost their lives from confirmed *Vibro cholera* cases. This was the result of lack of well treated water, grounded facilities, illegal discharges and monitoring failures. In Kenya, ground water is the source for over 90% of Kenyans including 99% of rural residents.

Environmental Management and Coordination Act (EMCA), responsible for water quality in Kenya were established by the act of parliament in 1999 (Clean Water Act). The act allows EMCA to establish drinking water standards. The 2000 amendments integrate risk assessment and benefit cost analysis into standard setting procedures. Through the subsidiary act, there is establishment of other water regulatory bodies such as Kenya National Bureau of Standards (KEBS) and Lake Victoria Region Water and Sanitation Initiative (LVWATSAN). LVWATSAN focuses on tap water safety originating from rivers and lakes of Western Kenya. The goals of LVWATSAN are not independent of the Clean Water Act. However, groundwater protection is more fragmented as no proper regulations are in place or implemented by government agencies. Consequently, there are no unified oversights. There is also false belief that groundwater is protected from contamination by soil and rocks. But several researchers have found contamination in ground water. The Kenya Bureau of Standards (KEBS) regulates bottled water, but there is no indication that bottled water is safer than tap water as the same health standards are applicable to both. Above all very minimal or no standards exist on emerging pollutants, some of which have a short or long term effects on human and ecosystem health.

6.1 Existing regulations and guidelines and effective regulatory frameworks in Kenya

Given the toxic nature of some industrial waste, the government of Kenya set up a pre-treatment program and prohibited some specific industrial discharges into aquatic systems before treatment. As such, there are technologically based pre-treatment standards for different types of industrial wastes. For other industries standards for pre-treatment are set at state or local level or delegated to LVWATSAN. These treatment standards to new and existing plants discharging into sewers were designed to prevent interference with plant operations and limit pass-through of untreated pollutants. To set local limits for pollutant discharges by industry, the WWTPs are required to conduct a headwork analysis to determine what a plant can safely accept from non-household sector. The amount so allocated is globally called Maximum Allowable Industrial Loading (MAIL). Industries have however continued to violate the laid down regulations, with majority them discharging raw wastewater into aquatic ecosystems. The fact that the laid down regulations and rules as appertains to industrial waste discharge are

never effectively implemented by the responsible bodies encourages discharge of pollutants among them those of environmental concern into aquatic systems. For instance, through the mid 2010 the discharge regulations were less vigorously applied at WWTPs. The non-compliance for pre-treatment permit requirements reportedly rose to about 90%.

The latest report released by Water Services Regulatory Board (WASREB -Kenya) on review of the country's water and sewerage services shows that sewage collection and disposal systems in urban areas has remained in a pathetic state. It had been projected in the National Water Service Strategy that by 2015, at least 40 per cent of Kenyans living in urban areas would have access to sewerage. However, the Wasreb report showed that only 16 per cent of Kenyans living in towns had access to sewer lines by 2015. At the same time, only 30 out of the 215 urban centres in the country had modern sewer systems according to the report.

In the 2015 WASREB report, it was noted that 23 utilities provided good quality water (defined as more than 95% compliance with standards), 15 provided water quality of acceptable standards while 53 utilities provided water that was not of acceptable quality (defined as less than 90% compliance). The two parameters measured were residual chlorine (40% weight) and compliance with bacteorological standards (60% weight).

7.0. POLICY GAPS AND IMPLICATIONS

This report has presented an extended review of available studies and datasets concerning the occurrence, transport and fate of emerging pollutants contributed by five main rivers that drain into the Lake Victoria Basin from the Kenyan side. Water pollution and waste management are critical environmental challenges in Kenya today. The existing legal regime has not been able to sufficiently address the problem. Until the enactment of the Environmental Management and Coordination Act (EMCA) in 1999. It was expected that the situation would change fast after the enactment of the EMCA, but it seems its operationalization has presented numerous difficulties. This shortcoming was mostly attributed to the fragmented nature of existing legal tools and lack of actual implementation. Many industries and individuals have continued to take advantage of

the existing vacuum with the initial trend of inhomogeneous enforcement and pollution check by the public, environmental NGOs, CBOs and human rights groups, and self-check/regulation by some industries to violet the existing pollution legal framework with impunity, this is clearly noticeable.

In the absence of a well-functioning environmental legal regime the future prospects of curbing emerging pollutants into the Lake Victoria basin of Kenya will remain a dream. Reliance on the industries to regulate themselves and the public to act as a watchdog of illegal acts is a very fragile approach. The current regulation system cannot be relied upon to steadily deliver desired results. Public initiative and self-regulatory commitments of foreign industries might become slack, or even fail.

Current registration practices are put in place to, as far as possible, ensure that proper use of pesticides minimizes risks to environmental and human health, but controls and enforcement of regulations are less than strict in the Lake Victoria basin, reflecting a situation common to many developing countries (Stadlinger *et al*. 2013). Absence of surveillance programs for pesticide residue levels in the agricultural and fisheries products from the Lake Victoria basin has wider policy and market implications. Absence of such programmes may be detrimental to the fish export from the East Africa states due to increasingly stringent regulation in the importing countries on residue limits in imported fisheries and agricultural/horticultural products. Lake Victoria fishing earns Kenya between KSh 4 billion and KSh 6 billion (USD 85 million) annually from fish exports revenue (LVEMP, 2003), that might be lost if pollution from agrochemicals is allowed to continue.

8.0. CONCLUSIONS

In the current report, the review of the environmental occurrence of several emerging pollutants in the Lake Victoria Basin region of Kenya was conducted. For this purpose about 15 scientific papers published between 2000 and 2015 were identified and evaluated. The presence of a variety of pesticides, dioxins, polychrorinated biphenols and other organohalogen compounds were confirmed at different concentration levels. However, many other known emerging

pollutants suspected of being endocrine disruptors are in use but their occurrence, fate and transport as well as their effects on human and the ecosystem health has not been researched. Likewise, many known emerging pollutants such as pharmaceuticals, veterinary and personal care products that are increasingly being used within the basin and are likely to be entering rivers from various domestic sources as effluents have not been individually researched. Studies on other known emerging contaminants whose potential sources were observed in the LVB such as surfactants, alkylphenolic substances, synthetic musk fragrances, and other endocrine disrupting chemicals in aquatic environment were not available, signifying a large gap in knowledge that needs to be filled.

The agricultural chemicals/pesticides and their residues that have frequently been detected in Lake Victoria basin at varying concentrations by various researchers should be taken more seriously. Although most of them were reported not to be of high concentrations to be considered a threat to human health, export products, or ecosystem integrity, the existence tends to bioconcentrate and bioaccumulate in the food chain, and their long-term impact on ecosystem and human health should be monitored.

Quantifying the sources, transport and fate of emerging pollutants discharged into Lake Victoria ecosystem is challenging, due to lack of resources and expertise, coupled with absence of tailored field experiments. In addition, conducting exhaustive field campaigns to enlighten the society on the risks posed by these pollutants is costly and hence most of the activities so far have been performed addressing only easy to measure and commonly known pollutants. For instance, in this review, most of the articles found were on pesticides as opposed to the many other emerging pollutants suspected to be present within the LVB.

An accurate analysis of existing information is therefore useful and necessary for identification of stressors that may act in synergy and to further design new field campaigns. The most relevant emerging pollutants in the region are discussed in light of the information extracted from a large number of studies. However, their cumulative effects on human and ecosystem

health remain largely unknown. Agricultural and industrial activities have not been explored at length. It is now evident that combinations of emerging contaminants similar to those present in the environment may have an even greater impact than simply adding up the effects of each individual chemical. This underscores a concern that even if a single chemical has not been shown to cause a significant human or environmental health impact, its effect as part of a mixture may indeed be significant.

From this review it should be emphasized with certainty that addressing the problem of emerging contaminants within the Lake Victoria basin requires focus on four main areas: new research; new technologies aimed at removing more contaminants during wastewater treatment; behavioural changes; and policy reforms. A more rigorous localized, multi-agency research program on emerging contaminants should be established to coordinate studies on occurrence, fate and exposures to these contaminants and their impacts on people and the ecosystem. The current legal requirement that a chemical cannot be removed from the market place without data showing a negative impact on people and the environment underscores the need for a more effective and realistic shift in policy on risk assessment programs. Changing some of the policies governing the production and use of new chemicals and existing emerging contaminants in the marketplace may well have the biggest impact. Not a single study was found relating the impact of emerging pollutants to the health of the basin's inhabitants directly. The presence of emerging pollutants within the Lake Victoria Basin or the availability of their potential sources is in itself an indication of the potential health risk to the basin's inhabitants.

It is apparent from this review that the challenges facing the LVB with regards to emerging pollutants is to better understand what emerging pollutants are, their occurrence, concentrations and sources in the environment as well as their toxic effects on organisms to better achieve risk management to human health and the environment. However, there is a common consensus that emerging pollutants are contaminating the environment, causing loss of biodiversity and ultimately, consequences on human health. Based on the articles reviewed,

we conclude that the most frequently discussed emerging pollutants in the Lake Victoria Basin of Kenya were the widely used pesticide group of chemicals.

9.0 Recommendations

Currently information on emerging pollutants in the Lake Victoria catchment is fragmentary and inadequate, and even that pertaining to pesticides of which majority of the authors studied was still meagre. Based on other studies available with regard to the health effects of exposure to emerging pollutants, there is need for the public health professionals, medical professionals, and policy makers to continuously monitor the on-going researches and to apply the precautionary principle on decision-making as appropriate. Careless disposal of contaminants and discharge of untreated wastewater and sewage into aquatic ecosystems should be discouraged with strict enforcement of existing legislations and laws. The challenge of sustainable development is to redesign an economic and technological system that is in harmony with ecological principles that promotes ecosystem and human health.

Acknowledgments

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APPENDICES

Appendix I. Check list

| Title	Item No	Checklist Item	
Title	**1**	A systematic review of effects of emerging pollutants on human health and livelihoods of populations living along Lake Victoria Basin of Kenyan	
ABSTRACT Structured summary	**2**	Provide a structured summary including, as applicable: **Background**: main objectives **Methods:** data sources; study eligibility criteria, participants, and interventions; study appraisal; and *synthesis methods, such as network meta-analysis.* **Results**: number of studies and participants identified; summary estimates with corresponding confidence/credible intervals; *treatment rankings may also be discussed. Authors may choose to summarize pairwise comparisons against a chosen treatment included in their analyses for brevity.* **Discussion/Conclusions**: limitations; conclusions and implications of findings. **Other**: primary source of funding; systematic review registration number with registry name.	
INTRODUCTION			
Background/Rationale	**3**	Explain the scientific background and describe the rationale for the review in the context of what is already known, *including mention of why the review has been done.*	
Objectives	**4**	State specific objectives, including pre-specified hypotheses if any.	
METHODS			
Study design	**5**	Present key elements of the study design early in the paper	
Setting & Eligibility criteria	**6**	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection as well as report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale. *(Clearly describe eligible treatments included in the treatment network, and note whether any have been clustered or merged into the same node (with justification).*	
Variables	**7**	Clearly define all outcomes, exposures, predictors, potential confounders, and effect	

		modifiers. Give diagnostic criteria, if applicable
Information sources	**8**	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.
Search	**9**	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.
Study selection	**10**	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).
Data collection process	**11**	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.
Data items	**12**	List and define all variables for which data will be sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.
Bias	**13**	Describe any efforts to address potential sources of bias
Summary measures	**14**	State the principal summary measures (e.g., risk ratio, difference in means). *Also describe the use of additional summary measures assessed, such as treatment rankings and surface under the cumulative ranking curve (SUCRA) values, as well as modified approaches used to present summary findings from meta-analyses.*
Statistical methods	**15**	Describe all statistical methods, including those used to control for confounding 　　*b*) Describe any methods used to examine subgroups and interactions 　　(*c*) Explain how missing data were addressed 　　(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
RESULTS		
Study selection	**16**	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.
Study characteristics	**17**	For each study, present characteristics for which data were extracted (e.g., study size, follow-up period) and provide the citations.
Risk of bias within studies	**18**	Present data on risk of bias of each study and, if available, any outcome level assessment.

Results of individual Studies	**19**	For all outcomes considered (benefits or harms), present, for each study: 1) simple summary data for each intervention group, and 2) effect estimates and confidence intervals. *Modified approaches may be needed to deal with information from larger networks.*
Synthesis of results	**20**	Present results of each meta-analysis done, including confidence/credible intervals. *In larger networks, authors may focus on comparisons versus a particular comparator (e.g., placebo or standard care), with full findings presented in an appendix. League tables and forest plots may be considered to summarize pairwise comparisons.* If additional summary measures were explored (such as treatment rankings), these should also be presented.
Results of additional analyses	**21**	Give results of additional analyses where applicable
DISCUSSION		
Key results	**22**	Summarize key results with reference to study objectives
Limitation	**23**	Discuss limitations of the study, taking into consideration sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.
Conclusions	**24**	Provide a cautious general interpretation of the results considering the objectives, limitation, multiplicity of analyses, results from similar studies and other relevant evidence.
Generalizability	**25**	Discuss the generalizability (external validity) of the study results
OTHER INFORMATION		
Funding	**26**	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

Appendix II.The 5 Major Drainage Basins of Lake Victoria, Kenya (Arrow)

Appendix III. Land Cover and Land Use Map of the Lake Victoria Basin
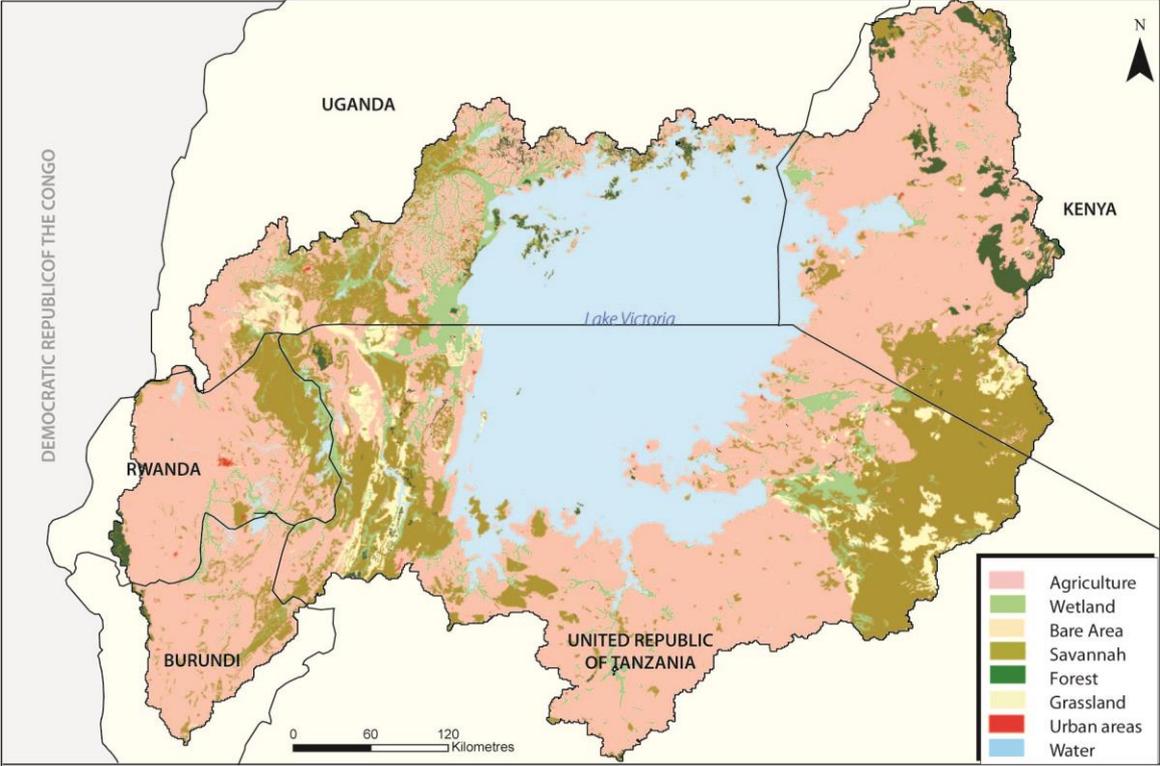
Simplified from FAO (AFRICOVER)

Appendix IV: Existing Standards for Discharge of Effluents into Aquatic Environment

Parameter	Limits	Remarks
PH	6.0 – 9.0	
BOD (5 Days at 20^0C	20 mgO_2/l	
COD	50 mgO_2/l	
Suspended solids	30 mg/l	
Total phenols	0.001 mg/l	2.0 mg/l in some cases
Copper	3 mg/l	0.05 mg/l in some cases
Zinc	0.5 mg/l	
Sulphates	250 mg/l	500 mg/l in some cases
Dissolved iron	10 mg/l	
Dissolved manganese	10 mg/l	0.1 mg/l in some cases
Chromium (Total)	2 mg/l	
Chromium (Hexavalent)	0.5 mg/l	
Chloride	200 mg/l	1000 mg/l in some cases
Fluoride	2.0 mg/l	
Free ammonia	0.2 mg/l	
Coliform Bacteria	300 mg/l /100 ml	1000/100 ml in some cases
Colour (Hazen units)	5	Not objectionable to the eye
Dyes	Nil	
Sulphide	0.1 mg/l	
Cadmium	0.1 mg/l	0.05 mg/l in some cases
Cyanide	0.1 mg/l	
Organic phosphorus	1.0 mg/l	
Nickel	1.0 mg/l	
Selenium	0.05 mg/l	
Barium	2.0 mg/l	
Lead	1.0 mg/l	
Arsenic	0.02 mg/l	
Total mercury	0.005 mg/l	
Alkyl mercury	Not detectable	0.001 mg/l in some cases
Polychlorinated biphenyls	0.03 mg/l	
Smell	Not objectionable to the nose	
Toxic substances	Nil	
Pesticides	Nil	0.05 mg/l in some cases
Oils and grease	Nil	
Degreasing solvents	Nil	
Calcium carbide	Nil	
Chloroform	Nil	
Condensing water	Nil	
Inflammable solvents	Nil	
Temperature	30^0C	
Dissolved solids (total)	1200 mg/l	