



**GRADUATE SCHOOL  
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**INVESTIGATING THE OCCURRENCE OF CONTAMINANTS OF  
EMERGING CONCERN IN URBAN SLUM AREAS: A CASE STUDY  
OF BWAISE, KAWEMPE DIVISION, KAMPALA - UGANDA**

**BY**

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## **DECLARATION**

I, Mafabi Martins, hereby declare that this dissertation is my own work and has not been previously published or written by another person nor material accepted for the award of any other degree of the university or other institute of higher learning except where due acknowledgement has been made within the text and the reference list.

Signature .....

Date.....

## **APPROVAL**

The undersigned certify that they have read and hereby recommend for acceptance by Kyambogo University a research dissertation entitled “Investigating the occurrence of contaminants of emerging concern in urban slum areas: a case study of Bwaise, Kawempe division”, in fulfillment of the requirements for the award of a Master of Science in Water and Sanitation Engineering Degree of Kyambogo University.

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## ABSTRACT

Contaminants of emerging concern (CECs) are defined as chemical compounds discovered in water or environment that are not currently monitored or regulated but are thought to cause adverse effects on the ecosystem and human health. The aim of this study was to investigate the occurrence, distribution, level of concentration, toxicology and risk rankings of four main pharmaceutically/personal care products active compounds (PPCPs) in the urban poor environment. The study was undertaken in Bwaise II & III, Kampala City, Uganda. Possible sources of contaminants of emerging concern were mapped and distances from housing and water sources established. Fifteen (15) water and waste samples were collected from water sources, open drains and solid waste dumping sites and analyses for various elements using the Liquid Chromatography tandem mass spectrometry (LC-MS-MS). The study found more healthcare centers (47%) than pharmacies (40%) and salons as possible sources of contaminants of emerging concern. These were found in low lying areas, mainly located along the main roads at an average distance of 20 metres from households and 20 metres from communal water stand taps and protected springs. LC-MS-MS analysis found Paracetamol in communal stand taps, grey water, drainage channel and protected springs, respectively with concentrations of (0.038; 0.017; 0.046 and 0.031ng/ml). Ibuprofen was detected in drainage channels (0.0083ng/ml), grey water (0.036ng/ml) protected spring (0.083ng/ml), unprotected spring (0.048ng/ml) and solid waste dump sites (0.285ng/ml). Other personal care products (PCPs) like Dichlorvos and Cypermethrin were detected in traceable amounts. Results derived from risk quotient approach established that Ibuprofen posed high acute risk of risk quotient (RQ) =1.96. This study recommends proper medical waste management especially from households, furthermore water treatment processes should target CECs and this can be captured at design stage.

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## **LIST OF ABBREVIATIONS**

|       |                                           |
|-------|-------------------------------------------|
| ADI   | Acceptable Daily Intake                   |
| ARGs  | Antibiotic Resistance Genes               |
| CECs  | Contaminants of Emerging Concern          |
| DDT   | Dichloro-Diphenyl-Trichloroethane         |
| DEET  | N,N-Diethyl-meta-toluamide                |
| DW    | Drinking Water                            |
| DWEL  | Drinking-Water Equivalent Level           |
| EA    | East Africa                               |
| EDC   | Endocrine Disruptors                      |
| EDCs  | Endocrine Disrupting Compounds            |
| EMEA  | European Medicines Evaluation Agency      |
| EPA   | Environmental Protection Agency           |
| EWG   | Environment Working Group                 |
| GC    | Gas Chromatography                        |
| GPS   | Geographical Positioning System           |
| JMP   | Joint Monitory Programme                  |
| KCCA  | Kampala Capital City Authority            |
| LC    | Liquid Chromatography                     |
| MoH   | Ministry of Health                        |
| MS    | Mass Spectrometry                         |
| MS/MS | Tandem Mass Spectrometry                  |
| NEMA  | National Environment Management Authority |
| NDP   | National Development Plan                 |

|       |                                               |
|-------|-----------------------------------------------|
| NIH   | National Institute of Health                  |
| NWQA  | National Water Quality Program                |
| PCBs  | Poly Chlorinated Biphenyls                    |
| PCPs  | Personal Care Products                        |
| PPCPs | Pharmaceuticals Personal Care Products        |
| RQ    | Risk Quotient                                 |
| SSA   | Sub-Saharan Africa                            |
| STPs  | Sewage Treatment Plants                       |
| TDI   | Tolerable Daily Intake                        |
| UBOS  | Uganda Bureau of Statistics                   |
| UNFPA | United Nations Fund for Population Activities |
| USGS  | United States Geological Survey               |
| WHO   | World Health Organization                     |
| UV    | Ultraviolet                                   |
| WWTPs | Wastewater Treatment Plants                   |

## OPERATIONAL DEFINITIONS

**Contaminants of Emerging Concern:** These are chemical compounds recently discovered in water or environment that are not currently monitored or regulated but are thought to cause adverse effects on ecosystem and human health

**Personal care products:** These are items other than pharmaceuticals products that are consumed or applied by an individual for personal health, hygiene or cosmetic reasons

**Pharmaceuticals:** These are drugs or medicines that are prepared or dispensed in hospitals or pharmacies and used in medical treatment.

**Toxicity:** The degree to which a substance/drug can harm humans or animals.

**Phenolic compounds:** These are a class of chemical compounds consisting of one or more hydroxyl groups bonded directly to an aromatic hydrocarbon group.

**Endocrine system:** This is responsible for regulating a range of bodily functions through release of hormones.

**Ecotoxicology:** This is the study of effects of toxic chemicals on biological organisms especially at the population, community, ecosystem and biosphere it integrates toxicology with ecology.

**Triclosan:** A compound used as an antimicrobial in deodorants, soaps, toothpaste and skin creams .

## **CHAPTER ONE: INTRODUCTION**

### **1.1 Introduction**

This chapter described the different aspects of the dissertation such as background, scope of study and many others.

### **1.2 Background of the study**

The world's human population is growing at a very high rate. In June 2019, the world's population was estimated to be about 7.7 billion and is expected to grow to over 10 billion by 2056 (United Nations Fund for Population Activities UNFPA, 2019). Population growth and migration of rural populations to urban areas have led to urban population sprawl and rapid growth in numbers of mega cities (Amrita *et al.*, 2014). One of the challenges of urbanisation is difficulty in sustainable supply of fresh drinking water to metropolitan areas. This is because there is a deterioration in fresh water bodies resulting from inadequate management of wastewater, solid waste and urban drainage (Bai *et al.*, 2018; Čelić *et al.*, 2019). A few of the areas of concern in relation to this are natural and synthetic organic chemicals (Ghesti and Gastaldini, 2019) collectively referred to as Contaminants of Emerging Concern (CECs).

Studies conducted worldwide have found significant traces of CECs in surface and drinking waters (Wilkinson *et al.*, 2017; Peña-Guzmán *et al.*, 2019). These CECs fall into several categories including pesticides, pharmaceuticals and personal care products (Rasheed *et al.*, 2018). CECs originate from various point and non-point sources of contaminations resulting from various processes like seepages, surface runoffs, sewage discharges and leakages (Onzima, 2015). Further effluents containing

pharmaceuticals from hospitals/clinics/medical centers are directly released to environment through grey water (Bai *et al.*, 2018).

CECs present a new global water quality challenge with potentially serious threats to human health and ecosystems (Varela, Nunes and Manaia, 2016; Pino-Otín *et al.*, 2017; Desbiolles *et al.*, 2018; Ivanová *et al.*, 2018). These include the development of antibiotic resistance, endocrine disruption and carcinogenicity in humans exposed to these contaminants. In addition, exposure of humans to endocrine-disrupting chemicals found under CECs include adverse reproductive outcomes, birth defects, breast cancer, developmental disabilities, endometriosis, thyroid problems and testicular cancer has been noted (Moll, 1999). Pharmaceutical residues within the aquatic environment have been reported to induce ecotoxic effects, hormonal disruption, and bacterial resistance (Fent, Weston and Caminada, 2006; Kostich, Batt and Lazorchak, 2014; Yan *et al.*, 2014)

Within the last three decades, there have been advances in water treatment but CECs still remain a challenge as they are most times poorly removed by conventional wastewater treatment techniques and behave as pseudo-persistent contaminants in the environment (De Graaff *et al.*, 2011; Verlicchi, Al Aukidy and Zambello, 2012; Rivera-Utrilla *et al.*, 2013; Fernández *et al.*, 2014; McEneff *et al.*, 2014). Consequently, they have been commonly detected in treated wastewater, surface water sources, randomly in groundwater and drinking water at concentrations ranging from the low ng L<sup>-1</sup> to mg L<sup>-1</sup> (Deblonde, Cossu-Leguille and Hartemann, 2011; Vergeynst *et al.*, 2015; Padhye *et al.*, 2014; Blair *et al.*, 2013; Carmona, Andreu and Picó, 2014; Vergeynst *et al.*, 2014; Lapworth *et al.*, 2012).

### **1.3 Statement of the problem**

Uganda like many developing countries is working to address issues related to inadequate water quality and its implications to the environment and health. Studies have found that urban slums contribute greatly to environmental pollution. This is because they are characterized by anthropogenic influences resulting from overcrowding, poor housing, inadequate water supply; poor human excreta disposal, grey water and solid waste management systems; and a high population growth rate (Ghesti and Gastaldini, 2019; Richmond, Myers and Namuli, 2018).

Studies within urban slums of Kampala have found that waste generating streams within these areas are no longer limited to domestic but include medical waste and personal care waste from saloons and cosmetics. In the past decade alone, Kampala district has experienced a tremendous increase in the number of both public and private healthcare establishments with a 15% increment from 4,450 facilities in 2010 to 5,117 facilities in 2016 (Katusiime, 2018) in addition to saloons and cosmetics. Management of medical and personal care wastes like other waste streams within urban slums is limited and they thus end up in pit latrines, greywater and solid waste streams. Grey water within slums of Kampala is discharged directly in open drains (Katukiza *et al.*, 2015). The dump sites are located along the main roads, next to drainage channels, or on open land making them unofficial dumping sites. Contents from pit latrines in areas of high water table are often discharged into drainages during rainy seasons as a way of emptying (Nyenje *et al.*, 2012). All this ultimately is washed down into available water bodies which are sources for domestic water.

In Uganda, a few environmental pollutants are being monitored in water, soil and air. These include; pesticides (Onzima, 2015) and heavy metals (Muhwezi, 2011; Egor, Jolocam, Mbabazi and Ntale, 2014). Water quality investigations in slums have mainly concentrated on nutrients, bacteria, heavy metals, and priority pollutants with known health effects (Katukiza *et al.*, 2015; Bakyayita, Norrström and Kulabako, 2019; Fuhrmann *et al.*, 2015) such as pesticides, industrial chemicals, and petroleum hydrocarbons (Amrita *et al.*, 2014). Only two studies including Nantaba *et al.* (2020); Dalahmeh *et al.* (2020) have investigated the occurrence and possible ecotoxic effects of various classes of commonly-used human and veterinary pharmaceuticals in various bays of Lake Victoria and Nakivubo wetlands

From the study by Nantaba *et al.* (2020), 18 pharmaceutical products were quantified, among which sulfamethoxazole, oxytetracycline, erythromycin, and Diclofenac were noted to pose a high toxic risk to aquatic organisms in the lake, while ciprofloxacin, norfloxacin, and ibuprofen pose a medium risk. Dalahmeh *et al.* (2020) analysed chemicals in water samples and established that trimethoprim and sulfamethoxazole were dominant in water from all sites with the exception of Lake Victoria. The continuous rise in urban population challenges and development has a potential effect on the environment and receiving water bodies. There is thus, a need to develop strategies for mitigation of any cited negative effects by protecting human health and information on nature and origins of CECs could guide this.

## **1.4 Objectives of the study**

### **1.4.1 Main objective**

The aim of this study was to investigate the origins, occurrence and associated risks of CECs within urban waste and water sources in an urban slum setting.

### **1.4.2 Specific objectives**

1. To establish sources of CECs
2. To assess the level of CECs in drinking water open and protected sources, grey water and solid waste dump sites.
3. To quantify toxic risks caused by CECs to human health.
4. To rank toxic risks based on the sources and quantities and propose management strategies

## **1.5 Research questions**

1. What are the potential sources of CECs?
2. What are the types and levels of CECs within the urban slum environment?
3. Are these levels above the recommended limits of CECs in the environment?
4. Which CECs pose a potential threat to human health and what is the order of their potential risk?

## **1.6 Justification of the study**

The availability of portable drinking water is a basic corner stone of public health. Increased access to safe water and better sanitation practices have done more to increase life span and enhance human health than any other developments in the field of medicine (Moll, 1999). This implies a continuous need to identify the potential

pollutants that could be transmitted through these means. Urban slums are some of the major sources of pollutants since their activities are characterised by indiscriminate waste disposal. Studies on CECs within such settings could help in the establishment of different research priorities and assist in improving water quality there by contributing to the livelihood of the people living in these setting and those accessing water from the final disposal points of wastes from such areas.

### **1.7 Significance of the study**

This study will provide the necessary information regarding the current status of CEC in urban slums. This is important to enable the responsible bodies such as Kampala Capital City Authority (KCCA) and National Environment Management Authority (NEMA) in setting the appropriate guidelines to regulate and mitigate their negative environmental impacts. This will also help in the development of different approaches to management and formulate policies in order to remove sources and sinks, block conduits that feed CECs into the environment.

The ultimate implication is improved drinking water quality, and health for the people within urban slums and Kampala in general, thereby contributing to Uganda's National Development Plan (NDP) II and Vision 2040 on water and sanitation component focusing on increasing access to safe water and sanitation in rural and urban areas thus improving on health welfare of citizens (NDPII, 2015). This will in turn also contribute to the Sustainable Development Goals (SDGs) (SDGs, 2015) No.3, 4 and 6 which are; Ensure healthy lives and promote well-being for all at all ages, ensure inclusive and equitable quality education and promote lifelong learning

opportunities for all and Ensure availability and sustainable management of water and sanitation for all respectively.

### 1.8 Conceptual Framework

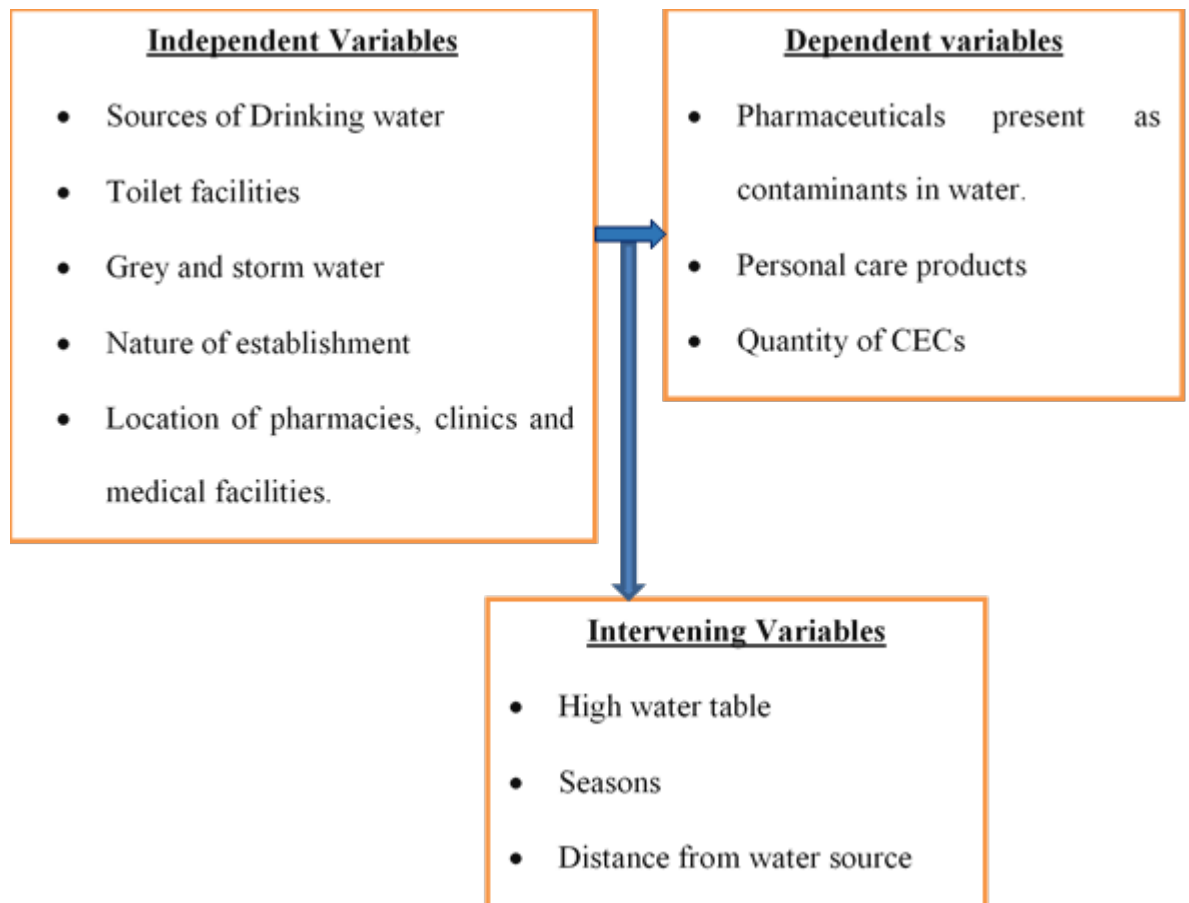


Figure 1-1: A conceptual framework of the study

## **1.9 Scope of the study**

The study was to investigate the occurrence of contaminants of emerging concern in water and waste streams within an urban slum of Kampala Uganda. It was limited and focused on determining the occurrence of selected pharmaceuticals and personal care products, in surface water (open and protected sources), drinking water and solid waste dump sites in high and low water table areas. The study was limited to Bwaise II/ III which is characteristic of an urban slum and has both high and low water table areas. The study was undertaken from August 2019 till June 2020.

## **1.10 Outline of the dissertation**

The dissertation is organized as a series of chapters. In total, the thesis consists of five (05) chapters. Chapter 1 is the introduction to the study, which covers the study background, problem statement, research objectives, justification of the study, significance of the study, scope of the study and conceptual frame work. Chapter 2 is a critical review of previous and current knowledge with special focus on urban areas of sub-Saharan Africa (SSA). Knowledge gaps and strategies/interventions to regulate the CECs were identified.

Chapter 3 covers the different methods and materials used in the study, it also presents how the data collected in the study was analysed and presented. Chapter 4 presents the results to the study and discussion of each objective.

Chapter 5 covers the general conclusion basing on the obtained results and the recommendations.

## **CHAPTER TWO: LITERATURE REVIEW**

### **2.1 Introduction**

This presents a review of existing literature related to the study.

### **2.2 Contaminants of emerging concern**

Contaminants have been present in the environment for a while, but their concern has just been raised. Awareness of emerging contaminants date to 1962 when first identified by Rachel Carson following her publication on the impact of Dichloro-Diphenyl-Trichloroethan (DDT) on bird disappearance Carson. (1962). However, her discovery was highly criticised due to tampering with the welfare of society from using (DDT) to control or eliminate pests most importantly mosquitoes (Sébastien and Desrosiers, 2014). The negative impacts of DDT and its subsequent ban was followed with academic research in this area (Tsefahunegn, 2016). Since then, a lot has been discovered in this field and thus the definition of emerging contaminants is relative in that what was emerging as an environmental contamination two decades ago might not be qualified as an emerging contaminant of recent. For example, Lead and arsenic are old contaminants with different emerging concerns through human history (Sébastien and Desrosiers, 2014). Acid Rain, and a number of pesticides have also been noted to be of concern (Haines, 1981). Currently, a number of substances such as pharmaceuticals and personal care products (PPCPs), natural and synthetic hormones, an array of agricultural pesticides, as well as perfluorinated compounds (PFCs) and other persistent and toxic organohalogen compounds (chemicals containing one or more carbon-halogen bonds) produced by modern society are

catagorised as CECs (Pignotti, 2018). Some of the CECs according to their uses and characteristics are listed in Table 2-1and discussed thereafter.

**Table 2-1: Common classes of CECs**

| <b>Class of CECs</b>              | <b>Example</b>                               | <b>Definition</b>                                                                                                                                                      |
|-----------------------------------|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Antibiotics                       | Tetracycline, erythromycin                   | Medications that fight bacterial infections, inhibiting or stopping bacterial growth                                                                                   |
| Antimicrobials                    | Triclosan                                    | Biochemicals that kill or inhibit the growth of microorganisms including bacteria and fungi                                                                            |
| Detergent metabolites             | Nonylphenol                                  | Chemical compounds formed when detergents are broken down by wastewater treatment or environmental degradation                                                         |
| Disinfectants                     | Alcohols, Aldehydes and oxidizing agents     | A chemical agent used on non-living surfaces to destroy, neutralize, or inhibit the growth of disease-causing microorganisms                                           |
| Disinfection by-products          | Chloroform, Nitrosodimethylamine (NDMA)      | Chemical substances resulting from the interaction of organic matter in water with disinfection agents such as chlorine                                                |
| Estrogenic compounds              | Estrone, Estradiol, Nonylphenol, Bisphenol A | Natural or synthetic chemicals that can elicit an estrogenic response                                                                                                  |
| Fire or flame retardants          | Polybrominated Diphenyl Ethers (PBDEs)       | Any of several materials or coatings that inhibit or resist the spread of fire                                                                                         |
| Fragrances                        | Galaxolide                                   | Chemical substances that impart a sweet or pleasant odor                                                                                                               |
| Insect repellants                 | DEET (N, N-diethyl-metatoluamide)            | Chemical substances applied to skin or other surfaces to discourage insects from coming in contact with the surface                                                    |
| PAHs (Poly-Aromatic Hydrocarbons) | Benzo(a)pirene, Fluoranthene, Naphthalene    | A large group of chemical substances usually found in the environment as a result of incomplete burning of carbon-coating materials like fossil fuels, wood or garbage |
| Personal Care Products            | Para-hydroxybenzoate                         | Chemical substances used in a diverse group of personal items including toiletries and cosmetic                                                                        |
| Pesticides or Insecticides        | Permethrin, Fenitrothion, Bacillus           | Chemical substances or microbiological agents that kill, incapacitate or                                                                                               |

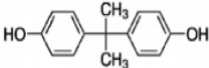
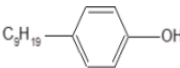
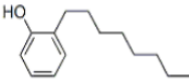
| Class of CECs         | Example                                                     | Definition                                                                                                                                   |
|-----------------------|-------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
|                       | thuringiensis israelensis (Bti)                             | otherwise prevent pests from causing damage                                                                                                  |
| Pharmaceuticals       | Fluoxetine, Carbamazepine, Diphenhydramine                  | Chemical substances used in the prevention or treatment of physiological conditions                                                          |
| Plasticizers          | Diethyl Phthalate (DEHP)                                    | Chemical additives that increase the plasticity or fluidity of a material                                                                    |
| Reproductive hormones | Dihydrotestosterone (DHT), Progesterone, Estrone, Estradiol | A group of chemical substances, usually steroids, whose purpose is to stimulate certain reproductive functions                               |
| Solvents              | Ethanol, Kerosene                                           | Chemical solutions, other than water, capable of dissolving another substance                                                                |
| Steroids              | Cholesterol, Coprostanol, Estrone, Progesterone             | A large group of fat-soluble organic compounds with a characteristic molecular structure, which includes many natural and synthetic hormones |
| Surfactants           | Sodium Lauryl Sulfate                                       | Chemical substances that affect the surface of a liquid                                                                                      |

Source (Pignotti, 2018 and Ragav *et al.*, 2013)

### 2.2.1 Other Categories found in Soil and Sediment – Phenolic compounds

Bisphenol A (BPA) is an organic chemical commonly used in the industry primarily for the production of epoxy resins and polycarbonate plastics, as an antioxidant and inhibitor of end of polymerization in polyvinyl chloride plastics (PVC) and as a precursor for the synthesis of the flame retardant tetrakisphenol-A (Geens *et al.*, 2012). This means it can be widely applied basing on polycarbonates and epoxy resins, such as water bottles, dental materials equipment, medical devices, impact-resistant safety, as well as food and drink packaging, food cans, and water supply pipes (NIH, 2017). Phenolic compounds considered under this are; persistent, toxic and bio accumulating compounds.

**Table 2-2: Main characteristics of the most abundant phenolic compounds**

|                          | Bisphenol A<br>(BPA)                                                              | Nonylphenol<br>(NP)                                                                | Octylphenol<br>(OP)                                                                 |
|--------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Structure                |  |  |  |
| Molecular Weight (g/mol) | 228.3                                                                             | 220.3                                                                              | 206.3                                                                               |
| Solubility (mg/L)        | 300                                                                               | 6.23                                                                               | 4.8                                                                                 |
| logK <sub>ow</sub>       | 3.4                                                                               | 4                                                                                  | 4.6                                                                                 |
| pK <sub>a</sub>          | 9.6                                                                               | 10.7                                                                               | 10.3                                                                                |

Source: (Pignotti, 2018)

In this study, CECs are defined as synthetic chemical compounds found in water recently being recognised as significant pollutants (Czech, B. and Rubinowska, 2013) and have been limited to pharmaceuticals and personal care products.

### 2.2.2 Origins of CECs

Within the urban watersheds CECs originate from hospitals, clinics, households, construction, transportation, animal feeding, and municipal waste disposal. As the majority of CECs, the occurrence of phenolic compounds in the environment is mainly related to the discharge of municipal and industrial WWTPs; however, there are other sources which include such as landfill disposal, proximity of industrialised areas, and runoff from agricultural lands with pesticide application can contribute to their introduction in the aqueous compartment (Soares *et al.*, 2012; Sánchez-Avila *et al.*, 2009; Zhu, Z Zuo, 2013; Careghini *et al.*, 2015). Current research has indicated the occurrence of hundreds of organic contaminants within wastewater and has affected urban surface waters, which are typically detected at a trace of µg/L or mg/L, (Pal *et al.*, 2014). There also are numerous factors that contribute to PPCPs contamination of water bodies especially in Africa particularly Sub-Saharan region. For instance, in many communities of Sub Saharan African countries due to poor or no sanitation

processes, such areas do not have wastewater treatment facilities, leading to a direct disposal of human excreta on the ground or in surface water. Hence, during the rainy seasons, faecal matter is washed off from the ground into the surface water bodies (Segura *et al.*, 2015).

The CECs or micro-pollutants are a vast and expanding array of anthropogenic compounds that are commonly present in water (Rasheed *et al.*, 2018). They normally contain a mixture of extensively used synthetic compounds which are cosmetics, pharmaceuticals, pesticides, steroid hormones, and personal care products (Luo *et al.*, 2014) that are indispensable in modern society around the globe. It is estimated that the worldwide production of pharmaceuticals increased from 1 million to 500 million tons per annum (Thomaidis, Asimakopoulos and Bletsou, 2012). Pharmaceuticals (both over the counter and prescribed formulations) span a broad range of classes, including but not limited to antidepressants, antibiotics, painkillers, and synthetic hormones. Specifically, there are concerns about pharmaceuticals remaining biologically active after entering the environment, since they are designed to impart therapeutic effects to humans and animals at low levels (Rebecca, Sedlak and Yee, 2013). Nonetheless, up to 25% percent of medical waste is hazardous/infectious and therefore is of concern because of the environmental hazards and public health risks that this waste poses (Katusiime, 2018). Figure 2-1 shows sources and pathways of PPCPs. Studies on risk assessment of CECs have noted that there is effect on aquatic life in relation to survival, growth and reproduction (Hull, Kleywegt and Schroeder, 2015). Mitigation of risks associated with CECs necessitates knowledge about their occurrence, exposure risk and potential impacts on human health. However, this information is limited within developing countries. There is thus a need for such

studies given that developing countries are most pressed with challenges of inadequate water, and poor wastewater and solid waste management.

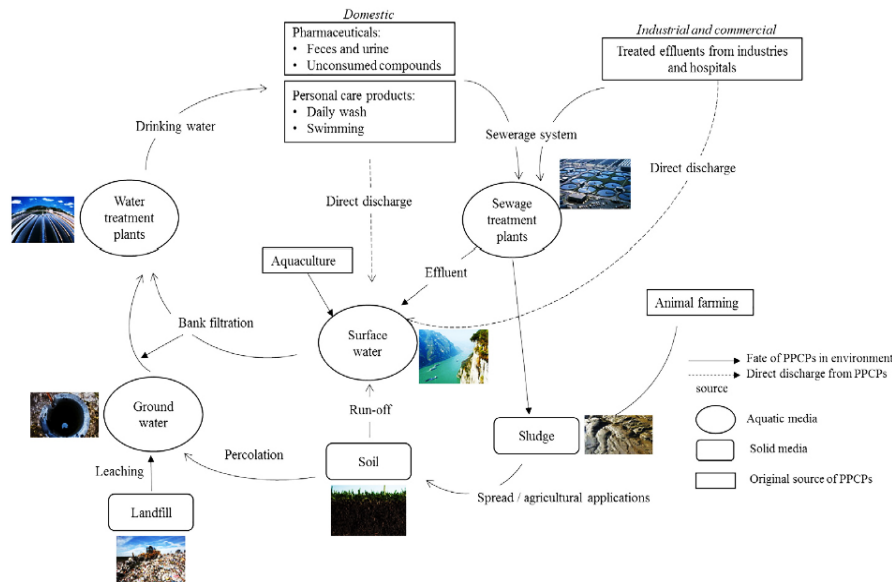


**Figure 2-1: Sources and pathways of PPCPs**

Source: (Yang *et al.*, 2017)

However, the other additional sources are leaking sewer lines, landfills and indiscriminate waste disposal. Flow through wetlands, River transport, and groundwater recharge and transport can reduce CECs concentrations to below the detection limit by the natural attenuation processes like sorption, dilution, volatilization, and degradation (Birgit, Naumann and Reinhard, 2004; Steffen, Amy and Jekel, 2005; Lin, Plumlee and Reinhard, 2006). Rainfall drains off toxic chemicals from streets, buildings and land surfaces or poorly disposed wastes which end up into surface waters (Xu *et al.*, 2011). The occurrence of heavy rainfall leads to flash floods which erode sediments on landfills and agricultural fields, leading to the possible release of CECs including pesticides (Moreno-González *et al.*, 2013) into surface waters.

### **2.2.3 Sources and Pathways of Pharmaceuticals in the Environment**

Pharmaceuticals and their metabolites are released continuously to the environment from point and nonpoint sources. Agricultural outputs to fields, unregulated domestic effluents and aquatic systems and aerial disposal sources are nonpoint origins of the pharmaceuticals. After being administered, these pharmaceuticals may or may not undergo metabolic transformations either by gut microbes or host enzymes before excretion (Patel *et al.*, 2019). One of the most important factors that governs the common occurrence pattern of individual pharmaceuticals within the environment is their consumption trend (Boxall *et al.*, 2012) that's to say, the disease pattern in the area affects its consumption trend. For example, low-income countries have a greater rate of infectious diseases (WHO, 2011) and generally greater rate of over-the-counter self-medication (Ayukekbong, Ntemgwa and Atabe, 2017).

The unused and expired pharmaceuticals normally enter the environment by being flushed into basins, drains, toilets, or disposal with household wastes. Pharmaceuticals thrown into household wastes end up in landfill sites which end up becoming groundwater leachates when landfill sites are not well sealed. Pharmaceuticals in the environment originate from human usage through release of both metabolized and un-metabolized drugs and disposal of unused medicines.

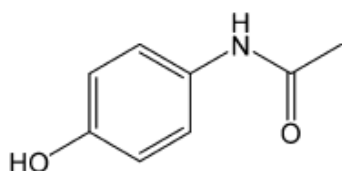
The veterinary antibiotics and hormones are normally found in animal waste collection lagoons or where these wastes are applied to agricultural fields. After a greater accumulation, they build up and migrate into surface water and groundwater. These further reach the environment through animal treatment, inappropriate disposal of unused medicines or livestock feed. Animal excretion of pharmaceuticals and their

metabolites make animal husbandry the third largest emission source (Ebele, Abdallah and Harrad, 2017).

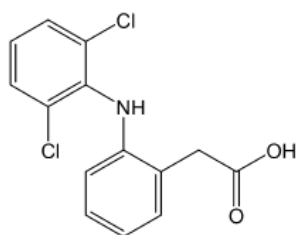
The commonly detected compounds with an overall detection frequency, DF > 90% include; antibiotics sulfamethoxazole, trimethoprim and metronidazole, and the antiretrovirals nevirapine and zidovudine (Philip, Aravind and Aravindakumar, 2018)

Below are the different molecular structures of the selected pharmaceuticals for the this study (Patel *et al.*, 2019).

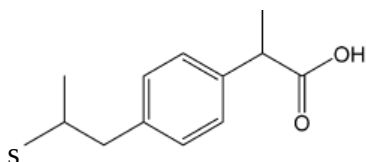
Chemical Structure of Paracetamol



Chemical Structure of Diclofenac



Chemical Structure of Ibrufen



#### **2.2.4 Personal care products**

These include cosmetics, mosquito repellants, antimicrobial and antifungal agents, surfactants, perfumes and sunscreens which are commonly used in urban settings. PCPs unlike pharmaceuticals, are applied externally. This means they do not undergo any metabolic changes prior to their release to the aquatic environment. Another compound used as an antimicrobial in deodorants, soaps, , toothpaste and skin creams is Triclosan, a biphenyl ether (McAvoy *et al.*, 2002) that has been identified in surface water in many works with consulted literature (Nishi, Kawakami and Onodera, 2008; Lyndall *et al.*, 2010; Lyndall *et al.*, 2010; Petrie *et al.*, 2016) .

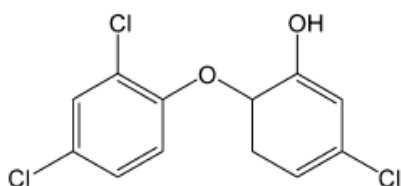
However, due to the fact that they are extensively used on a day-to-day basis, they are also highly detected in surface waters and have the potential of bioaccumulation (Brausch and Rand, 2011). PCPs normally find their way into the environment through different routes. The major sources of PCPs to the environment are; sewage treatment plants (STPs, WWTPs, landfill leaching and indiscriminate disposal of used water from different sources like salons. Furthermore, externally applied PCPs are mostly discharged through shower waste, bathing, swimming and washing sinks. They can pass through WWTPs, and reach the environment (Ebele, Abdallah and Harrad, 2017). They normally contain a greater number of non-biodegradable, active and inert organic contaminants, which normally enters surface water, groundwater and drinking water after waste discharge.

#### **2.2.5 Sources and Pathways of PCPs in the Environment**

The main route of mixing these contaminants with water sources is through leaching process. These contaminants are commonly found in urban water samples (Jonas *et*

*al.*, 2015). Most of the PCPs are mainly designed for external use and washed out without any chemical change in their structure and properties. As a result, the contaminants are easily mixed with the aquatic environment simply because they create their paths toward WWTPs and affect them more hardly. Some of the different possible fates caused by PCPs in WWTPs include; mixing with CO<sub>2</sub> and water, retain in solid form and transformation into lipophilicity, release into the water as an original compound or derivatives as a result of degradation. Currently, they are of a greater increase in groundwater through urban runoff (Yan, *et al.*, 2015; Rippey, *et al.*, 2016)

Below is the molecular structure for Triclosan;



#### 2.2.6 Occurrence

There is general realization of presence of human and veterinary pharmaceuticals in surface waters (Sébastien and Desrosiers, 2014). Estrogenic hormone concentrations in wastewater effluents and receiving water bodies have been detected to have high concentrations of feminization of fish and traces of pharmaceutical drugs have been detected in drinking water (DW).

Pharmaceutical compounds were found to be present in drinking water in Berlin, Germany (Heberer, 2002), and 24 of the 28 major cities that were sampled in the United States (Loeb, 2008). Also, CECs have been widely monitored and found in

different groundwater sources in Italy (Raffaella and Bustamante, 2014), Spain (Anna *et al.*, 2012) and the United States (Fram and Belitz, 2011). Pharmaceuticals have recently emerged in past two decades as emerging contaminants and yet drugs have been consumed for a very long period. These antibiotic-resistant bacteria and resistance genes are also found in reclaimed wastewater (Christou *et al.*, 2017), recreational water and even drinking water (O’Flaherty and Cummins, 2017) worldwide.

In developing countries and particularly in Africa, the information on the occurrence of pharmaceuticals in the environment is very scarce (Hughes, Kay and Brown, 2013; Aus der Beek *et al.*, 2016) with only few publications from Africa available in open literature (K’oreje *et al.*, 2012; Agunbiade and Moodley, 2014; Manickum and John, 2014; Wood, Duvenage and Rohwer, 2015; Ngumba, Gachanja and Tuhkanen, 2016). There is thus a need to undertake studies in this area to inform their management and mitigation.

CECs are not yet fully regulated within drinking water supplies; this means they aren’t commonly monitored in the environment. However, most of these contaminants have the ability to cause severe ecological and/or human health effects even at low levels.

**Table 2-3: Concentrations of BPA, NP and OP in different environmental compartments in the world**

| <b>Environmental compartment</b> | <b>Location</b>    | <b>BPA</b>  | <b>NP</b>  | <b>OP</b>  | <b>Reference</b>                |
|----------------------------------|--------------------|-------------|------------|------------|---------------------------------|
| Indoor air*                      | Tokyo              | —           | <4.5-680   | <0.87-45.7 | Saito et al., 2004              |
| Indoor air*                      | France             | <0.6-10     | —          | —          | Blanchard et al., 2014          |
| Outdoor air*                     | Tokyo              | —           | <4.5-53.1  | <0.87-5.3  | Saito et al., 2004              |
| Outdoor air*                     | North Sea          | —           | 0.03-0.11  | 0.005-39   | Xie et al., 2006                |
| Outdoor air*                     | China              | 0.23-1.26   | —          | —          | Fu and Kawamura., 2010          |
| Outdoor air*                     | Arctic             | 0.001-0.011 | —          | —          | Fu and Kawamura., 2010          |
| WWTP influent**                  | Spain              | 2.40        | 102        | 66.6       | Sanchez-Avila et al., 2009      |
| WWTP influent**                  | Australia          | 140         | 3,070      | 229        | Tan et al., 2007                |
| WWTP effluent**                  | Spain              | 0.62        | 21.9       | 53.8       | Sanchez-Avila et al., 2009      |
| WWTP effluent**                  | Australia          | 86.7        | 335        | 23.5       | Tan et al., 2007                |
| Surface water**                  | Spain              | 0.11-126    | 96-1,483   | 0.14-474   | Esteban et al., 2014a           |
| Surface water**                  | Spain-Portugal     | 20-4,800    | 30-1,030   | 8-88       | Salgueiro-Gonzalez et al., 2015 |
| Surface water**                  | Baltic Sea         | 31.6-713.9  | <LOQ-3,660 | <LOQ-329.5 | Stanizewska et al., 2015        |
| Surface water**                  | Belgium            | 3-55        | 32-2,500   | <LOQ       | Loos et al., 2007               |
| Surface water**                  | Italy              | 36-175      | 460-700    | 11-111     | Loos et al., 2007               |
| Surface water**                  | San Francisco, USA | —           | <LOQ-72.9  | —          | Klosterhaus et al., 2013        |
| Surface water**                  | Miami River, USA   | 4.4-190     | —          | —          | Singh et al., 2010              |

| <b>Environmental compartment</b> | <b>Location</b>      | <b>BPA</b> | <b>NP</b>   | <b>OP</b>  | <b>Reference</b>                |
|----------------------------------|----------------------|------------|-------------|------------|---------------------------------|
| Surface water**                  | Pearl River, China   | 7.72-311   | 64.8-1,550  | 2.38-16.85 | Zhao et al., 2011a              |
| Surface water**                  | Songhua River, China | 8.24-263   | 106-344     | 1.54-45.8  | Zhang et al., 2014              |
| Groundwater**                    | Spain                | —          | <10-5,280   | <10-1,800  | Tubau et al., 2010              |
| Groundwater**                    | Europe               | <1-2,299   | —           | —          | Loos et al., 2010               |
| Drinking water**                 | Italy                | <0.73-102  | <7.70-84    | —          | Maggioni et al., 2013           |
| Drinking water**                 | France               | —          | <10         | <2         | Devier et al. 2013              |
| Drinking water**                 | Guangzhou, China     | 2.3-317    | 196-1,070   | —          | Li et al., 2010                 |
| Drinking water**                 | China                | 2.1-128    | 8.1-558     | —          | Fan et al., 2013                |
| Soil/sediment***                 | Italy                | 7-127      | 31.9-224.2  | 15.8       | Viganò et al., 2015             |
| Soil/sediment***                 | Spain                | 4.5-100    | 36-538      | 9.4-45     | Gorga et al. 2014               |
| Soil/sediment***                 | Greece               | 7.2-39     | 223-2,695   | 6.0-25     | Arditsoglou and Voutsas., 2012  |
| Soil/sediment***                 | Spain-Portugal       | 4.3-130    | 21-4,460    | 9.3-74.5   | Salgueiro-Gonzalez et al., 2015 |
| Soil/sediment***                 | Baltic Sea           | —          | <LOQ-249.1  | 0.15-20.47 | Konieczko et al., 2014          |
| Soil/sediment***                 | San Francisco, USA   | —          | 21.5-86.3   | —          | Klosterhaus et al., 2013        |
| Soil/sediment***                 | Japan                | 1.88-23.0  | —           | —          | Liao et al., 2012               |
| Soil/sediment***                 | Pearl River, China   | <LOQ-76.6  | 11.4-3,750  | <LOQ-30.4  | Zhao et al., 2011a              |
| Soil/sediment***                 | Guangzhou, China     | 2.54-269   | 10.9-14,400 | —          | Peng et al., 2017               |
| Biota***                         | Italy                | 36.6-1530  | 240-4,191   | 12.0-223.2 | Viganò et al., 2015             |
| Biota***                         | Baltic Sea           | nd-273     | nd-263.8    | 0.8-176.1  | Stanizewska et al., 2017        |
| Biota***                         | Finland              | <LOQ-137.2 | 5.5-91.3 1  | 12.7-481.5 | Nehring et al., 2017            |
| Biota***                         | Turkey               | <50        | nd-52.73    | <3         | Yilmaz et al., 2016             |

| <b>Environmental compartment</b> | <b>Location</b>    | <b>BPA</b> | <b>NP</b>   | <b>OP</b>  | <b>Reference</b>   |
|----------------------------------|--------------------|------------|-------------|------------|--------------------|
| Biota***                         | Pearl River, China | 0.49-4.51  | 17.48-237.1 | <0.11-0.47 | Diao et al., 2017  |
| Biota***                         | NE coast USA       | —          | 122-2,380   | —          | Diehl et al., 2012 |
| Biota***                         | Ohio, USA          | —          | 6.6-110     | —          | Rice et al., 2003  |
| Biota***                         | SE Asia            | nd-13.7    | nd-643      | nd-14      | Isobe et al., 2007 |

nd: not detected; \* : ng/m<sup>3</sup> ; \*\*: ng/L; \*\*\*: ng/g

Source (Pignotti, 2018)

**Table 2-4: The concentrations of E1, E2 and EE2 in different environmental compartments in the world**

| <b>Environmental compartment</b> | <b>Location</b> | <b>E1</b> | <b>E2</b> | <b>EE2</b> | <b>Reference</b>          |
|----------------------------------|-----------------|-----------|-----------|------------|---------------------------|
| WWTP influent*                   | French WWTP     | 18.8-170  | 5.1-37.9  | <LOQ       | Gabet-Giraud et al., 2010 |
| WWTP influent*                   | French WWTP     | 0.1-58    | 0.5-11.9  | 1.6-4.6    | Gabet-Giraud et al., 2010 |
| Duck-weed ponds influent*        | The Netherlands | 43.5      | 29.7      | 9.71       | Shi et al., 2010          |
| Duck-weed ponds influent*        | The Netherlands | 2.45      | 1.38      | 0.59       | Shi et al., 2010          |
| Surface water*                   | Italy           | <1.2-10   | <1.0-175  | <0.8-34    | Pojana et al., 2007       |
| Surface water*                   | Portugal        | 2.4-4.0   | 4.9-10.1  | 4.6-9.14   | Rocha et al., 2015        |
| Surface water*                   | China           | 22.4-66.2 | <0.66-1.8 | nd         | Chen et al., 2007         |
| Groundwater*                     | The Netherlands | 9         | 31        | nd         | Lapworth et al., 2012     |
| Groundwater*                     | Europe          | 1.1       | <LOQ      | <LOQ       | Jurado et al., 2012       |

| <b>Environmental compartment</b> | <b>Location</b>     | <b>E1</b>  | <b>E2</b>  | <b>EE2</b> | <b>Reference</b>                       |
|----------------------------------|---------------------|------------|------------|------------|----------------------------------------|
| Drinking water*                  | Germany             | 0.20-0.60  | 0.20-2.1   | 0.15-0.50  | Kuch and Ballschmiter., 2001           |
| Drinking water*                  | Spain               | <LOQ       | nd         | <LOQ       | Huerta-Fontela et al., 2011            |
| Soil/sediment**                  | Spain               | <LOQ – 3.5 | <LOQ – 1.6 | nd         | Gorga et al., 2015                     |
| Soil/sediment**                  | Czech Republik      | 1.01-2.37  | 1.15-1.84  | 1.63       | Matejicek., 2011                       |
| Soil/sediment**                  | Tianjin area, China | 0.98-21.6  | nd-9.70    | nd-9.26    | Lei et al., 2009                       |
| Luoma Lake, China                | Luoma Lake, China   | nd         | 0.52-1.21  | 0.61-1.48  | Liu et al., 2017a                      |
| Luoma Lake, China                | Australia           | 0.16-1.17  | 0.22-2.48  | <LOQ-0.5   | Braga et al., 2005                     |
| Animal manure***                 |                     |            |            |            |                                        |
| Swine farrowing pits             | U.S.A.              | 4800       | 1500       | 500        | Combalbert and Hernandez-Raquet., 2010 |
| Poultry manure                   | U.S.A.              | 44.2       | 92.7       | 149.8      | Andaluri et al., 2012                  |
| Cow manure                       | U.S.A.              | 16.1       | 6.2        | 149.8      | Andaluri et al., 2012                  |

nd: not detected; \*: ng/L; \*\*: ng/g dw; \*\*\*µg/Kg

Source (Pignotti, 2018)

The first national survey of CECs in the drinking water in the African continent was carried out in major South African cities. It included qualitative screening for approximately 700 compounds, as well as a quantitation of three critical compounds identified in the qualitative screen. These critical compounds are; atrazine, terbuthylazine and carbamazepine (Christiaan *et al.*, 2015). These are transmitted through surface runoff, and on site treatment systems of residential wastewater disposal as evidenced by several recent studies in surface waters (Rebecca, Sedlak and Yee, 2013).

In Uganda only two studies by (Nantaba *et al.*, 2020; Dalahmeh *et al.*, 2020) have investigated the occurrence and possible ecotoxic effects of various classes of commonly-used human and veterinary pharmaceuticals in various bays of Lake Victoria and Nakivubo wetlands.

Urban storm water is a major source of CECs to surface waters and eventually drinking water. Continuous exposure to these contaminants is likely to have human health effect, for instance increased resistance to antibiotics, endocrine disruptions and cancer (Ghesti and Gastaldini, 2019) as shown in Figure 2-2. Establishment of the existence of Emerging Contaminants are important because the risk they pose to human health and the environment is not yet fully understood. Hence, understanding the occurrence and distribution of these complex contaminants helps predict and mitigate their potential effects on human health (Barber *et al.*, 2015)

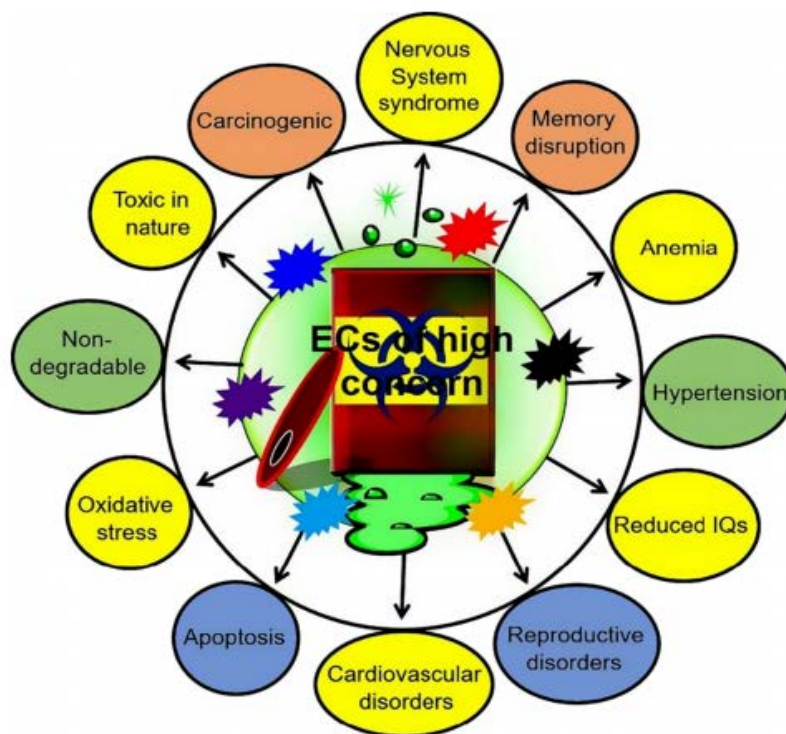


**Figure 2-2: Major consequences and advanced effects of CECs on Human health and the environment**

Source:(Rasheed *et al.*, 2018)

#### **2.2.6.1 Pharmaceuticals**

The occurrence of pharmaceuticals and their human metabolites into waterways is of a great increasing concern. They are normally found in the environment as parent compounds or as metabolites or conjugates, mainly because of disposal to the sewage system. They cannot be removed completely by WWTPs. The effluents containing pharmaceuticals from hospitals/clinics/medical centers which are released directly into nearby river waters and not collected by sewer system can be of a significant contaminant source to the environmental waterways (Lin, Plumlee and Reinhard, 2006). Globally consumption of antibiotics was 100,000 – 200,000 tons per year in 2002 and consumption of Paracetamol alone is more than 3500 tons, according to

estimates worldwide medicine use will reach 4.5 trillion doses by 2020 (Aus der Beek *et al.*, 2016). This rapid consumption is driven by high population growth.

**Table 2-5: Occurrence / treatment– available literature around the world**

| Source                               | Country                    | Nature of study                                                                                                                                          | CEC studied                                                                                                          | Remarks                                                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ghesti and Gastaldini, 2019)         | Brazil                     | A cross sectional study of analyzing the presence of pollutants in two water bodies in Brazil                                                            | Paracetamol, Estrone, Diclofenac, Ibuprofen, Megestrol acetate, Estriol and 17 $\beta$ -estradiol                    | The study assessed the presence of pharmaceuticals and hormonal compounds in two water bodies in the city of Santa Maria in southern Brazil. Two drugs were Ibuprofen and Paracetamol were found in several samples collected in the study area.                                                                                                                                             |
| (Rivera-Jaimes <i>et al.</i> , 2018) | Mexico                     | A Case Study of pharmaceuticals in surface and wastewater from Cuernavaca, Morelos, Mexico: occurrence and environmental risk assessment.                | Pharmaceutical residues in surface water and wastewater                                                              | Twelve pharmaceuticals were detected in the water samples analyzed, with detection frequencies above 78% and in most cases of 100%. Overall, the most abundant pharmaceuticals in surface water were the analgesic and anti-inflammatory drugs naproxen (732–4880 ng/L), acetaminophen (354–4460 ng/L), and Diclofenac (258–1398 ng/L), and the lipid regulator bezafibrate (286–2100 ng/L). |
| Gonzalez-Alonso <i>et al.</i> , 2017 | Antarctic Peninsula Region | A cross-sectional study for the occurrence of pharmaceutical, and psychotropic drug residues in surface water on the northern Antarctic Peninsula Region | The following drugs were analyzed.<br>Analgesics acetaminophen, Diclofenac, Ibuprofen and for the stimulant caffeine | All these substances were detected in waters that were discharged directly into the ocean without any prior purification processes.                                                                                                                                                                                                                                                          |

| Source                     | Country  | Nature of study                                                                                                                                | CEC studied                                                                                                                                                      | Remarks                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|----------------------------|----------|------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Paiga <i>et al.</i> (2016) | Portugal | A case study for Presence of pharmaceuticals in the Lis river (Portugal): Sources, fate and seasonal variation                                 | Ibuprofen, ketoprofen, carbamazepine and fluoxetine, and the metabolite salicylic acid                                                                           | A total of 27 pharmaceuticals and some of their human metabolites were found in the Lis river or in the wastewaters of two WWTPs that discharge their effluents into the river at levels up to 615, 3.3 and 1.3 µg L <sup>-1</sup> for WWTP influent, effluent and river water, respectively. The NSAIDs/analgesics ibuprofen, acetaminophen, ketoprofen, and the metabolite salicylic acid together with the psychiatric drugs fluoxetine and carbamazepine were among the commonly detected pharmaceuticals. |
| Kay <i>et al.</i> (2016)   | UK       | A Cross-sectional study of Widespread, routine occurrence of pharmaceuticals in sewage effluent, combined sewer overflows and receiving waters | Propranolol, Diclofenac, Erythromycin, Ibuprofen, Mefenamic acid                                                                                                 | The study found that the five pharmaceuticals monitored are ubiquitous in rivers (present in 51-94% of samples) throughout urban and even semi-rural rivers.                                                                                                                                                                                                                                                                                                                                                   |
| Na <i>et al.</i> (2013)    | China    | A cross-sectional study for the occurrence, distribution, and bioaccumulation of antibiotics in coastal environment of Dalian, China           | The occurrence, distribution, and bioaccumulation of 20 antibiotics categorizing into three groups, including 14 sulfonamides (SAs), two chloramphenicols (CAPs) | The results suggested that tetracyclines were the predominant antibiotics in the seawater (range: 2.11–9.23 ng L <sup>-1</sup> ), while sulfonamides were the dominant antibiotics in both sediments (range: 1.42–71.32 lg kg <sup>-1</sup> ) and aquatic organisms (range: 2.18–63.87 lg kg <sup>-1</sup> ).                                                                                                                                                                                                  |

| Source                           | Country   | Nature of study                                                                                                                                                                             | CEC studied                                                                                                                 | Remarks                                                                                                                                                                                                                                                                                                                                                                 |
|----------------------------------|-----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                  |           |                                                                                                                                                                                             | and four tetracyclines (TCs), were investigated                                                                             |                                                                                                                                                                                                                                                                                                                                                                         |
| Jeeva <i>et al.</i> (2017)       | India     | A field study for Emerging Contaminants in Indian Environmental Matrices – A review                                                                                                         | Pharmaceuticals belonging to the categories of antibiotics, antimycotics, analgesics, antihistamines, antiplatelets.        | They were detected in all matrices at higher levels                                                                                                                                                                                                                                                                                                                     |
| Balakrishna <i>et al.</i> (2017) | India     | A cross-sectional study for review of the occurrence of pharmaceuticals and personal care products in Indian water bodies                                                                   | Amoxicillin, ciprofloxacin, metoprolol and ofloxacin                                                                        | This review provided the following; Understanding on pharmaceutical residues in the aquatic ecosystem in India, important information for the stakeholders including regulatory agencies in India to establish the minimum permissible limits of pharmaceuticals in wastewater and spur research on cost-effective pharmaceutical removal strategies in the Indian WTPs |
| Roberts <i>et al.</i> (2015)     | Australia | A field study of Pharmaceuticals and personal care products (PPCPs) in Australia's largest sewage treatment plant and its contribution to a major Australian river during high and low flow | The removal of the following PPCPs in major inland STP; Anti-microbial, cardiovascular and antihistamines were investigated | The study showed the following: venlafaxine, carbamazepine and sotalol were shown to be removed by STPs.                                                                                                                                                                                                                                                                |

| Source                           | Country | Nature of study                                                                                                                                    | CEC studied                                                                                                                                     | Remarks                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|----------------------------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Raffaella and Bustamante, (2014) | Italy   | A longitudinal study of Emerging organic contaminants in surface water and groundwater: A first overview of the situation in Italy                 | Azithromycin, trimethoprim, indomethacin, metoprolol, lorazepam, glibenclamide                                                                  | Out of the 66 pharmaceuticals reported for surface waters, 13 compounds in majority sulfonamide antibiotics were never detected. Two antimicrobial agents (sarafloxacin and roxthromycin) were not quantified due to the use of inappropriate solid phase extraction (SPE) procedure (Loos et al., 2007) (Table A1). For other 6 compounds (azithromycin, trimethoprim, indomethacin, metoprolol, lorazepam, glibenclamide) data were estimated by interpretation of plots.                 |
| Fram.M and Belitz. K (2011)      | USA     | A field study for the occurrence and concentrations of pharmaceutical compounds in groundwater used for public drinking-water supply in California | Acetaminophen, caffeine, carbamazepine, codeine                                                                                                 | 7 pharmaceuticals were found at concentrations greater than or equal to method detection limits: acetaminophen (used as an analgesic, detection frequency 0.32%, maximum concentration 1.89µg/L), caffeine (stimulant, 0.24%, 0.29µg/L), carbamazepine (mood stabilizer, 1.5%, 0.42µg/L), codeine (opioid analgesic, 0.16%, 0.214µg/L), p-xanthine (caffeine metabolite, 0.08%, 0.12µg/L), sulfamethoxazole (antibiotic, 0.41%, 0.17µg/L), and trimethoprim (antibiotic, 0.08%, 0.018µg/L). |
| Celic et al. (2019)              | Spain   | A case study of Pharmaceuticals as chemical markers of wastewater contamination in the                                                             | Acetaminophen, salicylic acid, antihypertensives (valsartan), psychiatric drugs (carbamazepine), and antibiotics (clarithromycin, trimethoprim) | Twenty-eight (28) out of the fifty-seven (57) compounds detected in effluent wastewater were positively identified in estuary and seawaters, indicating that WWTP discharges are an important source of contamination in coastal environments                                                                                                                                                                                                                                               |

| Source                          | Country      | Nature of study                                                                                                                       | CEC studied                                                                                                           | Remarks                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|---------------------------------|--------------|---------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                 |              | vulnerable area of the Ebro Delta (Spain)                                                                                             |                                                                                                                       | and that PhACs are suitable markers of urban contamination in these areas.                                                                                                                                                                                                                                                                                                                                                                       |
| Madikizela <i>et al.</i> (2014) | South Africa | A Field study of the Status of pharmaceuticals in African water bodies: Occurrence, removal and analytical methods                    | Non-steroidal anti-inflammatory, antibiotic, antiretroviral, anti-epileptic, steroid hormones and anti-malarial drugs | This review shows that a number of pharmaceutical classes including non-steroidal anti-inflammatory, antibiotic, antiretroviral, anti-epileptic, steroid hormones and anti-malarial drugs have been detected in the water resources of African countries.                                                                                                                                                                                        |
| Odendaal, <i>et al.</i> (2015)  | South Africa | A controlled laboratory study for An LC-MS/MS based survey of contaminants of emerging concern in drinking water in South Africa      | Atrazine, terbuthalpyne and carbamazepine                                                                             | The concentration levels published were below the published maximum contaminant level thresholds, the range of CECs routinely detected in drinking water, and the large geographical and seasonal variability that we observed, suggest that a qualitative survey and quantitation of select CECs should be performed more frequently to have a current view of the presence of levels of CECs in drinking water that may impact on human health |
| Agunbiade and Moodley. (2016)   | South Africa | A cross-sectional study of Pharmaceuticals as emerging organic contaminants in Umgeni River water system, KwaZulu-Natal, South Africa | Antibiotics, antipyretics, atenolol, bezafibrate, and caffeine                                                        | The frequency of occurrences and concentrations in surface water were lower than in the influent. Blue Lagoon which is the mouth of the river and the discharge point into the ocean had the highest concentrations of some of the studied compounds in surface water which depict the possibility of downstream load                                                                                                                            |

| Source                            | Country | Nature of study                                                                                                                                           | CEC studied                                                                                                                              | Remarks                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-----------------------------------|---------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Oluwatosin <i>et al.</i> (2016)   | Nigeria | A field study for Quantification of pharmaceutical residues in wastewater impacted surface waters and sewage sludge from Lagos, Nigeria                   | Pharmaceuticals, including antibiotics, estrogens, and lipid-lowering drugs                                                              | The results of this monitoring campaign were evaluated in comparison to published measured environmental concentrations in Africa and worldwide. In surface water samples, 12 of 37 pharmaceutical substances were detected at concentrations ranging from Limits of Detection (LOD) up to 8.84 µg/l. Four of these pharmaceuticals were found at concentrations exceeding ecotoxicological predicted no-effect concentrations (PNEC) |
| K.O. K'oreje <i>et al.</i> (2015) | Kenya   | A cross-sectional study for Occurrence patterns of pharmaceutical residues in wastewater, surface water and groundwater of Nairobi and Kisumu city, Kenya | Antiretrovirals nevirapine and zidovudine, and the antibiotics metronidazole, sulfamethoxazole and trimethoprim                          | Twenty-four (24) pharmaceuticals were present in wastewater, surface water and groundwater in Nairobi and Kisumu, Kenya. Overall, the most frequently detected compounds were the Antiretrovirals and antibiotics. High concentrations, with values up to 160 mg L <sup>-1</sup> for compounds like Paracetamol (wastewater) and lamivudine (river water), were noticed..                                                             |
| Nantaba <i>et al.</i> (2020)      | Uganda  | A cross-study for Occurrence, distribution, and ecotoxicological risk assessment of selected pharmaceutical compounds in water                            | Pharmaceuticals (antibiotics, analgesic/anti-inflammatory drugs, anti-epileptic/antidepressant drugs, beta blockers, and lipid regulator | Ecotoxicological risk assessment showed that sulfamethoxazole, oxytetracycline, erythromycin, and Diclofenac pose a high toxic risk to aquatic organisms in the lake, while ciprofloxacin, norfloxacin, and ibuprofen pose a medium risk. This study is the first of its kind to report the levels and ecotoxic risks of pharmaceutical compounds in                                                                                  |

| Source                        | Country | Nature of study                                                                                                                 | CEC studied                                                                                                                                                                                                                                     | Remarks                                                                                                                                                                                          |
|-------------------------------|---------|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                               |         | from Lake Victoria, Uganda                                                                                                      |                                                                                                                                                                                                                                                 | Lake Victoria waters, of Uganda, and East Africa as a whole<br><br>This study established Nakivubo channel as the main route of pharmaceutical contamination in Lake Victoria.                   |
| Dalahmeh <i>et al.</i> (2020) | Uganda  | A cross sectional study for Pharmaceutical pollution of water resources in Nakivubo wetlands and Lake Victoria, Kampala, Uganda | Trimethoprim, sulfamethoxazole<br><br>ciprofloxacin, cetirizine, metformin, metronidazole, omeprazole, amlodipine, salbutamol, amoxicillin, amoxyl,<br><br>clotrimazole, lumefantrine, ampicillin, ibuprofen, ketoconazole and other substances | Of the substances identified in the survey, initial analyses were performed for ciprofloxacin, cetirizine, metformin, metronidazole, omeprazole, amlodipine, salbutamol, amoxicillin and amoxyl, |

### 2.3 Effects/Toxicity of selected CECs

CECs in general are persistent organic pollutants such as PCBs (poly-chlorinated biphenyls), PFASs (Perfluoroalkyl substances) and PBDEs (Polybrominated Diphenyl Ethers). These pollutants were designed specifically in order to maximize their biological activity at low measures and to target certain metabolic, enzymatic, or cell-signaling mechanisms. The evolutionary conservation of these molecular targets in a given species normally raises the possibility that these PPCPs will be pharmacologically active in non-target organisms. A major concern raised by the existence of PPCPs in the aquatic environment is their ability to interfere with the endocrine system to produce undesired effects/disruption of homeostasis. According to the World Health Organization (WHO, 2015), Endocrine Disruptors (ED) are exogenous substance which alters functions of the endocrine system and end up causing adverse health effects in an organism and its offspring. In addition, toxicity arising from complex mixtures of PPCPs at low concentrations could lead to synergistic interactions. This means that while individual PPCPs may be available at low concentrations that doesn't mean that the toxic effects are of a lower significance when acting singly (Cleuvers, 2003). However, the widespread existence of antibiotics within the environment may develop antibiotic-resistant bacteria. This is because these organisms have a very fast adaptation capability that enables them to survive the exposure to these drugs by means of either a genetic mutation or the acquisition of resistance genes from another bacteria (Christou *et al.*, 2017; Kümmerer, 2009a).

Recently, environmental pollution concern has plummeted due to higher standards of living and increased consumption. Disposal of pesticides spreading, use of fertilizers, sludge and waste of other hazardous materials are leading to serious threats to the environment. These contaminants have been naturally or synthetically associated to exert known or suspected adverse consequences on human's health and the environment (Wilkinson *et al.*, 2016).

A study on the brown trout, a salmonid species native to German rivers, was carried out in order to ascertain the effect of Diclofenac, one of the most prevalent pharmaceuticals in surface water. The obtained results indicated water-borne Diclofenac at levels of 5-50µg/L affects kidney, gill integrity and selected immune parameters in the fish (Birgit *et al.*, 2005). This too demonstrated that an exposure to waterborne gemfibrozil on goldfish (*Carssius auratus*) resulted into a decrease on plasma testosterone by over 50% after 14days (Mimeault *et al.*, 2005). However, increased use of antibiotics in human medicine and animal husbandry is the major cause for the emergence and spread of antibiotic resistant bacteria, which has posed a threat to the effective prevention and treatment of various infectious diseases caused by antibiotic-resistant pathogenic bacteria (World Health Organization., 2015). In addition, further research carried on the ecotoxicological effect of 27 different pharmaceuticals established that the most harmful to the environment are Diclofenac, Ibrufen, metoprolol and oestriol (Tiismus and Merisaar, 2019). Acidic pharmaceutical compounds may trigger different toxicological responses at different PH levels in exposure (Karl, Weston and Caminada, 2006).

Recently, various studies focusing on the acute toxic effects to aquatic organisms resulting from drug usage have been reported. Propranolol has strong acute toxicity on benthos and zooplankton, whose lethal dose of 50% (LC<sub>50</sub>) is about 1 mg/L, and fluoxetine toxicity on benthos is stronger than propranolol, whose LC<sub>50</sub> is less than 0.5 mg/L (Miller *et al.*, 2015; MacKay and Vasudevan, 2012). Most times, human pharmaceuticals acute toxicity is nonspecific, for example, unspecific membrane toxicity by oxidative stress. Several studies regarding the human health prioritized CECs based on the potential risk posed to human health through consumption of groundwater or surface water (Vulliet, Cren-Olivé and Grenier-Loustalot., 2011).

Numerous negative effects that are expected to occur include the development of antibiotic resistant bacteria and genes (Rizzo *et al.*, 2013;Varela, *et al.*, 2016) and other hazardous ecotoxicological effects (Schultz *et al.*, 2011;Caldwell *et al.*, 2014; Saravanan *et al.*, 2014); Peltzer *et al.*, 2017). The occurrence of antibiotics and the dissemination of anti-resistance genes (ARGs) within natural environment are evolving as a major public health concern around the world (Davies and Davies, 2010; Oberlé *et al.*, 2012; Pruden *et al.*, 2013;Yin *et al.*, 2013;Marti *et al.*, 2014; Berglund, 2015; Li *et al.*, 2015).

The careless use of antibiotics for therapeutic and non-therapeutic purposes has led to a higher growth and propagation of microbial resistance determinants, both in clinical and nonclinical settings (Berglund, 2015; Igbinosa, E. and Odjadjare, E., 2015; (McEachran *et al.*, 2015).

Ecotoxicological effects of PPCPs are being reported in numerous review articles (Brausch and Rand, 2011).

Eco-toxicology risk assessment through the derivation of hazard quotient (HQ) of carbamazepine and parabens for amphibian, fish and mussel showed that Triclosan contained the highest risk for aquatic life carbamazepine and parabens (Philip, Aravind and Aravindakumar, 2018).

From available literature One of the most convenient tools used for the characterization of potential ecological risk of PPCPs in the aquatic environment is the risk quotient (RQ) based on European Medicines Evaluation Agency EMEA guideline (EMEA, 2006) in three trophic levels of the aquatic ecosystem (fish, invertebrates and algae). In this guideline, RQ of each pharmaceutical was assessed by calculating the ratio between Measured Environmental Concentration (MEC) and Predicted No-Effect Concentration (PNEC) (Gros, Petrovic and Barceló, 2009; Kosma *et al.*, 2014; Ramaswamy *et al.*, 2011). MEC corresponds to the highest concentration found in wastewaters, while PNEC was calculated (i) for acute toxicity, by using the lowest values of  $EC_{50}$  or  $LC_{50}$  divided by an assessment factor (AF) (usually 1000) and (ii) for chronic toxicity, by using No observed effect concentration (NOEC) divided by an assessment factor (AF). For chronic toxicity an AF of 100 is used when one long-term NOEC is available, an AF of 50 is used when two-long term NOECs are available in two trophic levels and finally, an AF of 10 is used when long-term NOECs from the three trophic levels are available (European Commission, 2003; Kosma *et al.*, 2014). Afterwards, a classification of the RQ values with the levels of

concern took place. When  $RQ \geq 1$ , there is a potential “high risk”, while when  $0.1 \leq RQ < 1$  there is “medium risk” and finally when  $0.01 < RQ < 0.1$  there is low or negligible risk (Hernando, Mezcuca, R, *et al.*, 2006; Kosma *et al.*, 2014).

$$RQ = \frac{\text{exposure/toxicity}}{\text{Water or Sediment concentration}}$$

Where,

$$PNEC_{\text{acute}} = \frac{EC_{50} \text{ or } LC_{50}}{1000} \dots\dots\dots 2.1$$

$$PNEC_{\text{chronic}} = \frac{NOEC}{AF} \dots\dots\dots 2.2$$

According to European Medicines Evaluation Agency (EMA) the toxicity studies, and the resulting risk quotients are:

**Table 2-6: Calculated risk quotients based on PEC estimations by EMA and refined by adsorption to particles and biodegradation**

| Lowest NOEC/EC50<br>mg/L |       | AF   | PNEC<br>(µg/L) | EMA<br>PEC/PNEC |      | Conventional<br>PEC/PNEC |      |
|--------------------------|-------|------|----------------|-----------------|------|--------------------------|------|
|                          |       |      |                | Min             | Max  | Min                      | Max  |
| Diclofenac               | 0.001 | 10   | 0.1            | 0.51            | 5.7  | 0.34                     | 3.8  |
| Ibuprofen                | 1     | 50   | 20             | 0.056           | 0.50 | 0.039                    | 0.35 |
| Paracetamol              | 9.2   | 1000 | 9.2            | 0.016           | 0.70 | 0.048                    | 2.0  |

Source (Grung *et al.*, 2008) table attached in appendix IV

In addition to that, adverse effects of these PPCPs on health and the environment have also been reported previously (Tanoue *et al.*, 2012; Jiang, Zhou and Sharma, 2013; Rajapaksha *et al.*, 2015). The adverse effects of PPCPs on ecosystems are also

significant to human health because PPCP residues have been detected in the food chain like fruits, vegetables, and drinking water (Hernando *et al.*, 2006; Carmona, Andreu and Picó., 2014; Awad *et al.*, 2016). The other risks include; development of microbial resistance to antibiotics and feminization or masculinization of aquatic organisms on exposure to CECs (Jones, Voulvoulis and Lester, 2004). The Environmental Working Group of the United States (EWG, 2008) conducted a survey on 20 girls aged 14–19 years old and ascertained that sixteen (16) hazardous chemicals, including synthetic musk, 2-benzenedicarboxylic salt, and Triclosan (TCS), were present in the girls' bodies as a result of constant usage of cosmetic products (Yang *et al.*, 2017).

There are two studies that have made a persuasive case for the advanced impacts on the world life at low environmentally relevant concentrations as described below; First, approximately 40 million vultures in Pakistan which is a greater population are believed to have died from consuming Diclofenac from the carcasses of cattle that were treated with this drug (Oaks *et al.*, 2004). Secondly, a study that involved the feminization and collapse of world fish populations by extremely low levels of 17- $\alpha$  ethinyl estradiol EE2 dozed into a lake in the experimental lakes region of Ontario Canada was also done (Kidd *et al.*, 2007).

### 2.3.1 Maximum concentration of CECs in drinking water

Comparison of Pharmaceutical Drinking Water Equivalent Level (DWELs) with Maximum Drinking Water Concentrations Data (Obtained from Snyder, 2008a). The DWEL process the U.S. EPA uses in this conversion assumes a 70 kg human being drinking 2 liters of water per day and often assuming decades of exposure for a lifetime using the acceptable daily intake (ADI).

**Table 2-7: Maximum concentration of CECs in drinking water**

| Drug       | Class         | ADI (µg/kg <sup>-</sup><br>d) | DWEL (µg/L)* | Maximum drinking water conc. (µg/L)* | Minimum Margin |
|------------|---------------|-------------------------------|--------------|--------------------------------------|----------------|
| Triclosan  | Antibacterial | 75#                           | 2,600        | 0.0012                               | 2,200,000      |
| Diclofenac | NSAID         | 67#                           | 2,300        | <0.00025                             | >9,200,000     |

Source (Snyder *et al.*, 2017) table in appendix IV

\*Single highest discrete sample concentration, from finished drinking water unless otherwise noted.

### 2.3.2 Fate of CECs

Concentrations of CECs during monitoring of a 5 km length of the River Aire were of the order observed in the monthly monitoring. Findings indicated that there was no noticeable reduction in CECs concentrations along the entire section (Kay *et al.*, 2017). There was no significant variation in the CECs concentrations detected at the same sites on different dates (Hughes, Kay and Brown, 2013). CECs may change into other products which are most often unknown. This may be more persistent and toxic than the parent compound and pose unwanted biological effects on the exposed

organisms (La Farre *et al.*, 2008; Noguera-Oviedo, Katia and Aga, 2016; Postigo and Richardson, 2014).

Overall peak and average concentrations detected indicated that were of the same order of magnitude in effluent and receiving waters which implied that there is no significant dilution in river systems which receive large volumes of effluent, such as the Aire and Calder (Jürgens *et al.*, 2002). The study showed consistent presence of CECs along a 5 km stretch of river indicated that in-stream dissipation along reaches of several kilometres is negligible for the CECs and that exposure of freshwater ecosystems to CECs pollution will occur well beyond the locality of sewage treatment discharges (Kunkel and Radke, 2011).

CECs are also frequently detected in cultured aquatic products and pesticides were found present in the fish samples in Northeast China. Among them, atrazine and linuron and concentrations far above those of other pesticides in fish samples from Liaoning province and Inner Mongolia, respectively. The findings indicate a warning that the potential risk of consuming aquatic products should have more attention (Fu *et al.*, 2018)

There was an analysis of veterinary antibiotics used in swine production and their degradation products using the method described by (Sollicec *et al.*, 2016). Manure and soil samples were analysed using solid phase extraction. Water samples were acidified and filtered with a similar aqueous citric acid and buffer before extraction. This was used for analysis samples from a swine production facility, and results indicated that

the degradation products often occurred at significantly higher concentrations (Snow *et al.*, 2017).

In wastewater treatment organic substances and nitrogen from wastewater are removed under certain conditions by activated sludge plants through the formation of biological floc using dissolved oxygen. Eventually in the tertiary treatment phosphorous can be removed by precipitation and filtration (Batt, Kim and and Aga, 2007). Also, some WWTPs disinfection of the effluent is done by UV irradiation or chlorination, before discharging them in the environment. But these treatments alone do not ensure complete removal of the CECs. The most common activated sludge technique which is used globally cannot remove all PPCPs efficiently and entirely e.g. Diclofenac and carbamazepine that are resistant to biodegradation (Celiz, Tso and Aga, 2009). Additionally various processes like biological and chemical degradation and photolysis may transform CECs into forms that can be more toxic than their parent compound (Gogoi *et al.*, 2018)

Often after introduction of wastewater into a river, contaminant concentrations are typically higher when effluent is discharged into tributaries with lower volume. As contaminants flow down-stream, their interaction with the aquatic environment becomes more complex and confusing. Ultimately the final fate and attenuation of contaminant concentrations can occur through several mechanisms, usually depending on the properties of each individual compound, each river or aquatic system, biotic and abiotic contaminant degradation, how and when the compound was introduced to the environment, and its partition to solid components (Osenbrück *et al.*, 2007;

Musolff *et al.*, 2009). Much research is needed to further characterize the conditions leading to specific pathways of river transport and contaminant fate (Wilkinson *et al.*, 2017).

## **2.4 Key findings and knowledge gaps**

Various contaminants of emerging concern present in the environment range from pharmaceuticals and personal care products to persistent organic pollutants used in many industrial processes. Their origins have been mainly from hospitals, households, construction, transportation, animal feeding, and municipal waste disposal while their occurrence has been attributed to presence in drinking water, surface water and groundwater.

This review focused on pharmaceuticals and personal care products and found to be present (in relation to occurrence origins and concentration). Available literature shows interest to address shortfalls related to CECs however these are still limited especially in SSA.

Most of the existing WTPs around the world are not well designed for the complete removal of pharmaceutical contaminants because the extent of the ecological threats posed by PPCPs aren't clearly understood (Balakrishna *et al.*, 2017). The Lag in detection of present CECs in the environment can be attributed to the slow development or lack of commercial instruments that are capable of detecting very polar and highly soluble compounds like PPCPs, (Noguera-Oviedo and Aga, 2016).

However, there is a need for continuous monitoring and identifying precursors to CECs

The sound knowledge of the existing environmental legislation during wastewater treatment and within the environment is currently lacking and this has led to numerous uncertainties (Petrie, Barden and and Kasprzyk-Hordern, 2015; de Godos, Muñoz and Guieysse, 2012). This requires policy formulation to ensure proper management of CECs in wastewater treatment and subsequently in drinking water.

There has been much research on CECs in the environment for the last two decades but there still exists significant knowledge gaps, which include a lack of repeat sampling, quantification of spatial and temporal patterns of pollution like in-stream dissipation, seasonal and diurnal variation (Kolossa-Gehring, 2009)

Given that current risk assessments indicate very low concentrations of CECs in drinking-water and are very unlikely to pose serious risks to human health, there are knowledge gaps in terms of assessing the risks associated with long term, low-level exposures to pharmaceuticals and possible combined effects of chemical mixtures. Future research investigating the possible additive or synergistic effects of mixtures would be beneficial for an accurate exposure assessment to determine whether there are any potential risks to human health.

In developing countries especially in Africa where there is little/no studies in identifying or quantifying pharmaceuticals in environmental samples (K'oreje *et al.*, 2012; Hughes *et al.*, 2013; Agunbiade and Moodley, 2014; Ngumba *et al.*, 2016 and

Wood *et al* 2017 there is need to urgently intensify research to identify the presence of pharmaceuticals in environmental bodies and form policy to guide their management (WHO, 2011).

Majority of studies in urban slums focuses on health-damaging settings, where poverty and unfavorable environmental conditions pose threats to public health and sanitation and no specific study in relation to the occurrence of CECs in urban slum areas (Alaazi and Aganah, 2020)

### CHAPTER THREE: RESEARCH METHODOLOGY

This section presents methods and materials used in the study.

#### 3.1 Description of the Study Area

The study was carried out within the two parishes of Bwaise (II and III), Kawempe division, Kampala district. The study area 2.25 km<sup>2</sup> is bordered by Kyebando to the East, Mulago to the southeast, Kawempe to the North, Kasubi to the southwest and Makerere to the south. This location lies approximately 5 kilometres (3.1 miles) by road, north of Kampala's central business district. The coordinates of Bwaise are 00° 21' 00"N and 32° 33' 40"E. Figure 3-1 presents the location of the study area.

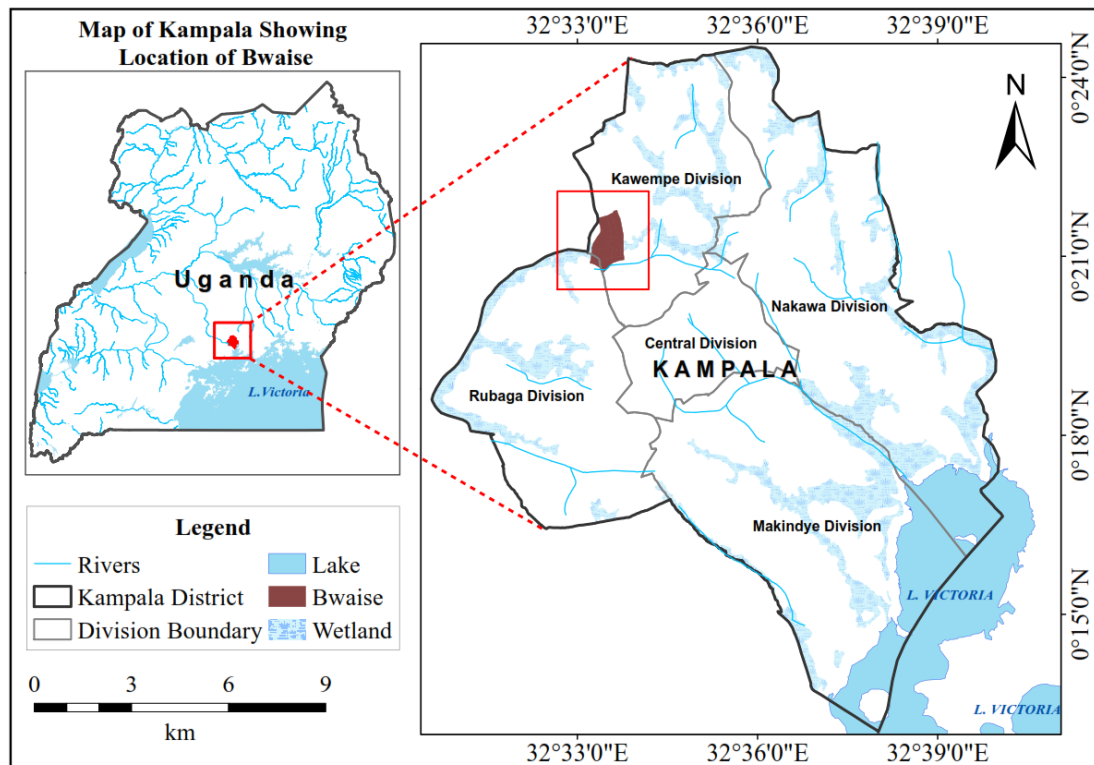


**Figure 3-1: Location of Bwaise in Kawempe Division, Kampala District**  
(Source: UBOS 2016)

## **3.2 Study Design**

This is a cross sectional study that involves a descriptive survey and laboratory analysis of samples collected from the study area. The research was conducted in three stages, first a detailed literature review of past studies related to CECs. This was followed by a rapid survey where quantitative data was collected in order to identify and map out potential sources of CECs and obtain information of how management of waste was done. Finally, samples were collected from various sources which included; water (surface water, drinking water), wastewater (grey water) and solid waste dump sites in both low and high water table areas and analysed for various CECs.

## **3.3 Research Approach**

### **3.3.1 Cross sectional survey**

This was done in order to identify and map the potential sources of CECs. This was done by the aid of GPS (mapping out), and questionnaires (for conducting interviews).

#### **3.3.1.1 Quantitative data collection**

Quantitative data was collected using questionnaire. Data collection was limited to owner/caretakers of establishments that are potential sources of CECs. As the establishments were not already known a sample size could not be determined thus all potential areas that could contribute to CECs were involved in the study. Areas of interest while collecting data were nature of the facility, most common product sold, form of waste disposal, distance from the water source available water sources and their distance from the potential source of CECs. A copy of the survey questionnaire

is included in Appendix 1. Figure 3-2 shows the researcher mapping out potential CECs sources while Figure 3-3 shows the researcher conducting interviews.



**Figure 3-2: Researcher mapping out potential sources of CECs**



**Figure 3-3: Researcher conducting interviews**

### **3.3.2 Laboratory analysis**

This was done in order to assess the level of CECs in drinking water, grey water and solid waste dump sites. Samples were collected from the field and analysed in the laboratory using liquid chromatography in mass spectrometry technique.

#### **3.3.2.1 Water, wastewater and solid waste sample collection and analysis**

Samples were collected from various water, waste streams in both low and high water table areas within the slum, in order to ascertain the occurrence and existence of CECs. These included protected and unprotected springs, pipe water stand taps, grey water discharge points and solid waste dump sites. Samples were collected using a one litre plastic bottles with screw cap. Before sampling, the bottles were cleaned. After sampling, excess quenching agent (sodium thiosulfate) was added to dechlorinate the water samples to neutralise any residual halogen and prevent continuation of bactericidal action during sample transit. The bottles were placed in cooler box and transferred to government analytical laboratory in Wandegeya for further treatment and analysis. The samples for the solid waste was a mixture of various samples collected at the same solid dump sites. GIS coordinates for all locations where samples were collected were obtained. The instruments used included the following;

- A Global Positioning System (GPS) was used for actual geographical locations of sampled points
- Camera was used for pictorial evidence of sampled points in study area.

- Cooler Box was used in order to preserve the samples from temperature variations before actual laboratory testing
- Disinfectants were done in-order to avoid contamination
- Sampling or collection bottles were used to collect samples.

The sample analysis was conducted at the government analytical laboratory using Liquid Chromatography Mass Spectrometry (LC-MS).

#### ***Sample handling in the laboratory***

In laboratory, water samples were filtered through a 0.45µm acetate cellulose filter and were acidified by adding 3.0 M H<sub>2</sub>SO<sub>4</sub>, followed by addition of 0.2 g disodium ethylenediamine tetraacetate (Na<sub>2</sub>EDTA). Under such conditions any drug activity in the samples was kept to the minimum, and their tendency to be bound to divalent ions may be decreased. The samples were stored in dark at 4°C until they were extracted, typically within 1 week.

#### ***Solid-Phase Extraction***

Solid-phase extraction (SPE) experiments were conducted using 200 mg/6 mL Oasis HLB cartridges on a Resprep® 12-Port Vacuum Manifold. The cartridges were preconditioned with 4 mL of MeOH and 6 mL of deionized water.

A volume of 500 mL of water sample with pH 2.8–3 (H<sub>2</sub>SO<sub>4</sub>) was passed through the cartridge at a flow-rate of 5–8 mL min<sup>-1</sup> using a vacuum extraction manifold at 7–9 in Hg. Afterwards the cartridges were rinsed with 10 mL of ultra-pure water and

were air-dried for 5 min. The retained analytes were subsequently eluted with 5 times 2 mL of methanol into a glass test tube.

The extract was concentrated to dryness under a stream of Nitrogen and reconstituted to ~250  $\mu$ L in a solvent mixture of ultra-pure water/methanol (8:2). The extract was filtered through a 4 mm id., 0.2  $\mu$ m pore size cellulose acetate syringe filters, transferred to an amber vial, and stored at  $-15^{\circ}\text{C}$  until LC-MS/MS analysis.

### ***LC-MS-MS Analysis***

The extracts were separated on the reverse phase Zorbax Eclipse XDB-C18 column, 4.6 mm  $\times$  50 mm ID and 1.8  $\mu$ m particle size (Agilent Technologies, CA, USA) using LC system with a quaternary pump, a vacuum degasser, and an auto sampler. The injection volume of sample aliquots was 5  $\mu$ L, and a binary gradient with a flow rate of 0.3 mL/min was used. Mobile phase A contained 0.1% aqueous solution of formic acid (v/v) and mobile phase B contained 0.1% formic acid (v/v), in MeOH. The gradient started with 0% of mobile phase B for 0.5 min, increased to 20% from 0.5–3 min, to 70% from 3.0–7.5 min, and to 95% from 7.5–11 min, decreased to 0% from 11–12 min, and remained at 0%. All target compounds were eluted out of the column within 15 min, and the auto sampler was operated at room temperature.

The flow from the LC column was transferred to a triple-quadrupole mass spectrometer equipped with an ESI source. The electrospray voltage was 4 kV, the capillary temperature  $350^{\circ}\text{C}$ , and maximum isolation time 200 ms. Nitrogen was used

as the nebulizing and drying gas, and a nebulizer pressure of 20 psi and a drying gas flow of 13 L/min were selected.

Figure 3-4 shows the researcher collect samples while Figure 3-5 shows the researcher analysing samples for CEC



**Figure 3-4: Researcher collecting samples (a) from protected spring and (b) from drainage channel**



**Figure 3-5: Laboratory analysis of collected samples for CEC**

### 3.4 Descriptive statistics

This was used to quantify the toxic risks of the CECs using excel. Ranking was done using the EMEA standards.

#### 3.4.1 Data analysis and presentation

ArcGIS 10.5 was used for mapping out the existing CECs sources because its readily available and has a user friendly interface. Quantitative data was analyzed descriptively for mean, standard deviation range, maximum and minimum. Multivariate analysis was used to compare two variable while analysis of variance (ANOVA) was used to test for significant differences tables attached in appendix VI. Risk assessment was guided by the recommended EMEA standards.

Ranking of toxic risks was analysed using the following equations from EMEA: -

- RQ                      -        exposure/toxicity
- Water or Sediment concentration

Where,

$$PNEC_{acute} = \frac{EC_{50} \text{ or } LC_{50}}{1000} \dots\dots\dots 3.1$$

$$PNEC_{chronic} = \frac{NOEC}{AF} \dots\dots\dots 3.2$$

$$PNEC_{acute} = \frac{EC_{50} \text{ or } LC_{50}}{1000} \dots\dots\dots 3.3$$

$$PNEC_{chronic} = \frac{NOEC}{AF} \dots\dots\dots 3.4$$

$$\begin{aligned}\text{Hence } RQ_{\text{Paracetamol}} &= \frac{MEC}{PNEC_{\text{acute}}} \\ &= \frac{0.22}{0.048}\end{aligned}$$

$$\text{Hence } RQ_{\text{Paracetamol acute}} = 0.458 < 1$$

$$\begin{aligned}RQ_{\text{Paracetamol}} &= \frac{MEC}{PNEC_{\text{chronic}}} \\ &= \frac{0.22}{2.0}\end{aligned}$$

$$\text{Hence } RQ_{\text{Paracetamol chronic}} = 0.011 < 1$$

$$\begin{aligned}RQ_{\text{Diclofenac}} &= \frac{MEC}{PNEC_{\text{acute}}} \\ &= \frac{0.0643}{0.34} \\ &= 0.189 < 1\end{aligned}$$

$$\begin{aligned}RQ_{\text{Diclofenac}} &= \frac{MEC}{PNEC_{\text{chronic}}} \\ &= \frac{0.0643}{0.38} \\ &= 0.169 < 1\end{aligned}$$

$$\begin{aligned}RQ_{\text{Ibuprofen}} &= \frac{MEC}{PNEC_{\text{acute}}} \\ &= \frac{0.077}{0.039}\end{aligned}$$

$$= 1.9689 > 1$$

$$RQ_{Ibuprofen} = \frac{MEC}{PNEC_{chronic}}$$

$$= \frac{0.077}{0.35}$$

$$= 0.2194$$

Data was presented in tables, bar graphs, pie charts with accompanying texts to describe their meaning.

### **3.5 Ethical consideration**

An introductory letter was obtained from the Department of Civil and Environmental Engineering, Faculty of Engineering, Kyambogo University in order to facilitate clearance from KCCA and Government analytical laboratory to give approval and consent. A letter from KCCA Public Health Directorate was presented to Local council offices during data collection (Copies have been included in the appendix I). An information sheet was used in order to explain to the participants in their local languages about the research and its intended purpose. It was also used as an assurance that the participant won't be harmed. The study was explained to participants who consented, respect and confidentiality of the participant was highly valued.

## CHAPTER FOUR: ANALYSIS AND DISCUSION OF RESULTS

### 4.1 Introduction

This chapter shows the results obtained from the study. In addition, discussion of the results is also presented here within. This results and discussions are presented as per the specific objectives of the study.

### 4.2 Potential sources of CECs

The locations of potential sources of CECs, urban water and waste streams as identified and mapped in this study are presented in Figure 4.1

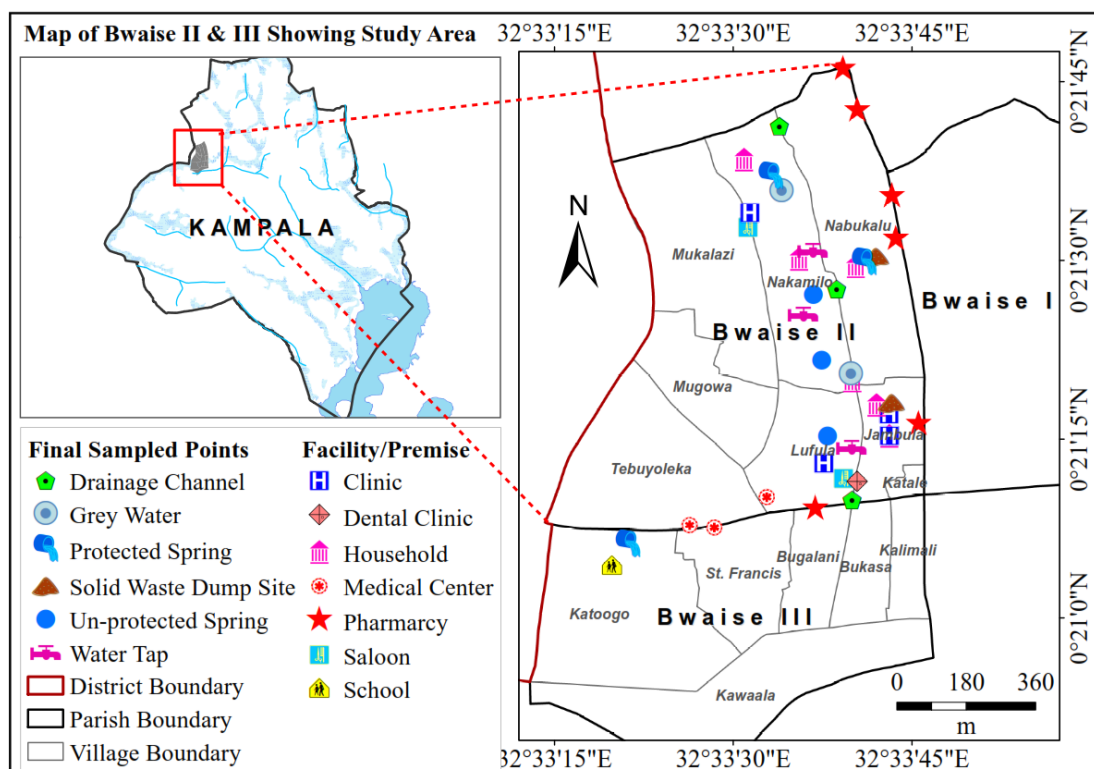


**Figure 4-1: Shows the location of potential CECs sources, water and waste streams within the slum**

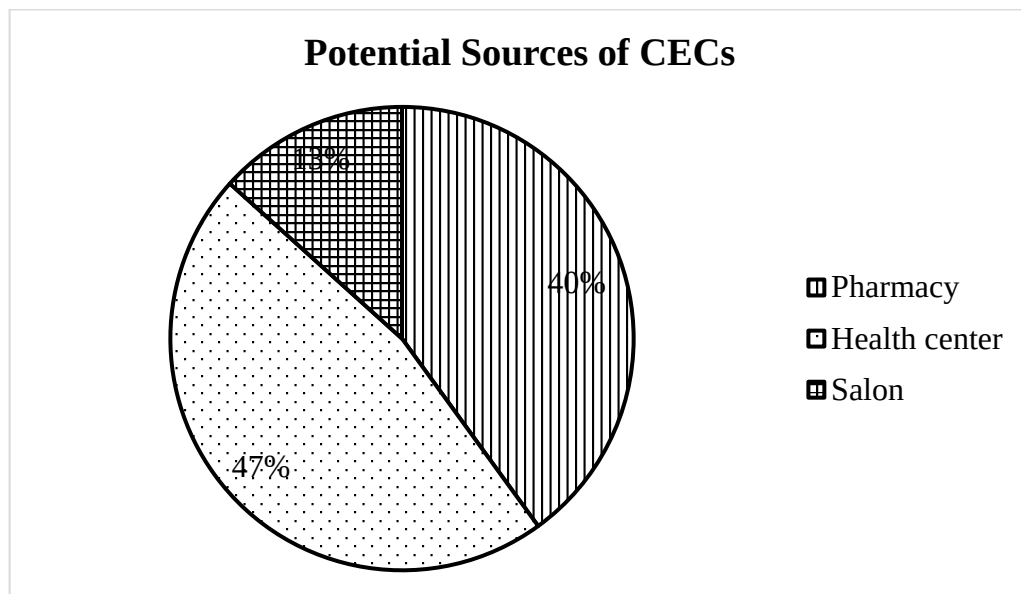


**Figure 4-2: Potential sources of CECs**

The area had mostly healthcare centres (47%) followed by pharmacies (40%) and finally salons (Figure 4-2). This could be explained by demand and high interest/economic potential in the health care sector given that slums have the highest prevalence of diseases (Okurut *et al.*, 2014). The healthcare centres could be considered as the major CECs sources while salons were the least source of CECs.

Most pharmacies were located along the main roads (Bombo and Nabweru road) as shown in

with an average distance of 20 metres from households. The healthcare centres were mainly located within the households, while salons were found along main roads. Based on the terrain in the area, it was noted most of these facilities were found in low lying areas. This could be because they mainly serve the urban poor people in the area who often set up housing in these areas (Richmond, Myers and Namuli, 2018).

Assessing the management of waste streams in the area that could contribute to transportation of the CECs into water stream considered wastewater, storm water and solid waste. Wastewater comprising grey water from washing and cleaning was mainly disposed off by discharging in open drains. In the study area majority of people's access to sanitation is in form of pit latrines (Nakagiri *et al.*, 2015) and septic tanks were limited to healthcare centres and pharmacies.

The common solid wastes from pharmacies and health centres was mainly disposed and picked from where it was collected and transported by trucks from Kampala Capital City Authority. In this study it was found that the unconsumed drugs within the households are openly dumped. The findings in this study are similar from those conducted by (Mukama *et al.*, 2016) as evidenced in the high presence of Ibrufen in solid waste dump sites.

There were two main drainage channels located within in the study area with subsidiary drains along households, healthcare centers and salons that fed into the main drains. The main drainage channels were located within 10m of the potential source of CECs. The distance was smaller for the tributary channels.

The study established that the people collected their water mainly from protected springs (60%) followed by communal stand taps (30%) and lastly unprotected springs (10%). This could be attributed to a cost attached to drawing water from a communal tap unlike the springs where they do not pay (Heymans, Eales and Franceys, 2014) . The cost of a 20 liter jerrycan within urban slum ranges from shs.200 to shs.500 while NWSC subsidised the cost at a communal stand post to 50shs (Bartram *et al.*, 2014)

Communal stand taps and protected springs were located at an average of 20m from the CEC source. This distance was significantly ( $p > 0.05$ ) distant compared to the unprotected springs. The protected water sources (communal taps and protected springs) were within 15m from households which indicated adequate access to safely managed water as per Joint Monitoring Program for water supply and sanitation (WHO/UNICEF-JMP, 2017).

The distances of clinics to water sources within the study area was an average of 25m Figure 4-3 (a). The existing clinics located in Jambula and Nakamilo zones as shown to be in close proximity to water sources. This is because the area has a high water table.

Figure 4-3 (b) shows the distances of potential CECs sources (Households) to water sources within the study area. The average distance of households from the water sources is approximated to be 25m. Location coordinates and size of clinics, households and type of water source attached in appendix II table A.2 and A.3

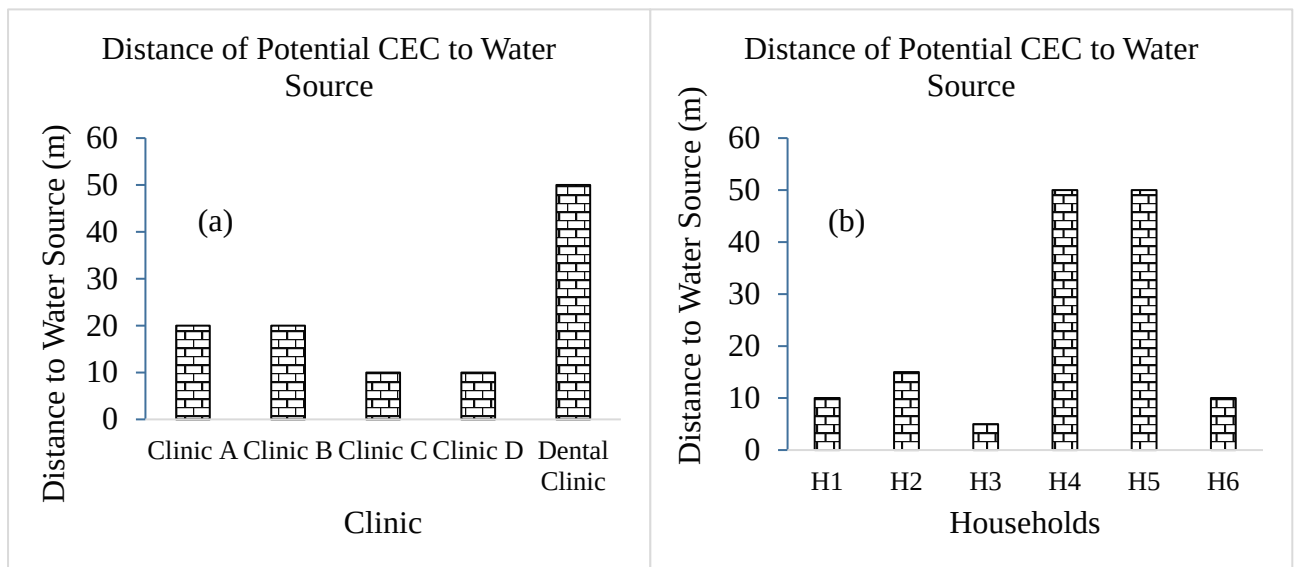


**Figure 4-3: Potential CEC source to water sources**

Figure 4-4 (a) shows the distances of potential CECs sources (Medical centers) to water sources within the area. The average distance of medical centres from the water sources was approximated to be 30m. This is because the medical centers are located in strategic places unlike private clinics as per plans from the relevant authorities. This distance is more than the recommended distance of a water source from a medical facility (15m) within which water may not be polluted (WHO, 2015). The existing medical Centre in Lufula zone was in close proximity to the water sources.

Figure 4-4 (b) shows the distances of potential CECs sources (Pharmacies) to water sources within the study area. Under this, the average distance of pharmacies from the water sources is approximated to be 20m. The closest pharmacy to water sources is found in Nabukalu zone. Location coordinates of medical centres and size of pharmacies attached in appendix II table A.4 and A5

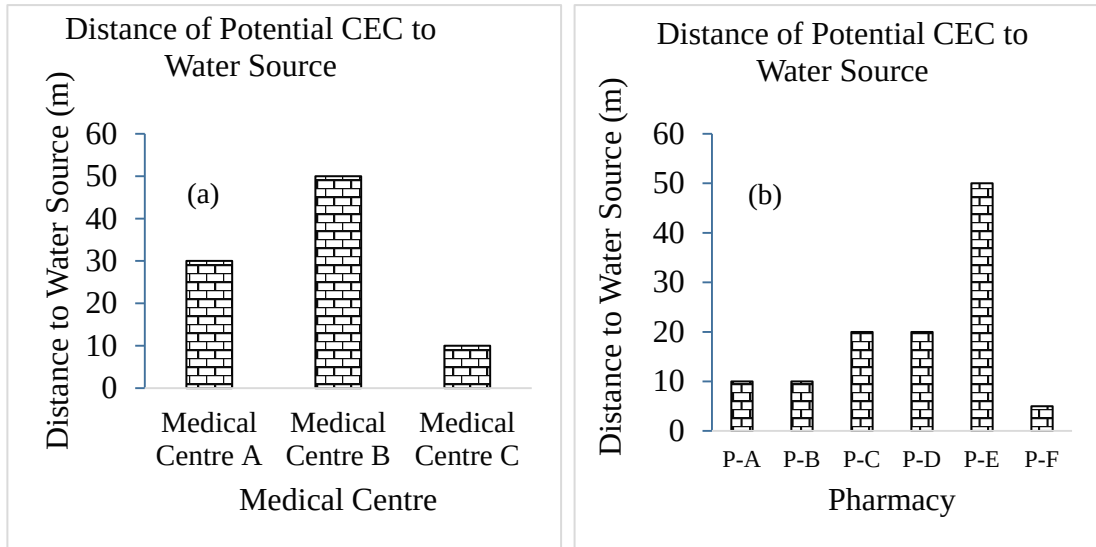


**Figure 4-4: Potential CEC source to water source**

Figure 4-5 (a) shows the distances of salons to water sources within the study area. The average distance of salons from the water sources is approximated to be 5m. Most of the salons were in close proximity to the water sources.

Figure 4-5 (b) shows that the distance of School within the study area with a proximity of 20m to a water source.

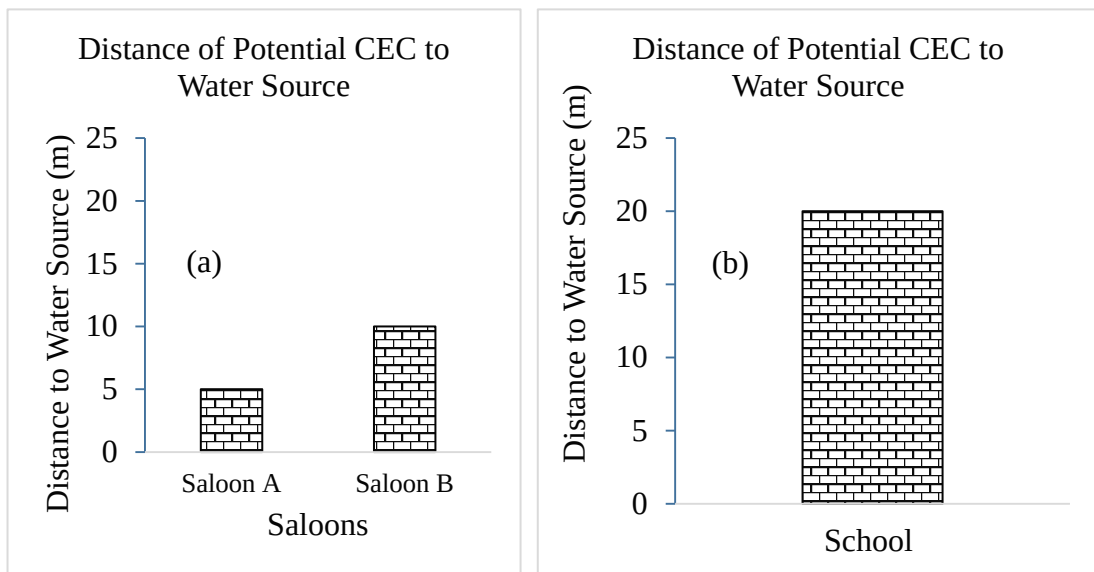


**Figure 4-5: Potential CEC source from (a) saloons and (b) school to water source**

### 4.3 Levels of CECs in water and waste sources

The commonest product that could likely contribute to CECs in these establishment were found to be Paracetamol and Ibrufen all sold in pharmacies and health centers. There were no PCPs from saloons that were detected. The concentration of the various CECs in water and waste streams within the slums are presented in Fig 4 – 10(a-j)

Analysis of samples from water sources (stand taps, protected springs and unprotected springs) found the concentrations of Paracetamol, Diclofenac, Ibrufen and Diclovos to be  $0.038 \pm 0.022 \text{ ng/ml}$ ;  $0.031 \pm 0.018 \text{ ng/ml}$  and  $0 \text{ ng/ml}$ ; ( $0.368 \pm 0.024 \text{ ng/ml}$ ); ( $0 \text{ ng/ml}$ ;  $0.083 \pm 0.144$ ;  $0.121 \pm 0.166$ ) respectively.

Concentration data for PPCPs found in the sampled water sources for Pharmaceuticals like Diclofenac, Ibrufen and Paracetamol were detected into traceable amounts with overall means of  $0.123 \pm 0.014 \text{ ng/ml}$ ;  $0.044 \pm 0.072 \text{ ng/ml}$ ;  $0.023 \pm 0.012 \text{ ng/ml}$  and  $0.070 \pm 0.087$  respectively. The concentrations of Triclosan, an anti-bacterial was not detected. Could imply that these concentrations could have been too low to be detected or absent in any samples within the study area. The values of Diclofenac and Ibrufen from this study were lower than those found in Lake Victoria by Nantaba *et al.*, 2020 and in Brazil by Ghesti and Gastaldini, 2019 for paracetamol. The concentration of Diclofenac and Paracetamol was higher ( $p > 0.05$ ) in communal stand taps than other sources. The existence of Paracetamol and Diclofenac within communal stand taps could be attributed to inadequate removal during water treatment or pipe bursts and leakages (Sakomoto, Lutaaya and Abraham, 2020). Pharmaceuticals have often been detected in surface waters the main source of water supply at concentrations generally

ranging between 0.01 to 1.0µg/L (Le Page *et al.*, 2017). Nantaba *et al.*, 2020 found the concentration of Ibrufen ranging between (1 to 5600ng/L)

The commonest traditional water treatment technologies are not designed to remove these products and could account for their presence in pipe water supply (Ben *et al.*, 2019) (World Health Organization., 2012).

The presence of Diclofos, Paracetamol and Diclofenac in protected springs, could be due to uncontrolled dumping of unused expired drugs which end up in the springs as a result of leaching (Pérez-Lucas *et al.*, 2018). The distance of open dumps in this study was found to be 15m to water source. In ANOVA analysis the test for Diclofenac between streams returned *p*-value of 0.096 and hence statistical difference between the mean concentrations (*p*>0.05) implying that there was no significant difference.

Fig 4-10(b, d, f, g and h) shows concentrations of various CECs in waste streams (drainage channel, grey water and solid dumps). Concentrations of Paracetamol, Diclofenac, Ibrufen, Diclofos and Cypermethrin in waste streams were 0.046±0.033ng/ml; 0ng/ml; 0.018±0.013ng/ml; 0.008±0.014; 0.036±0.051ng/ml; 0.285±0.403ng/ml; 0ng/ml; 0.245±0.346ng/ml; 0.095±0.134ng/ml respectively. Concentration data in sampled waste streams pharmaceuticals like Paracetamol, Diclofenac, Ibrufen, Diclofos and Cypermethrin were detected into traceable amounts in drainage channel, grey water and solid waste dumps with the overall means of 0.021±0.012ng/ml; 0.006± 0.007ng/ml; 0.110±0.0215ng/ml; 0.113±0.175ng/ml and 0.041±0.069 respectively within waste streams. These values from this study were found to be lower than those found in Brazil study ref 4.2.1 paragraph 2) for

Paracetamol and lower than the values found in Lake Victoria refer to section 4.2.1 paragraph 2) for Diclofenac and Ibuprofen. The existence of Paracetamol, Diclofenac, Cypermethrin within drainage channel/grey water and Ibuprofen in solid dump sites could be attributed to uncontrolled dumping of unused drugs by the consumers (Mukama *et al.*, 2016). The cause of the significantly higher concentration of Paracetamol, Ibuprofen, Diclofenac and Cypermethrin in the drainage channel could be as a result of grey water being discharged ultimately in the drains. In ANOVA analysis the test for Cypermethrin between streams returned  $p$ -value of 0.168 and hence statistical difference between the mean concentrations ( $p>0.05$ ) implying that there was no significant difference.

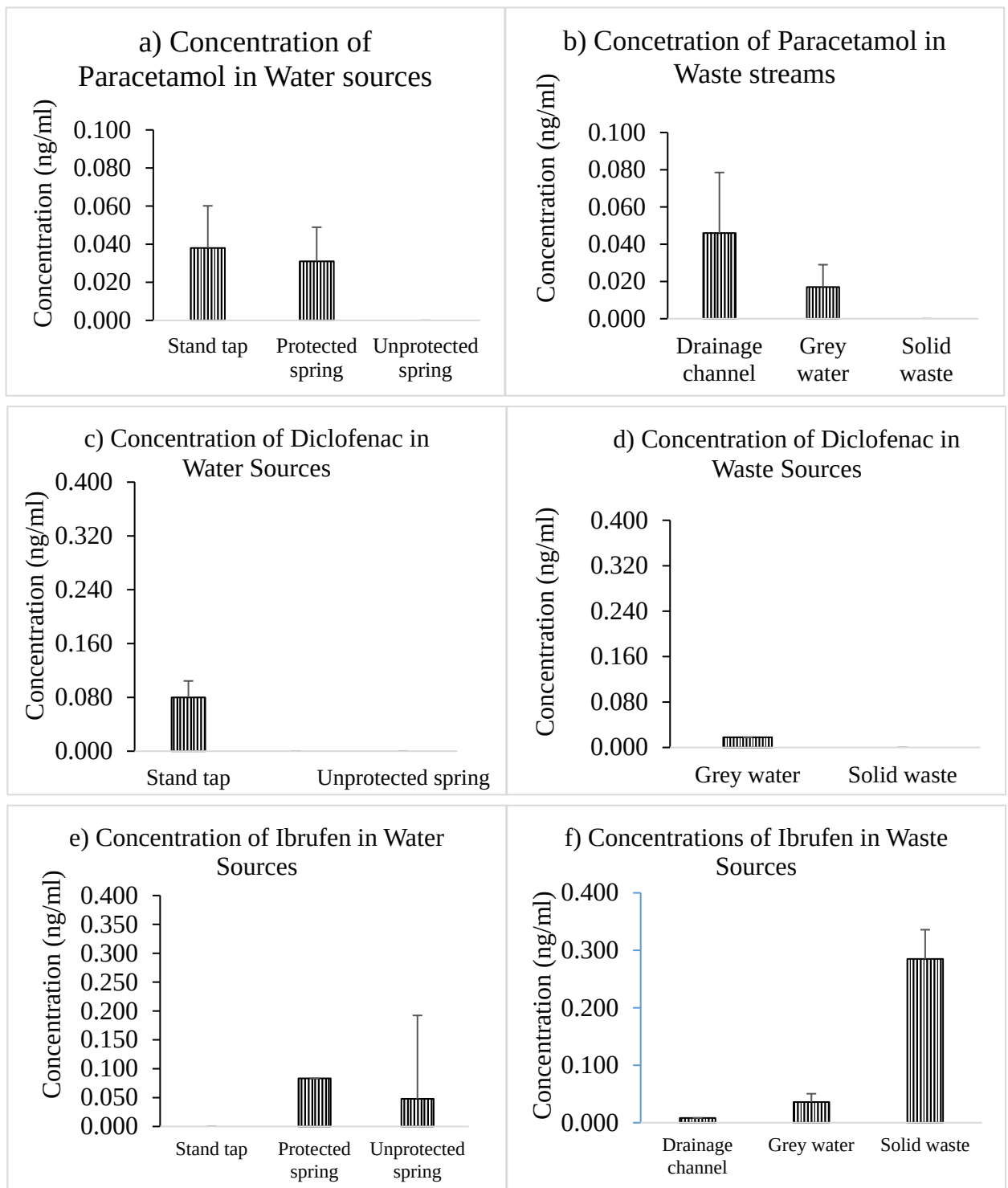


**Figure 4-6: Concentrations of CECs in various water sources and waste streams (Paracetamol, Diclofenac and Ibrufen  $n = 15$ )**

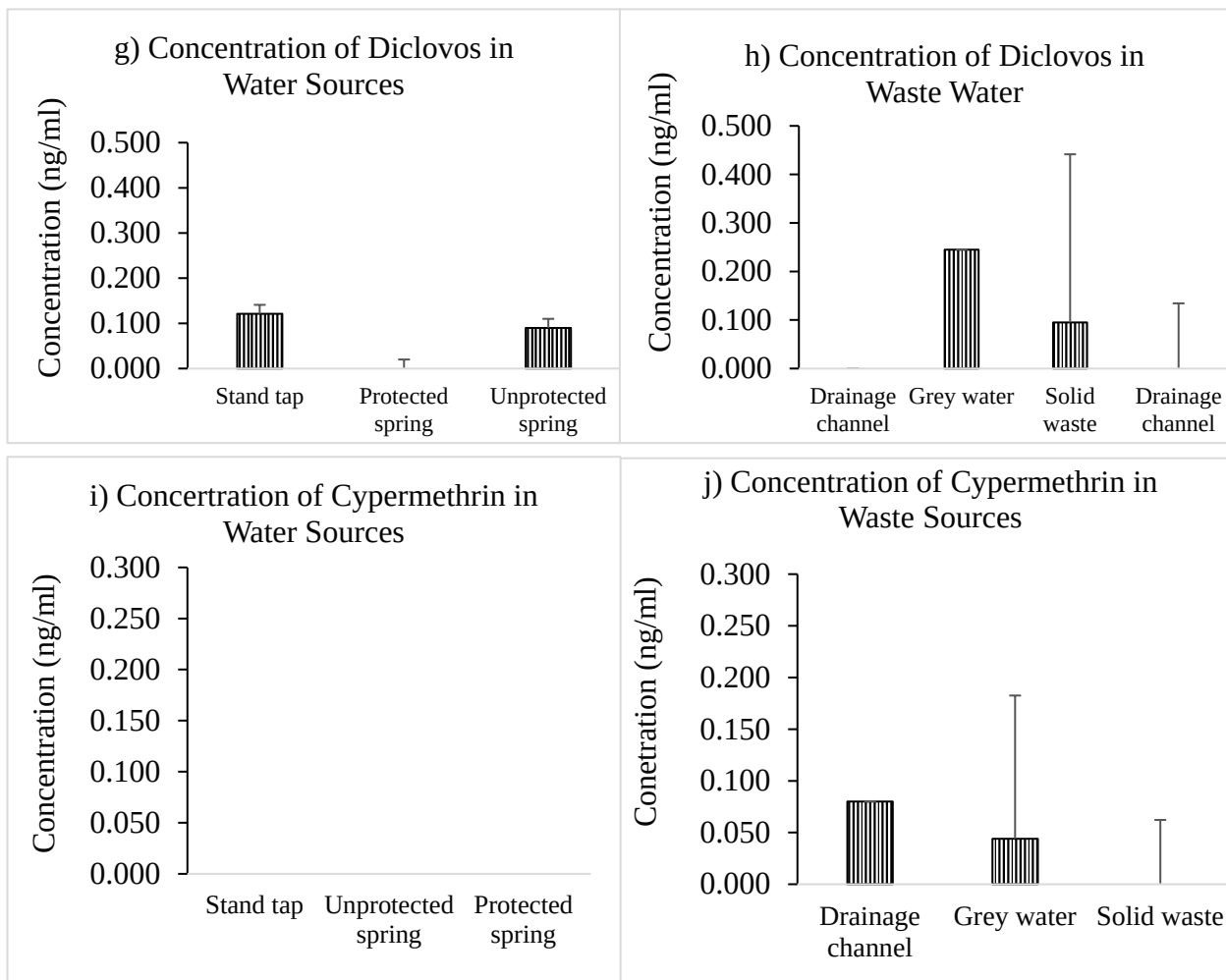


**Figure 4-7: Concentrations of CECs in various water sources and waste streams**

**(Diclofos and Cypermethrin  $n = 15$ )**

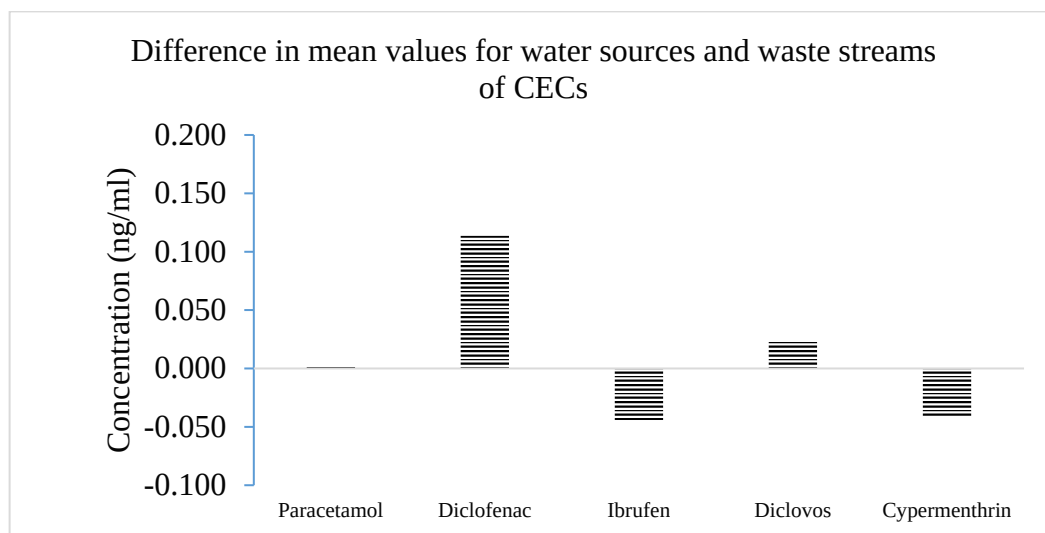


**Figure 4-8: Mean value difference of CECs in water sources vs waste streams (n=15)**

(positive value means a higher concentration in water streams while negative value means a higher concentration in waste streams),

Available literature has noted higher values of pharmaceuticals in waste compared to water streams by (Björnberg and Elenström, 2016) also found some pharmaceuticals, like atenolol and carbamazepine, had their concentration increase after the water treatment in Bugolobi wastewater treatment facility. Higher concentrations of Ibuprofen in the waste stream could be attributed to its break down over time. In a study conducted in European waters, Ibuprofen was found to have degraded in wastewaters and surface waters in both field observations and laboratory incubations, However, metabolites have been found to be more toxic than the parent compound. In soil, in a (14- 189) day study Ibuprofen persistence was reported to have varied depending on the moisture content (Caracciolo, Topp and Grenni, 2015).

#### 4.4 Quantification of Toxic Risks caused by CECs in drinking water

According to figure 4-9, the Paracetamol concentrations were higher than the acceptable limit in communal stand taps and protected springs whereas within unprotected spring there was no detection. The permissible limit of Paracetamol in drinking water is  $0.006\mu\text{gL}^{-1}$ , (Ghesti and Gastaldini, 2019).

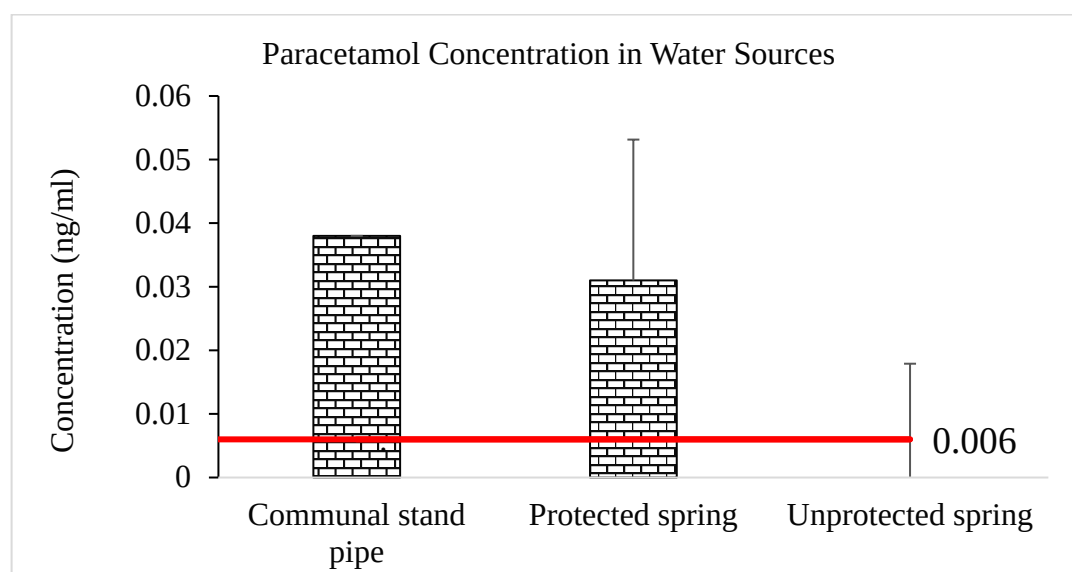


**Figure 4-9: Required Limits of Paracetamol  $0.006\mu\text{gL}^{-1}$  maximum ( $n = 8$ )**

According to figure 4-10, the Diclofenac concentrations were higher than the acceptable limit in communal stand taps whereas within protected and unprotected springs there was no detection or concentration was below detection limits. The permissible limit of Diclofenac in drinking water is  $0.00025\mu\text{gL}^{-1}$ , (Snyder, 2008a).

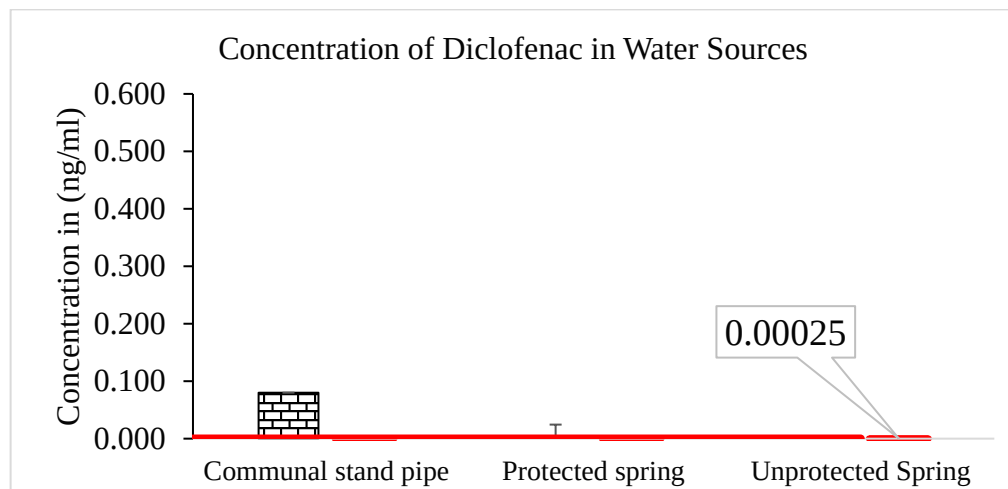


**Figure 4-10: Required maximum concentration of Diclofenac  $0.00025\mu\text{gL}^{-1}(n= 8)$**

According to figure 4-11, the Ibrufen concentrations were higher than the acceptable limit in protected and unprotected springs whereas in communal stand taps higher concentrations were not detected. The permissible limit of Ibrufen in drinking water is  $0.006\mu\text{gL}^{-1}$ , (Ghesti and Gastaldini, 2019).

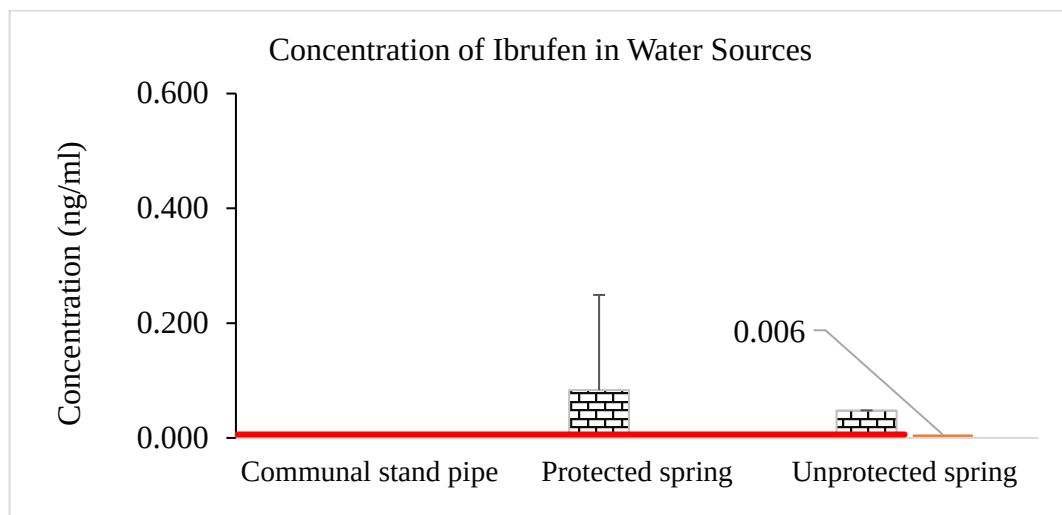


**Figure 4-11: Required Limits of Ibrufen  $0.006\mu\text{gL}^{-1}$  maximum ( $n = 8$ )**

According to figure 4-12, the Diclofos concentrations were higher than the acceptable limit in communal stand taps and unprotected springs. The permissible limit of Diclofos in drinking water is  $0.0012\mu\text{gL}^{-1}$ , (Snyder, 2008a).

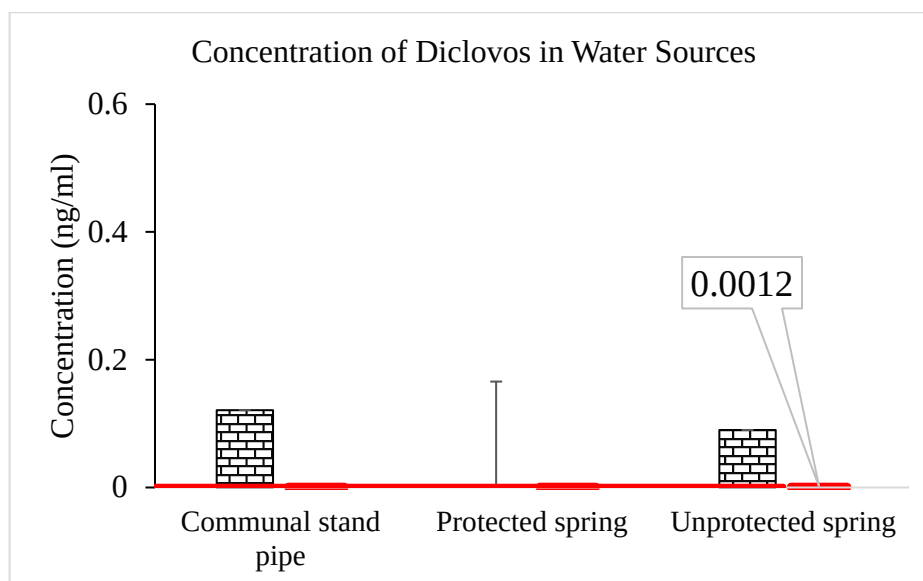


**Figure 4-12: Required maximum concentration of Diclofos  $0.00012\mu\text{gL}^{-1}$  ( $n = 8$ )**

Figure 4.9 – 4.12 all show higher than the recommended concentrations that could be harmful to human health (Ghesti and Gastaldini, 2019; Snyder, 2008) and thus there is need to address CECs within urban slums.

#### 4.5 Ranking of Toxic Risks

**Table 4-1: Summary ranking**

| CECs Parameters | RQ <sub>Acute</sub> | RQ <sub>chronic</sub> | Remarks                                     |
|-----------------|---------------------|-----------------------|---------------------------------------------|
| Paracetamol     | 0.458               | 0.011                 | Medium risk                                 |
| Diclofenac      | 0.189               | 0.169                 | Medium risk                                 |
| Ibuprofen       | 1.969               | 0.219                 | High Risk (Acute) and Medium risk (Chronic) |

The results derived from risk quotient approach in three trophic levels showed that three of the analysed CECs, Ibrufen pose high acute risk  $RQ > 1$ . This means Paracetamol and Diclofenac pose no risk since both acute and chronic risk  $RQ < 1$ . This implies that Ibrufen presented high risk in urban slum water sources while a study by Nantaba *et al.* (2019) found Diclofenac posing a high acute risk of 3.2 in Murchison bay, Lake Victoria. Hence, Ibrufen should be seriously considered as a candidate for regulatory monitoring and prioritization on a European scale on the basis of realistic PNECs (Kosma *et al.*, 2014).

## **CHAPTER FIVE: CONCLUSION AND RECOMMENDATION**

### **5.1 Conclusion**

The study aimed at investigating the occurrence, distribution, level of concentration, toxicology and risk rankings of four main pharmaceutically/personal care products active compounds (PPCPs) in the urban poor environment.

The potential sources of CECs were noted to be pharmacies, salons, and medical establishments located within the households.

The assessed samples found presence of CECs and analysis of water and waste streams found pharmaceuticals like Paracetamol (0.038ng/ml), Diclofenac (0.031ng/ml) and Ibrufen (0.368ng/ml); and PCPs like Diclofos (0.036ng/ml). High levels of Paracetamol, Diclofenac and Ibrufen in both water and waste streams were detected.

The presence of CECs especially in water streams is of concern as these are above the recommended concentration limits.

Basing on the risk quotient, Ibrufen posed the highest acute risk/ threat to human health. This implies there is occurrence of CECs in the urban slum environment.

Contaminants of emerging concern were found within urban slum water and waste streams.

### **5.2 Recommendation**

#### **5.2.1 General recommendation**

Sensitization on proper medical waste management

Proper greywater management and water treatment mechanisms should target CECs as these were found in piped water

Proper waste management in urban slums

Promote and emphasize routine monitoring programs for pharmaceuticals in water sources and drinking water. Enhance public communication and education on water quality issues from the human health standpoint. For example, sensitizing of the public on potential health risks from exposure to very low concentrations of pharmaceuticals in drinking-water will help them to better understand this issue relative to other hazards, such as waterborne pathogenic microorganisms.

#### **5.2.2 Recommendation for further study**

- Additional research is needed to establish the presence of CECs in piped drinking water in case there are some parameters that water treatment plants are not capturing and further investigate presence of antibiotics.
- Trace the movement of CEC from source to environment and water stream.
- With rapid urban development longitudinal studies are required help keep track of CECs in both water/waste sources and in the environment.

#### **5.2.3 Recommendations for policy**

KCCA and NEMA to formulate guidelines on pharmaceuticals in drinking-water and proper management of waste generated in health-care facilities. Failure to comply with the guidelines under this Act through improper management and disposal of waste can

potentially constitute serious violations and incur heavy penalties. Implementation of KCCA sewage and faecal sludge management) ordinance, 2019 should be observed.

Sensitize consumers and support efforts for the proper disposal of unwanted and excess medicines and reduce the environmental impact of pharmaceuticals entering our environment, including water sources.

Pharmaceuticals therefore must be seen as important environmental pollutants that should be added to and regulated under existing KCCA policies. Future monitoring strategies should hence move towards robust sampling programs

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## **APPENDICES**

### **Appendix 1: Questionnaire**

INVESTIGATING THE OCCURRENCE OF EMERGING CONTAMINANTS OF  
CONCERN IN URBAN WATER BODIES IN SLUMS AREAS:

A CASE OF BWAISE, KAWEMPE DIVISION

MSc Research

Baseline Survey Questionnaire

January 2020

## CEC in slum water bodies: Survey

|                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Objective of the survey:</b></p> <p>This survey is conducted for research purposes only to better Investigating the occurrence of contaminants of emerging concern in urban water bodies in slums areas. The answers of the interviewees shall be strictly used for research purposes and kept confidential.</p> |
| <p><b>Parts</b></p> <p>The survey questionnaire is divided into two parts</p> <p><b>PART 1 : QUESTIONNAIRE</b></p> <p>Questions to be answered by owner/ employee of the facility</p> <p><b>PART 2: OBSERVATION GUIDE</b></p> <p>To be filled by the one conducting the survey</p>                                     |

|                         |                         |                                                                          |
|-------------------------|-------------------------|--------------------------------------------------------------------------|
| <p><b>Location:</b></p> |                         | <p><b>Questionnaire</b></p> <p>no.</p>                                   |
| <p>A0</p>               | <p><b>Division:</b></p> | <div style="border: 1px solid black; height: 150px; width: 100%;"></div> |
| <p>.....</p>            |                         |                                                                          |
| <p>A1</p>               | <p><b>Parish:</b></p>   |                                                                          |
| <p>.....</p>            |                         |                                                                          |

|                                            |                                    |                       |  |  |
|--------------------------------------------|------------------------------------|-----------------------|--|--|
|                                            |                                    |                       |  |  |
| A2                                         | Zone:                              | .....                 |  |  |
|                                            |                                    |                       |  |  |
| A4                                         | Name of person doing<br>the survey |                       |  |  |
|                                            |                                    |                       |  |  |
| A5                                         | Date of survey                     |                       |  |  |
|                                            |                                    |                       |  |  |
| A6                                         | Time of survey                     |                       |  |  |
|                                            |                                    |                       |  |  |
| Consent of Owner/ user (signature/ tel no) |                                    |                       |  |  |
| Supervisor                                 |                                    | Data Entrant          |  |  |
| Name and Signature                         |                                    | Date of Data<br>Entry |  |  |

PART 1      QUESTIONNAIRE (Questions to be answered by owner/ employee of the facility)

|                         |                                                                                                                     |                              |   |
|-------------------------|---------------------------------------------------------------------------------------------------------------------|------------------------------|---|
| (Tick most appropriate) |                                                                                                                     |                              |   |
| General                 |                                                                                                                     |                              |   |
| 1                       | Coordinates of facility                                                                                             | .....                        |   |
| 2                       | Nature of Facility                                                                                                  | Pharmacy                     | 1 |
|                         |                                                                                                                     | Veterinary shop              | 2 |
|                         |                                                                                                                     | Saloon                       | 3 |
|                         |                                                                                                                     | Health centre (include type) | 4 |
|                         |                                                                                                                     | Others                       | 5 |
| 3                       | What is the respondent's position?                                                                                  |                              |   |
| 4                       | How long have the facility been in this area?(include number)                                                       | 2                            |   |
| 5                       | What are the most commonly sold/ used drugs/ products in your facility<br>.....<br>.....<br>.....<br>.....<br>..... |                              |   |

|    |                                                               |                                    |   |
|----|---------------------------------------------------------------|------------------------------------|---|
|    | .....                                                         |                                    |   |
| 6a | Do you dispose products with solid waste?                     | Yes                                | 1 |
|    |                                                               | No                                 | 2 |
| B  | If yes, how do you dispose off your solid waste               | In open                            | 1 |
|    |                                                               | In the dug-pit within the compound | 2 |
|    |                                                               | Dry and burn them                  | 3 |
|    |                                                               | Town council skip bins             | 4 |
|    |                                                               | Others (specify)                   | 5 |
| 7a | Do you dispose products with wastewater/ human excreta        | Yes                                | 1 |
|    |                                                               | No                                 | 2 |
| B  | If yes, how do you dispose off your wastewater/ human excreta | To a sewer                         | 1 |
|    |                                                               | Septic tank and soak pit           | 2 |
|    |                                                               | Pit latrine                        | 3 |
|    |                                                               | Others (specify)                   | 4 |
| 8a | Do you dispose products with greywater                        | Yes                                | 1 |
|    |                                                               | No                                 | 2 |
| b  | If yes, how do you dispose off your greywater                 | To a sewer                         | 1 |
|    |                                                               | Pit latrine                        |   |
|    |                                                               | Soak pit                           | 2 |

|    |                                                                                                                                       |                                |   |
|----|---------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|---|
|    |                                                                                                                                       | Drainage ditch                 | 3 |
|    |                                                                                                                                       | Others (specify)               | 4 |
| 9  | What do you consider as the most significant water and sanitation related challenges in my area (Rank from highest (1) to lowest (4)) | Garbage collection problem     |   |
|    |                                                                                                                                       | Water drainage problem         |   |
|    |                                                                                                                                       | Water supply problem           |   |
|    |                                                                                                                                       | Construction of public latrine |   |
| 10 | Water is the source of your water                                                                                                     | Piped water                    | 1 |
|    |                                                                                                                                       | Spring                         | 2 |
|    |                                                                                                                                       | Borehole/deep well             | 3 |
|    |                                                                                                                                       | Rain water harvest             | 4 |
| 11 | Have you ever heard of CEC                                                                                                            | Yes                            | 1 |
| a  |                                                                                                                                       | No                             | 2 |
|    | If so from where (specify)                                                                                                            |                                |   |
| 12 | Do you know of any effect of discharging your products in the environment                                                             | Yes                            | 1 |
|    |                                                                                                                                       | No                             | 2 |
| 13 | Any other remarks                                                                                                                     | .....<br>..                    |   |

|  |  |                                                 |
|--|--|-------------------------------------------------|
|  |  | <p>.....</p> <p>.</p> <p>.....</p> <p>.....</p> |
|--|--|-------------------------------------------------|

PART 2: OBSERVATION GUIDE (To be filled by the one conducting the survey)

|         |                                                    |       |
|---------|----------------------------------------------------|-------|
|         |                                                    |       |
| General |                                                    |       |
| 1       | What is the nature of the premise/facility?        | ..... |
| 2       | How is solid waste disposed off?                   |       |
|         |                                                    |       |
|         |                                                    |       |
|         |                                                    |       |
|         |                                                    |       |
| 3       | How is waste water/ human excreta disposed off?    |       |
| 4       | How is grey water managed?                         |       |
| 5       | Distance of the garbage dump site from the premise |       |

|   |                                                  |                       |             |  |
|---|--------------------------------------------------|-----------------------|-------------|--|
| 6 | Distance of the garbage dump site from the house |                       |             |  |
| 7 | Type of water source                             |                       |             |  |
| 8 | Location of water source (coordinates)           |                       |             |  |
| 9 | Distance of the water source from;               | Facility              | 0 - 10m     |  |
|   |                                                  |                       | 10m - 20m   |  |
|   |                                                  |                       | 20m - 30m   |  |
|   |                                                  |                       | 30m - 40m   |  |
|   |                                                  |                       | 40m - 50m   |  |
|   |                                                  |                       | 50m & above |  |
|   |                                                  | House                 | 0 - 10m     |  |
|   |                                                  |                       | 10m - 20m   |  |
|   |                                                  |                       | 20m - 30m   |  |
|   |                                                  |                       | 30m - 40m   |  |
|   |                                                  |                       | 40m - 50m   |  |
|   |                                                  |                       | 50m & above |  |
|   |                                                  | Solid waste dump site | 0 - 10m     |  |
|   |                                                  |                       | 10m - 20m   |  |
|   |                                                  |                       | 20m - 30m   |  |
|   |                                                  |                       | 30m - 40m   |  |

|  |  |                        |                |  |
|--|--|------------------------|----------------|--|
|  |  |                        | 40m - 50m      |  |
|  |  |                        | 50m &<br>above |  |
|  |  | Sanitation<br>facility | 0 - 10m        |  |
|  |  |                        | 10m - 20m      |  |
|  |  |                        | 20m - 30m      |  |
|  |  |                        | 30m - 40m      |  |
|  |  |                        | 40m - 50m      |  |
|  |  |                        | 50m &<br>above |  |
|  |  | Open drain             | 0 - 10m        |  |
|  |  |                        | 10m - 20m      |  |
|  |  |                        | 20m - 30m      |  |
|  |  |                        | 30m - 40m      |  |
|  |  |                        | 40m - 50m      |  |
|  |  |                        | 50m &<br>above |  |

Letters



**Department of Civil and Building Engineering**  
P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA  
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TEL: +256-41-4287340, FAX: +256-41-4289056/4222643

December 16<sup>th</sup>, 2019

The Director,  
Public Health and Environment,  
Kampala Capital City Authority,  
P.O. Box 7010,  
City Hall, Plot 1-3, Apollo Kagwa Road,  
Kampala - Uganda,

Dear Dr.,

**RE: LETTER OF INTRODUCTION FOR MR. MAFABI MARTINS TO ACQUIRE  
RELEVANT DATA REQUIRE FOR HIS MASTER OF SCIENCE RESEARCH**

Mr. Martin Mafabi is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. He is conducting a research study on "Investigating the occurrence of emerging contaminants of concern in urban water bodies in slums areas: A case of Bwaise, Kawempe Division". The researcher is being supervised and co-supervised by Eng. Dr. Anne Nakagiri, and Dr. Charles Onyutha, respectively.

This research is very vital regarding the caution to regulate disposal of pharmaceuticals, solid wastes, and wastewater. The specific objectives of this study are (1) To identify and map potential sources of Emerging Contaminants of Concern (CECs), (2) To assess the level of CECs in the soil, drinking water, gray water, stormwater, and sanitary user interfaces, (3) Quantifying toxic risks caused by of CECs to human health, and (4) Based on the sources and toxic quantities of CECs, rank the proposed management strategies.

To achieve the specific objectives, both primary and secondary data from the study area are required. This letter is therefore to introduce the researcher and seek for support toward data acquisition for the research.

I shall be grateful for your cooperation and support toward this research.

Yours Sincerely,

Lawrence Muhwezi (PhD)  
Head of Department of Civil and Building Engineering



CC. Dean, School of Graduate Studies, Kyambogo University  
Dr. Charles Onyutha - Department of Civil and Building Engineering, Kyambogo University  
Eng. Dr. Anne Nakagiri - Department of Civil and Building Engineering, Kyambogo University

**DIRECTORATE OF PUBLIC HEALTH AND  
ENVIRONMENT**

**REF: DPHE/KCCA/201/17**

13<sup>th</sup> January, 2020

The Head of Department of Civil and Building Engineering  
Kyambogo University,

**RE: PERMISSION FOR MR. MARTIN MAFABI TO CARRY OUT A  
STUDY ENTITLED "INVESTIGATING THE OCCURRENCE OF  
EMERGING CONTAMINATION OF CONCERN IN URBAN  
WATER BODIES IN SLUMS AREAS A CASE OF BWAISE,  
KAWEMPE DIVISION."**

I refer to the letter from your department dated 16<sup>th</sup> December, 2019 requesting for permission for a student from your department Mr. Martin Mafabi to carry out a study on the above subject matter.

This is to inform you that permission has been granted to Mr. Martin Mafabi to conduct research at Bwaise Parish from 20<sup>th</sup> January 2020 to 20 February 2020.

The above permission is granted to Mr. Martin Mafabi on the following conditions: -

1. Participation in research is voluntary and the informed consent process should be observed at all times.
2. Provision of a report to the office of the Director of Public Health and Environment.

By copy of this letter, the Town Clerk Kawempe Division, Division Solid Waste Officer Kawempe, LC II Chairperson Bwaise Parish and LC I Chairpersons Bwaise Parish are requested to render Mr. Martin Mafabi all the necessary support.



Najib B. Lukooya (PhD)

**AG. DIRECTOR PUBLIC HEALTH AND ENVIRONMENT**

**Copy:** Town Clerk –Kawempe Division  
Division Solid Waste Officer  
Mr. Martin Mafabi

**LC II Chairperson, Bwaise Parish, Kawempe Division**  
**LC I Chairperson Bwaise Parish**

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October 14, 2019

The Director,  
Uganda Government Analytical Laboratory,  
Plot 2 Lourdel Rd,  
Kampala - Uganda,

Dear Eng.,

**RE: REQUEST FOR SUBSIDIZING RATES FOR LABORATORY TESTS TO BE  
CONDUCTED BY MAFABI MARTINS**

Mr. Martin Mafabi is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. He is conducting a research study on "Investigating the occurrence of emerging contaminants of concern in urban water bodies in slums areas: A case of Bwaise, Kawempe Division". The researcher is being supervised and co-supervised by Eng. Dr. Anne Nakagiri, and Dr. Charles Onyutha, respectively.

This research is very vital regarding the caution to regulate disposal of pharmaceuticals, solid wastes, and wastewater. However, because the pertinent laboratory tests are quite expensive in nature, I hereby write to your office in line with the above reference. The necessary support to enable the researcher timely conduct the laboratory tests and complete his research will be duly acknowledged in the dissemination of the results. The researcher will also require from your office (if available) the current standards against which the results from the laboratory tests will be compared.

I shall be grateful for your cooperation and support toward this research.

Yours Sincerely,

Jacob Nyende (PhD)

Head of Department of Civil and Building Engineering



CC. Dean, School of Graduate Studies, Kyambogo University

Dr. Charles Onyutha - Department of Civil and Building Engineering, Kyambogo University

Eng. Dr. Anne Nakagiri - Department of Civil and Building Engineering, Kyambogo University

The specific objectives of this study are;

- To identify and map potential sources of Emerging Contaminants of Concern (CECs).
- To assess the level of CECs in the soil, drinking water, gray water, stormwater, and sanitary user interfaces.
- Quantifying toxic risks caused by of CECs to human health and investigating the impacts of the CECs.
- Ranking of the different parameters of the CECs.

## Appendix II:

**Table A.1 Interviews Response**

| Facility/Premise | Parish    | Zone     | Coordinates   | Drugs commonly sold/used | Disposal method                        | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|----------|---------------|--------------------------|----------------------------------------|--------------------------|-------------------|----------------------|
| Pharmacy         | Bwaise II | Nabukalu | 451279, 39667 | Panadol,                 | KCCA Skips & grey water in septic tank | 5m                       | 20m               | No Knowledge         |
|                  |           |          |               | Ampillox,                |                                        |                          |                   |                      |
|                  |           |          |               | Diclofenac               |                                        |                          |                   |                      |
| Household        | Bwaise II | Jambula  | 451259, 39156 | Amoxy,                   | Open pit and burning & Grey            | 10m                      | 50m               | No Knowledge         |
|                  |           |          |               | Ibrufen,                 |                                        |                          |                   |                      |
|                  |           |          |               | Seprine                  |                                        |                          |                   |                      |
|                  |           |          |               | Panadol,                 |                                        |                          |                   |                      |
|                  |           |          |               | Amoxyl                   |                                        |                          |                   |                      |

| Facility/Premise | Parish    | Zone     | Coordinates   | Drugs commonly sold/used        | Disposal method                                     | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|----------|---------------|---------------------------------|-----------------------------------------------------|--------------------------|-------------------|----------------------|
|                  |           |          |               |                                 | water - open drain                                  |                          |                   |                      |
| Clinic           | Bwaise II | Jambula  | 451259, 39156 | Pain killers, antimalarial, ORS | Bio Waste & grey water into open drain              | 20m                      | 15m               | No Knowledge         |
| Household        | Bwaise II | Nabukalu | 451172, 39593 | Panadol                         | Garbage by KCCA & burning, Grey water in open drain | 15m                      | 5m                | No                   |
|                  |           |          |               | Ibrufen                         |                                                     |                          |                   |                      |
|                  |           |          |               | Septrin                         |                                                     |                          |                   |                      |

| Facility/Premise | Parish    | Zone     | Coordinates   | Drugs commonly sold/used    | Disposal method                                      | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|----------|---------------|-----------------------------|------------------------------------------------------|--------------------------|-------------------|----------------------|
| Household        | Bwaise II | Nakamilo | 451025, 39612 | Panadol,                    | Garbage in open dump site & grey water in open drain | 5m                       | 5m                | No                   |
|                  |           |          |               | Diclofenac, dewormer        |                                                      |                          |                   |                      |
| Clinic           | Bwaise II | Lufula   | 451089, 39085 | Anti biotics,               | Garbage use biowaste & grey water in open drain      | 20m                      | 20m               | No                   |
|                  |           |          |               | Pain killers & Anti malaria |                                                      |                          |                   |                      |

| Facility/Premise | Parish    | Zone    | Coordinates   | Drugs commonly sold/used         | Disposal method                                   | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|---------|---------------|----------------------------------|---------------------------------------------------|--------------------------|-------------------|----------------------|
| Clinic           | Bwaise II | Jambula | 451258, 39212 | Anti-malaria, Dewormers and UTIs | Garbage use biowaste & grey water in open drain   | 10m                      | 10m               | No                   |
| Household        | Bwaise II | Jambula | 451226, 39236 | Coatem,                          | Organics eaten by cows & grey water in open drain | 50m                      | 10m               | No                   |
|                  |           |         |               | Panadol,                         |                                                   |                          |                   |                      |
|                  |           |         |               | Dewormers                        |                                                   |                          |                   |                      |
| Saloon           | Bwaise II | Lufula  | 451140, 39046 | N/A                              | Grey water into the drain                         | 5m                       | 5m                | No                   |

| Facility/Premise | Parish    | Zone     | Coordinates   | Drugs commonly sold/used                                 | Disposal method                             | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|----------|---------------|----------------------------------------------------------|---------------------------------------------|--------------------------|-------------------|----------------------|
| Saloon           | Bwaise II | Mukalazi | 450892, 39693 | N/A                                                      | Grey water in open drain                    | 10m                      | 10m               | No                   |
| Clinic           | Bwaise II | Nakamilo | 450897, 39730 | Panadol, Painex, Ibrufen, Diclofenac, Septrin & Cold pex | Garbage biowaste & Grey water in open drain | 10m                      | 10m               | No                   |

| Facility/Premise | Parish    | Zone     | Coordinates   | Drugs commonly sold/used   | Disposal method                                        | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|----------|---------------|----------------------------|--------------------------------------------------------|--------------------------|-------------------|----------------------|
| Household        | Bwaise II | Nakamilo | 451163, 39298 | Panadol, Painex, Dewormers | Organics consumed by cattle & grey water in open drain | 50m                      | 10m               | No                   |
| Household        | Bwaise II | Nakamilo | 450882, 39868 | Panadol, Ibrufen, Septrin  | Organics used as manure & grey water in open drain     | 10m                      | 10m               | No                   |
| School           |           |          |               | Panadol,                   |                                                        | 20m                      | 50m               | No                   |

| Facility/Premise | Parish     | Zone      | Coordinates   | Drugs commonly sold/used                             | Disposal method                                       | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|------------|-----------|---------------|------------------------------------------------------|-------------------------------------------------------|--------------------------|-------------------|----------------------|
|                  | Bwaise III | Katogo    | 450539, 38823 | Diclofenac<br>Ibuprofen                              | Garbage KCCA & Grey water open drain                  |                          |                   |                      |
| Pharmacy         | Bwaise III | Bugala ni | 451067, 38972 | Action, Ampicillin, Panadol<br>Diclofenac, Ibuprofen | Garbage taken by biowaste & grey water into the drain | 10m                      | 20m               | No                   |
| Medical Centre   | Bwaise II  | Bugala ni | 450805, 38920 | Paracetamol, Diclofenac,                             | Garbage taken by biowaste &                           | 30m                      | 10m               | No                   |

| Facility/Premise | Parish    | Zone       | Coordinates   | Drugs commonly sold/used                      | Disposal method                                      | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|------------|---------------|-----------------------------------------------|------------------------------------------------------|--------------------------|-------------------|----------------------|
|                  |           |            |               | Ibrufen, Painex & Septrin                     | grey water in open drain                             |                          |                   |                      |
| Medical Centre   | Bwaise II | Tebyol eka | 450741, 38926 | Coatem, Ronart, Panadol, Ibrufen & Diclofenac | Garbage taken by biowaste & Grey water in open drain | 50m                      | 10m               | No                   |
| Medical Centre   | Bwaise II | Lufula     |               | Panadol,                                      |                                                      | 10m                      | 10m               | `                    |

| Facility/Premise | Parish    | Zone    | Coordinates   | Drugs commonly sold/used                     | Disposal method                                      | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|---------|---------------|----------------------------------------------|------------------------------------------------------|--------------------------|-------------------|----------------------|
|                  |           |         | 450941, 38998 | Ibuprofen, Diclofenac, Coartem               | Garbage taken by Biowaste & grey water in open drain |                          |                   |                      |
| Dental Clinic    | Bwaise II | Jambula | 451175, 39039 | Antibiotics, Panadol, Ibuprofen & Diclofenac | Garbage taken by Biowaste & grey water in open drain | 50m                      | 50m               | No                   |
| Pharmacy         | Bwaise II | Jambula | 451335, 39190 | Painkillers, Antibiotics,                    | Garbage taken by biowaste &                          | 10m                      | 10m               | No                   |

| Facility/Premise | Parish    | Zone     | Coordinates   | Drugs commonly sold/used                            | Disposal method                                      | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|----------|---------------|-----------------------------------------------------|------------------------------------------------------|--------------------------|-------------------|----------------------|
|                  |           |          |               | Antimalaris & Extractions                           | grey water in open drain                             |                          |                   |                      |
| Pharmacy         | Bwaise II | Nabukalu | 451139, 40105 | Paracentamol, Ibrufen, Septrin, Painex & Diclofenac | Garbage taken by Biowaste & Grey water in open drain | 20m                      | 10m               | No                   |
| Pharmacy         | Bwaise II | Nabukalu | 451176, 39998 | Panadol, Diclofenac,                                | Garbage taken by Biowaste &                          | 20m                      | 20m               | No                   |

| Facility/Premise | Parish    | Zone     | Coordinates   | Drugs commonly sold/used       | Disposal method                                      | Distance to water source | Distance to drain | Knowledge about CECs |
|------------------|-----------|----------|---------------|--------------------------------|------------------------------------------------------|--------------------------|-------------------|----------------------|
|                  |           |          |               | Ibrifen antibiotics and Coatem | Grey water in open drain                             |                          |                   |                      |
| Pharmacy         | Bwaise II | Nabukalu | 451266, 39777 | Piankillers, Antibiotics       | Garbage taken by Biowaste & Grey water in open drain | 50m                      | 50m               | No                   |

**Table A.2      Location of Clinic showing coordinates and zones**

| <b>Potential CEC Source</b> | <b>Location Longitude &amp; Latitude</b> | <b>Zone</b> | <b>Size</b> | <b>Nature of Medical services</b> |
|-----------------------------|------------------------------------------|-------------|-------------|-----------------------------------|
| Clinic A                    | 451259, 39156                            | Jambula     | Small       | General services                  |
| Clinic B                    | 451089, 39085                            | Lufula      | Small       | General services                  |
| Clinic C                    | 451258, 39212                            | Jambula     | Medium      | Maternity services                |
| Clinic D                    | 450897, 39730                            | Nakamilo    | Large       | General services                  |
| Dental Clinic               | 451175, 39039                            | Jambula     | Medium      | Dental services                   |

**Table A.3: Location of Households showing coordinates and water source**

| <b>Potential CEC Source</b> | <b>Location Longitude &amp; Latitude</b> | <b>Zone</b> | <b>Water Source</b> |
|-----------------------------|------------------------------------------|-------------|---------------------|
| H1                          | 451259, 39156                            | Jambula     | Protected Spring    |
| H2                          | 451172, 39533                            | Nabukalu    | Protected Spring    |
| H3                          | 451025, 39612                            | Nakamilo    | NWSC tap            |
| H4                          | 451226, 39236                            | Jambula     | Protected Spring    |
| H5                          | 451163, 39298                            | Nakamilo    | Protected Spring    |
| H6                          | 450882, 39868                            | Nakamilo    | NWSC tap            |

**Table A.4: Location of medical centres showing coordinates and zones**

| Potential CEC Source | Location Longitude & Latitude | Zone      | Size   | Nature of Medical services |
|----------------------|-------------------------------|-----------|--------|----------------------------|
| Medical Centre A     | 450805, 38920                 | Bugalani  | Small  | General services           |
| Medical Centre B     | 450741, 38926                 | Tebyoleka | Medium | General services           |
| Medical Centre C     | 450941, 38998                 | Lufula    | Medium | General services           |

**Table A.5: Location of pharmacies showing coordinates and zones**

| Potential CEC Source | Location Longitude & Latitude | Zone     | Size   |
|----------------------|-------------------------------|----------|--------|
| Pharmacy - A         | 451279, 39667                 | Nabukalu | Medium |
| Pharmacy - B         | 451067, 38972                 | Bugalani | Medium |
| Pharmacy - C         | 451335, 39190                 | Jambula  | Small  |
| Pharmacy - D         | 451139, 40105                 | Nabukalu | Large  |
| Pharmacy - E         | 451176, 39998                 | Nabukalu | Medium |
| Pharmacy - F         | 451266, 39777                 | Nabukalu | Medium |

## Appendix II: Table A.6 Descriptive Statistics

### a) Results analysed in descriptive statistics

| <i>Parameter</i>            | <i>Paracetamol</i><br>(ng/ml) | <i>Diclofenac</i><br>(ng/ml) | <i>Ibuprofen</i><br>(ng/ml) | <i>Dichlovos</i><br>(ng/ml) | <i>Cypermethrin</i><br>(ng/ml) |
|-----------------------------|-------------------------------|------------------------------|-----------------------------|-----------------------------|--------------------------------|
| Mean                        | 0.011                         | 0.007                        | 0.068                       | 0.082                       | 0.022                          |
| Standard Error              | 0.005                         | 0.004                        | 0.040                       | 0.038                       | 0.017                          |
| Median                      | 0.000                         | 0.000                        | 0.000                       | 0.000                       | 0.000                          |
| Mode                        | 0.000                         | 0.000                        | 0.000                       | 0.000                       | 0.000                          |
| Standard Deviation          | 0.018                         | 0.015                        | 0.154                       | 0.148                       | 0.064                          |
| Sample Variance             | 0.000                         | 0.000                        | 0.024                       | 0.022                       | 0.004                          |
| Kurtosis                    | -0.520                        | 4.343                        | 8.792                       | 3.332                       | 10.782                         |
| Skewness                    | 1.119                         | 2.246                        | 2.903                       | 1.943                       | 3.241                          |
| Range                       | 0.046                         | 0.048                        | 0.570                       | 0.490                       | 0.240                          |
| Minimum                     | 0.000                         | 0.000                        | 0.000                       | 0.000                       | 0.000                          |
| Maximum                     | 0.046                         | 0.048                        | 0.570                       | 0.490                       | 0.240                          |
| Sum                         | 0.170                         | 0.098                        | 1.013                       | 1.223                       | 0.328                          |
| Count                       | 15.000                        | 15.000                       | 15.000                      | 15.000                      | 15.000                         |
| Confidence Level<br>(95.0%) | 0.010                         | 0.008                        | 0.086                       | 0.082                       | 0.036                          |

**b) Concentration data**

| Sample/parameter | PARACETAMOL | DICLOFENAC | IBUPROFEN | DICHLOVOS | CYPERMETHRIN |
|------------------|-------------|------------|-----------|-----------|--------------|
| PSP3             | 0.035       | 0.048      | 0         | 0.31      | 0            |
| PSP2             | 0.041       | 0.032      | 0         | 0.053     | 0            |
| PSP1             | 0           | 0          | 0         | 0         | 0            |
| DC3              | 0.046       | 0          | 0         | 0         | 0.24         |
| DC2              | 0           | 0          | 0         | 0         | 0            |
| DC1              | 0           | 0          | 0.025     | 0         | 0            |
| GW1              | 0.017       | 0          | 0         | 0.49      | 0            |
| GW2              | 0           | 0.018      | 0.072     | 0         | 0.088        |
| PS1              | 0.031       | 0          | 0.25      | 0         | 0            |
| PS2              | 0           | 0          | 0         | 0         | 0            |
| PS3              | 0           | 0          | 0         | 0         | 0            |
| WS2              | 0           | 0          | 0         | 0         | 0            |
| WS1              | 0           | 0          | 0.57      | 0.19      | 0            |
| USW3             | 0           | 0          | 0.096     | 0.18      | 0            |
| USW1             | 0           | 0          | 0         | 0         | 0            |

Appendix III

Figure A.1 Concentration of CECs in water/waste sources

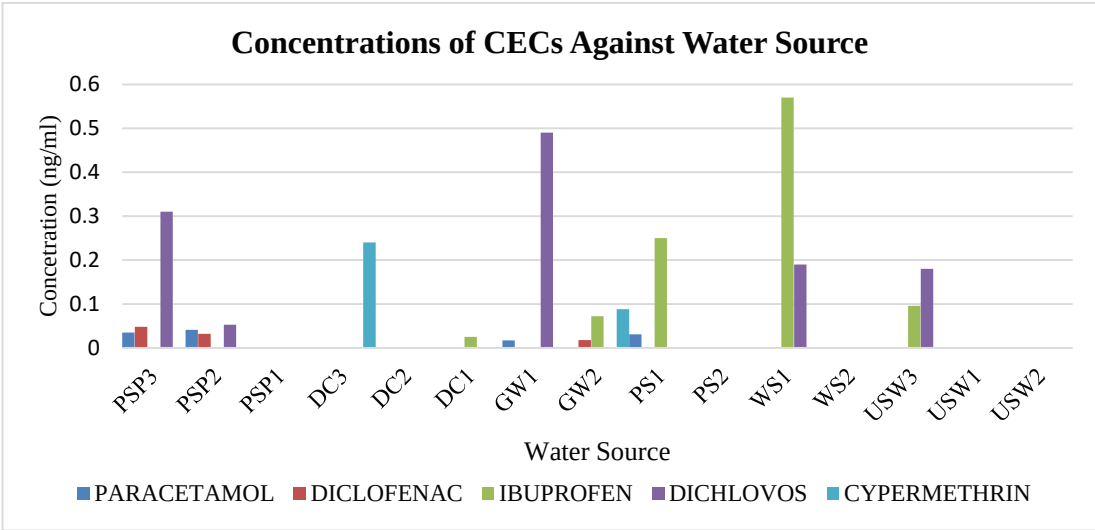


Figure A.2 Mapped sources for potential CECs

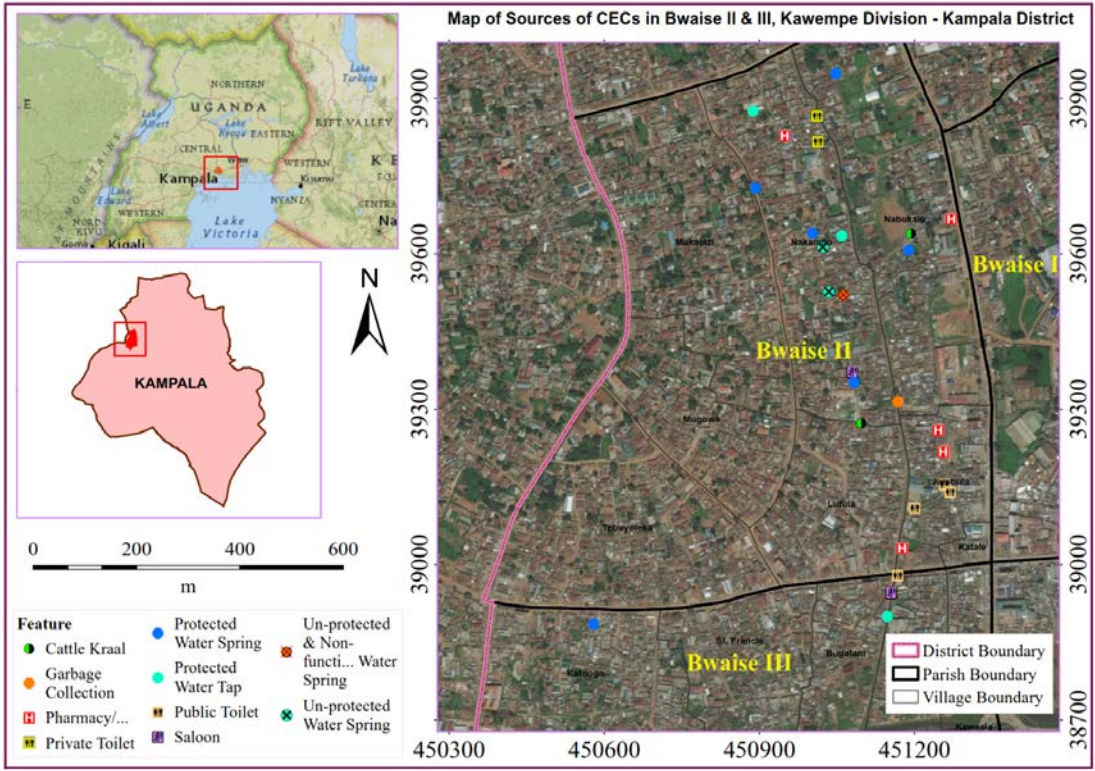
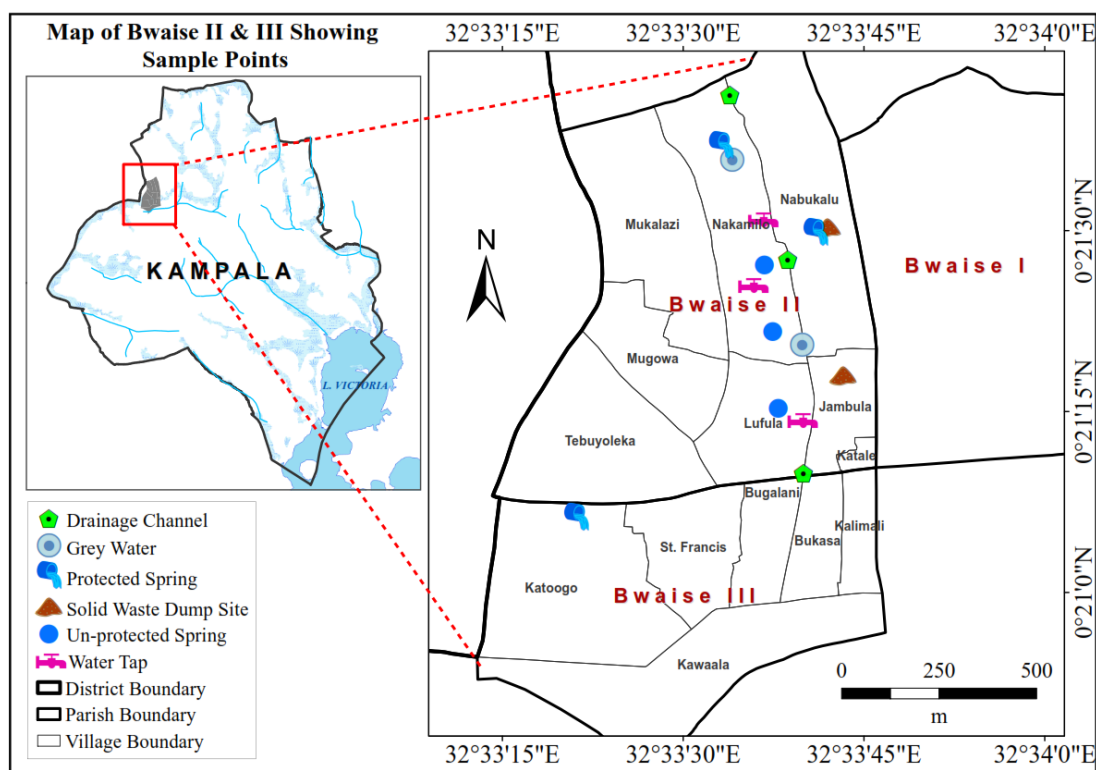


**Figure A.3 Final sampled points**



## Appendix IV

**Table A.3 Potential CECs sources in relation to water source**

| Sample<br>/parameter | Sample<br>Parameter   | Location<br>Distance<br>(m) | CEC<br>Source    | Parac<br>enta<br>mol | Dicl<br>ofen<br>ac | Ibu<br>pof<br>en | Dic<br>lov<br>os | Cyper<br>menth<br>rin |
|----------------------|-----------------------|-----------------------------|------------------|----------------------|--------------------|------------------|------------------|-----------------------|
| PSP3                 | Communal<br>tap stand | 42                          | Public<br>Toilet | 0.035                | 0.04<br>8          | 0                | 0.3<br>1         | 0                     |
| PSP2                 | Communal<br>tap stand | 5                           | Househol<br>ds   | 0.041                | 0.03<br>2          | 0                | 0.0<br>53        | 0                     |

|      |                                    |    |                                |       |           |           |          |       |
|------|------------------------------------|----|--------------------------------|-------|-----------|-----------|----------|-------|
| PSP1 | Communal<br>tap stand              | 3  | Househol<br>ds                 | 0     | 0         | 0         | 0        | 0     |
| DC3  | Drainage<br>Channel<br>down stream | 10 | Hair<br>Saloon                 | 0.046 | 0         | 0         | 0        | 0.24  |
| DC2  | Drainage<br>Channel mid<br>stream  | 10 | Pharmac<br>y                   | 0     | 0         | 0         | 0        | 0     |
| DC1  | Drainage<br>channel up<br>stream   | 6  | Househol<br>ds                 | 0     | 0         | 0.0<br>25 | 0        | 0     |
| GW1  | Grey water                         | 10 | Househol<br>ds                 | 0.017 | 0         | 0         | 0.4<br>9 | 0     |
| GW2  | Grey water                         | 9  | Solid<br>Waste<br>Dump<br>Site | 0     | 0.01<br>8 | 0.0<br>72 | 0        | 0.088 |
| PS1  | Protected<br>spring                | 24 | Solid<br>Waste<br>Dump<br>Site | 0.031 | 0         | 0.2<br>5  | 0        | 0     |
| PS2  | Protected<br>spring                | 10 | Clinic                         | 0     | 0         | 0         | 0        | 0     |

|      |                          |    |                |   |   |           |          |   |
|------|--------------------------|----|----------------|---|---|-----------|----------|---|
| WS1  | Solid Waste<br>dump site | 2  | Househol<br>ds | 0 | 0 | 0.5<br>7  | 0.1<br>9 | 0 |
| WS2  | Solid Waste<br>dump site | 10 | Clinic         | 0 | 0 | 0         | 0        | 0 |
| USW3 | Unprotected<br>Spring    | 2  | Househol<br>ds | 0 | 0 | 0.0<br>96 | 0.1<br>8 | 0 |
| USW1 | Unprotected<br>Spring    | 19 | Saloon         | 0 | 0 | 0         | 0        | 0 |
| USW2 | Unprotected<br>Spring    | 3  | Househol<br>ds | 0 | 0 | 0         | 0        | 0 |

## Appendix V

**Table A.4 EPA Maximum Limit and EMEA RQ Tables**

Table 5  
Refined PEC according to Phase II guidelines and determined PEC/PNEC ratios

| Compound         | PEC EMEA<br>(µg/L) | PEC Conv.<br>(µg/L) | $K_d$<br>(L/kg) | Refined PECads |         | Biodeg.    |            | EMEA               |                    | Conv               |                    |
|------------------|--------------------|---------------------|-----------------|----------------|---------|------------|------------|--------------------|--------------------|--------------------|--------------------|
|                  |                    |                     |                 | EMEA           | Conv.   | Max<br>(%) | Min<br>(%) | Refined<br>PEC min | Refined<br>PEC max | Refined<br>PEC min | Refined<br>PEC max |
| Cefuroxime       | 45                 | 0.029               |                 | 45             | 0.029   | 28         | 0          | 32                 | 45                 | 0.021              | 0.029              |
| Ciprofloxacin    | 7.5                | 0.27                | 417             | 7              | 0.25    | 0          | 0          | 7.0                | 7.0                | 0.25               | 0.25               |
| Cyclophosphamide | 2.5                | 0.00026             |                 | 3              | 0.00026 | 0          | 0          | 2.5                | 2.5                | 0.00026            | 0.00026            |
| Diclofenac       | 0.75               | 0.48                | 165             | 1              | 0.46    | 93         | 22         | 0.051              | 0.57               | 0.032              | 0.36               |
| Ethinylestradiol | 0.000175           | 0.00057             | 691             | 0              | 0.00051 | 20         | 0          | 0.00013            | 0.00016            | 0.00041            | 0.00051            |
| Ibuprofen        | 12                 | 8.0                 | 453             | 11             | 7.4     | 90         | 10         | 1.1                | 10                 | 0.74               | 6.7                |
| Metoprolol       | 1                  | 1.7                 | 37              | 1              | 1.7     | 10         | 0          | 0.89               | 0.99               | 1.5                | 1.7                |
| Paracetamol      | 15                 | 42                  | 36              | 15             | 42      | 99         | 57         | 0.15               | 6.4                | 0.42               | 18                 |
| Sulfamethoxazole | 12                 | 0.067               | 38              | 12             | 0.066   | 4          | 0          | 11                 | 12                 | 0.063              | 0.066              |
| Tetracycline     | 5                  | 0.31                | 8400            | 2              | 0.13    | 62         | 0          | 0.78               | 2.1                | 0.049              | 0.13               |
| Trimethoprim     | 2.4                | 0.16                | 76              | 2              | 0.16    | 4          | 0          | 2.27               | 2.37               | 0.15               | 0.16               |

PEC<sub>Adc</sub>: Refinement made based upon partition coefficient ( $K_d$ ) and assuming a suspended solid concentration of 17 mg/L (based on Vogelsang et al., 2006).

Table A.5

**Comparison of Pharmaceutical DWELs with Maximum  
Drinking Water Concentrations Data (Obtained from Snyder. 2008a)**

| Drug                        | Class                          | ADI<br>(µg/kg-d) | DWEL<br>(µg/L) | Maximum<br>drinking<br>water conc.<br>(µg/L)* | Minimum<br>margin of<br>safety |
|-----------------------------|--------------------------------|------------------|----------------|-----------------------------------------------|--------------------------------|
| Atenolol                    | Beta-blocker                   | 2.0†             | 70             | 0.018                                         | 3,900                          |
| Carbamazepine               | Anticonvulsant                 | 0.34†            | 12             | 0.018                                         | 670                            |
| Diazepam                    | Benzodiazepine<br>tranquilizer | 1.0‡             | 35             | 0.00033                                       | 110,000                        |
| Fluoxetine                  | SSRI<br>antidepressant         | 0.97‡            | 34             | 0.00082                                       | 41,000                         |
| Norfluoxetine               | Metabolite                     | 0.97‡            | 34             | 0.00077**                                     | 44,000                         |
| Gemfibrozil                 | Antilipidemic                  | 1.3§             | 45             | 0.0021                                        | 21,000                         |
| Meprobamate                 | Antianxiety agent              | 7.5‡             | 260            | 0.042                                         | 6,190                          |
| Phenytoin                   | Anticonvulsant                 | 0.19§            | 6.8            | 0.019                                         | 360                            |
| Risperidone                 | Antipsychotic                  | 0.014†           | 0.49           | 0.0029**                                      | 170                            |
| Sulfamethoxazole            | Anti-infective                 | 510‡             | 18,000         | 0.0030                                        | 6,000,000                      |
| Triclosan                   | Antibacterial                  | 75‡              | 2,600          | 0.0012                                        | 2,200,000                      |
| Atorvastatin                | Antilipidemic                  | 0.54†            | 19             | <0.00025                                      | >76,000                        |
| o-hydroxy<br>atorvastatin   | Metabolite                     | 0.54†            | 19             | <0.00050                                      | >38,000                        |
| p-hydroxy<br>atorvastatin   | Metabolite                     | 0.54†            | 19             | <0.00050                                      | >38,000                        |
| Diclofenac                  | NSAID                          | 67‡              | 2,300          | <0.00025                                      | >9,200,000                     |
| Enalapril                   | ACE inhibitor                  | 0.23‡            | 8.1            | <0.00025                                      | >32,000                        |
| Naproxen                    | NSAID                          | 570‡             | 20,000         | <0.00050                                      | >40,000,000                    |
| Simvastatin                 | Antilipidemic                  | 0.54†            | 19             | <0.00025                                      | >76,000                        |
| Simvastatin<br>hydroxy acid | Metabolite                     | 0.54†            | 19             | <0.00025                                      | >76,000                        |
| Trimethoprim                | Antibacterial                  | 190‡             | 6,700          | <0.00025                                      | >27,000,000                    |

\*Single highest discrete sample concentration, from finished drinking water unless otherwise noted.

†Derived from a cancer endpoint using the Maximum Tolerated Dose (MTD) method.

‡Derived from a non cancer endpoint.

§Derived from a cancer endpoint using the tumor data and the one-hit model.

\*\*Concentration from distribution drinking water.

## Appendix VI

**Table A.6 ANOVA**

### SUMMARY

| Groups       | Count | Sum     | Average   | Variance  |
|--------------|-------|---------|-----------|-----------|
|              |       | 0.17000 | 0.0113333 | 0.0003103 |
| PARACETAMOL  | 15    | 000     | 3         | 8         |
|              |       | 0.09800 | 0.0065333 | 0.0002151 |
| DICLOFENAC   | 15    | 000     | 3         | 2         |
|              |       | 1.01300 | 0.0675333 | 0.0238581 |
| IBUPROFEN    | 15    | 000     | 3         | 2         |
|              |       | 1.22300 | 0.0815333 | 0.0219852 |
| DICHLOVOS    | 15    | 000     | 3         | 7         |
|              |       | 0.32800 | 0.0218666 | 0.0041551 |
| CYPERMETHRIN | 15    | 000     | 7         | 2         |

### ANOVA

| Source of |               |         |    |         |         |         |         |
|-----------|---------------|---------|----|---------|---------|---------|---------|
|           | Variation     | SS      | df | MS      | F       | P-value | F crit  |
| SS        | Between       | 0.07092 |    | 0.01773 | 1.75484 | 0.14778 | 2.50265 |
| B         | Groups        | 941     | 4  | 235     | 390     | 395     | 646     |
| SS        |               | 0.70733 |    | 0.01010 |         |         |         |
| W         | Within Groups | 627     | 70 | 480     |         |         |         |
| SS        |               | 0.77826 |    |         |         |         |         |
| T         | Total         | 568     | 74 |         |         |         |         |