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"COMPRENSSIVE ASSESSMENT OF INDUSTRIAL WASTEWATER TREATMENT SYSTEMS AT SELECTED INDUSTRIES IN RWANDA"

A PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of

A MASTER OF SCIENCE DEGREE IN WATER RESOURCES AND ENVIRONMENTAL MANAGEMENT

Submitted by

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APRIL 2022

BONAFIDE CERTIFICATE

Certified that this thesis titled “comprehensive assessment of industrial wastewater treatment systems at selected industries in Rwanda.” is the Bonafide work of Mrs. Rachael BUSINGE, who carried out the research under my supervision; certified further, that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other scholar.

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Declaration

I declare that this Dissertation contains my own work except where specifically acknowledged

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CERTIFICATION

This research thesis has been submitted for examination with my approval as university supervisor.

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ABSTRACT

Developing countries are characterized by a fast growing in industrialization sector. This push them to heavily rely on water need because one the first industrial requirement is water. A worrisome problem, is the production of unplanned wastewater that is discarded in the environment without treatment or inadequately treated. This study aimed at comprehensive assessment on industrial wastewater treatment systems at Kigali special economic zone (KSEZ) and three more selected industries in Kigali and one secondary city.

To achieve this assignment, the study targeted the comparison of treated and untreated wastewater effluents from those industries with national and international tolerance limits of industrial wastewater parameters that are allowed to be discarded off in the environment. Wastewater samples were collected at points before treatment, near the treatment sites after treatment and far from the treatment sites in the months of December, February and June,2020 for three industries. Questionnaires were used to assess the management of treatment systems during operation. Microsoft excel and a statistical package of social sciences (SPSS) were used in data analysis. Two of the four selected industries was found that it has no treatment plant and the treatment method employed was very poor. However, wastewater treatment in all of four selected industries was inadequate in removal of the parameters: pH, nutrients (TN, TP), COD, BOD, TSS, O&G, FC, and heavy metals. Industrial effluents that were discharged of in the environment contain some parameters that are not compliant with RSB and international tolerable limits. It was recommended to establish wastewater treatment plants at two industries and improve the management of treatment systems for all the selected industries.

Key words: comprehensive assessment, industrial waste water, treatment systems, tolerance limits and compliance.

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CHAPTER I. INTRODUCTION

1.1 Background

Developing countries like Rwanda are characterized by growing in industrialization and urbanization sectors. One of fearsome outcome from these growing sectors is the increase in wastewater production, a waste stream to the environment that poses serious effects namely: water pollution, air pollution and soil pollution.

The same to air and soil, Water pollution is any chemical, biological, or physical change in water qualities that has a harmful effect on living organism or makes water unsuitable for desire use. Excessive water pollution has been triggered by rapidly growing population and industrialization with the resultant degradation of the environment. Degradation of water quality is the unfavorable alteration of the physical, chemical and biological properties of water that prevents domestic, commercial, industrial, agricultural, recreational and other beneficial uses of water (Mishra, 2012). Industrialization is one of the main pillars of the country's economy. All developed and developing countries rely heavily on industrialization for boosting their economy. However, the growth of industrialization lead to the rise of wastewater production since most of their activities use water as the main component and hence lead to increase of pollution lad on the environment.

The environmental issues due to globalization and rapid industrialization are becoming more and more nuisance for human being (Gunatilake S.K, 2015). Water is one of the main requirement used by all types of industries. Water is used in different industrial processes including; washing, dilution, formation, cooling, cleaning and other several purposes. From the different uses, almost all industries generate wastewater which needs urgent proper wastewater treatment, re use and disposal.

The main concerning contaminants of industrial wastewater are bacteria, parasites and viruses, inorganic and organic pollutants including heavy metals. Discarding of industrial wastewater to the river, lake or wetland without proper treatment can cause the damage of eco-system and human's welfare (Tun , 2015). The communities that utilize water from rivers, lakes and ground water for different purposes like drinking, irrigation, domestic use are facing challenges from water pollution without leaving out the various effects on aquatic life.

The supply of water, sanitation, treatment of wastewater, drainage of water and management of solid wastes is a requirement for different Countries and various regulations have been enacted to support and guide the different activities although the implementation is still a challenge.

In bid of promoting Made in Rwanda incentives and promotion of Made in Rwanda products and promotion of industrial developments, more industries are coming in the Kigali Special Economic Zone and other designated industrial zones in the Secondary Cities. More to those there are other industries that were constructed out of the industrial zones. Those located in the industrial zones are required by regulation to pretreat their wastewater before release to the centralized wastewater treatment system where wastewater should be treated to the required effluent standards. Industries out of the industrial zones are also required to treat their wastewater to the required effluent standards (MINICOM, 2011)

In this research, three industries that are close to water resources by location and the Kigali Special Economic zone have been selected to assess their industrial wastewater management systems in order to come out with findings that can guide the improvement of the entire process of industrial wastewater management and re-use opportunities to ensure environmental sustainability

1.2. Problem statement

Rwanda as well as other developing countries, is characterized by the growth of industrialization sector. In most cases, industrial effluents are discarded to nearby environment including wetlands and water bodies. A fearsome problem is that some of these wastewater effluents are untreated or inadequately treated before being discharged, that result to adverse impacts on environment without leaving behind the human being (Okereke et al, 2016). In addition, there is no centralized public sewerage system in Kigali as well as its secondary cities for treatment of wastewater while the few semi centralized wastewater treatment plants (SCWWPs) do not function appropriately as initially designed (Mourad, 2018).

Improper wastewater management causes negative environmental impacts which include contamination of upper soil surfaces, storm water drainage facilities, surface water, and groundwater which cause consequences like disturbance of ecosystem, death of aquatic life and cause variety of water borne diseases human beings, with high vulnerability to children and pregnant women and old people (Bartram, 2008).

1.3. Research questions

- What is efficiency of industrial wastewater treatment systems in Rwanda?
- What management practices are carried out during the operation of wastewater treatment plants?
- Are there possible areas of improvement that could be suggested for the selected idustries to promote environmental sustainability?

1.4. Objectives of the study

1.4.1. Main objective

The main objective of this research was to assess the performance, operation and management practices of selected industrial wastewater treatment systems in Rwanda and suggest possible improvements for environmental sustainability.

1.4.2. Specific objectives

The following was specific goals of the study:

- To determine the influent wastewater characteristics at selected industries in Rwanda
- To compare the effluent characteristics with national and international discharge standards
- To determine the level of wastewater treatment performance for each selected industry
- To assess the management practices of wastewater treatment plants during operation
- To suggest possible improvements for the wastewater management systems for the selected industries

1.5 Hypothesis

The following hypotheses was made before undertaking the study

i. The effluent discharge from industries in Rwanda may not be complying with environmental regulations
ii. The different industrial wastewater treatment systems may not be efficient to treat wastewater
iii. Effluent from industries that is not treated to the required standards may be discharged to water resources and pose adverse impacts
iv. Possible improvements may be required for proper operation and maintenance of treatment plant
v. Regular monitoring and maintenance of the wastewater treatment systems is essential

1.6. Scope of the study

This study was limited to the:

- ✓ Comprehensive assessment of industrial wastewater treatment systems at four selected industries
- ✓ Assessment and evaluation of the influent and effluent characteristics of raw and treated wastewater through laboratory testing of different physical, chemical and biological parameters.
- ✓ Comparison of laboratory results with national and international standards to know and explain the compliance of the treatment plants.
- ✓ Consultations made to learn more on the regular management of the wastewater treatment system.
- ✓ Suggestions where necessary improvement of the wastewater treatment systems to ensure sustainability and environmental protection.

1.7. Research significance

1.7.1 Researchers

This dissertation will be helpful for researchers as the findings will be a guiding tool for further studies on treatment systems in wastewater treatment systems.

1.7.2 Technical

This study is a tool to help wastewater treatment plant technicians to know and mark points of attention and maintenance, and hence it is helpful in the design of industrial wastewater treatment systems.

It is also the conferment of the compliance of treated wastewater to national and international tolerable limits of industrial wastewater quality to be discharged of in the environment

1.7.3. Authorities in charge of wastewater management

This study will not only be a reference for the design of industrial wastewater treatment systems for other industries in Rwanda, but also an audit baseline.

It is a reference for the government authority in charge of environmental management and water pollution control to ensure the compliance of wastewater treatment systems to environmental regulations in place.

1.7.4 Education

This study is tools to help environmental management students, in their assignments, and knowledge of industrial wastewater treatment systems, and help them to think beyond hence propose, and study future improvements on industrial wastewater management

CHAPITER II. LITERATURE REVIEW

2.0. Introduction

In this chapter, reviews of the literature that guide this research are illustrated. The knowledge and ideas that have been established on this topic are discussed here. The strengths, weaknesses, design of Conceptual framework as well as the gaps on previous studies are discussed in this chapter. We will focus on the details about knowledge and practice regarding assessment of pharmaceutical waste at selected hospitals and homes in Rwanda. Both theoretical and empirical literatures will be presented

2.1 Definitions of the basic terms

2.1.1 Comprehensive assessment

From dictionary, comprehensive means including or dealing with all or nearly all elements or aspects of something. To assess means to evaluate or estimate the nature, ability or quality of something, then assessment is the action of assessing something or someone. Therefore, a comprehensive assessment is the action of evaluating or estimating the nature, working behaviors, quality, ability, uniqueness, and what is missing for something or someone.

2.1.2 Industrial wastewater

Wastewater that results from industrial processes and manufacturing. It may either be disposed of separately or become part of the sanitary or combined wastewater.

2.1.2 Removal efficiency

Removal means the action of taking away or abolishing something unwanted. Efficiency is the quality or the state of being efficient. In science, efficiency is often measured in percentages. Hence the removal efficiency means the state or at what quality something unwanted have been completely abolished.

2.1.3 wastewater treatment system

A waste water treatment system is a public good sanitation system that treats water to be discharged into environment and hence turn back to water cycle (Water aid, 2019). A wastewater treatment system removes harmful constituents into waste water by physical, chemical and biological techniques so that treated wastewater can be re-used or discharged into environment without harming it and the life of population

2.1.4 Sewage treatment option

Sewage treatment options can be divided into three broad categories:

1. **Conventional /aerobic treatment** including conventional and high-rate trickling filters, aeration lagoons, activated sludge, extended aeration (including oxidation ditches) and some others.
2. **Anaerobic systems**: septic tanks, anaerobic waste stabilization ponds, Imhoff tanks, baffled reactors, upward flow anaerobic filters, upward flow anaerobic sludge blanket reactors.
3. **Extensive' systems**: facultative and maturation ponds and constructed wetlands (reed beds), which rely on natural, mainly aerobic, processes.

2.1.5. Centralized and decentralized systems

A decentralized wastewater treatment system is defined as an approach to sewage treatment in not centralized way, i.e. the fact that raw sewage is treated near the source (Giovanni et al, 2012)

Centralized systems are Large-scale systems that gather wastewater from many users for treatment at one or a number of sites (Water aid, 2019; Giovanni et al, 2012)

2.2. Characteristics of industrial wastewater

The functioning of industries require some components, including raw materials, machines and chemicals according to the purpose and functions of individual industries. However, water is the first essential component that is required in all industries (Tun , 2015). As a result, a sewage effluent is generated with 99% water and 0.01% waste.

Table 1: Substances present in industrial effluents (Alturkmani, 2014)

Substances	**Present in Wastewaters from:**
Acetic acid	Acetate rayon, beet root manufacture
Acids	Chem. manufacture, mines, textiles manufacture
Alkalis	Cotton and straw kiering, wool scouring
Ammonia	Gas and coke and chem. manufacture
Arsenic	Sheep dipping
Cadmium	Plating

Chromium	Plating, chrome tanning, alum anodizing
Citric acid	Soft drinks and citrus fruit processing
Copper	Copper plating, copper pickling
Cyanides	Gas manufacture, plating, metal cleaning
Fats, oils, grease	Wool scouring, laundries, textile industry
Fluorides	Scrubbing of flue gases, glass etching
Formaldehyde	Synthetic resins and penicillin manufacture
Free chlorine	Laundries, paper mills, textile bleaching
Hydrocarbons	Petrochemical and rubber factories
Mercaptans	mills Oil refining, pulp
Nickel	Plating
Nitro compounds	Explosives and chemical works
Organic acids	Distilleries and fermentation plants
Phenols	Gas and coke manufacture., chem. plants
Starch	Food processing, textile industries
Sugars	Dairies, breweries, sweet industry
Sulfides	Textile industry, tanneries, gas manufacture.
Sulfites	Pulp processing, viscose film manufacture.
Tannic	acid Tanning, sawmills
Tartaric acid	Dyeing, wine, leather, chem. manufacture
Zinc	Galvanizing zinc plating, rubber process.

2.3 Most economic and efficient wastewater treatment plant and innovations

This sub-chapter includes the literature on the economy of wastewater treatment systems comparison and innovations that can be hybridized with conventional wastewater treatment.

2.3.1 Cleaner production

A general industrial wastewater treatment plant cost prediction is complicated because the treatment objectives are different (SAMCO, 2017) (SAMCO, 2017). However, Gijze introduced a concept of "cleaner production "concept that combines the approaches of pollution prevention and re-use (Gijze, 2001). His idea is to consume less to achieve what he so called dry sanitation and not to combine sewage for pollution prevention, resource recovery and re-use.

2.3.2 Constructed wetlands

A constructed wetland is an efficiently engineered system for treatment of wastewater in a green, sustainable, low cost and robust manner(Carvalho et al., 2017).

It is also a LID Tech or a nature based technique as it is systematically and intelligently designed system which is built on natural parametric design (Slope, Plants, Filtration & Flotation Materials) that allows effective clean-up of wastewater using locally available materials (Jacques N., 2017; Jacques N., 2017; Jacques N., 2017). A nature-based wastewater treatment system is a system for removal of pollutants in influent wastewater into a harmless effluent in a natural way, and this solution brings more benefits on economy for people, culture and environment.

Comparing a constructed wetland to a conventional treatment systems, nature-based systems are more economic, easily operated and maintained in addition to their strong potential for its application in a small community (Yue Zhang, 2012)

Design and construction of a constructed wetland:

Before designing, it is required to know how to classify constructed wetlands and project outline. CWs are classified according to their mode of operation as horizontal flow system (HFS) and vertical flow system (VFS), (Ezeah et al., 2015). Figure 1 and 2 illustrates some of the types of those configurations and project development process (Ezeah et al., 2015), illustrates detailed information on the design of constructed wetlands.

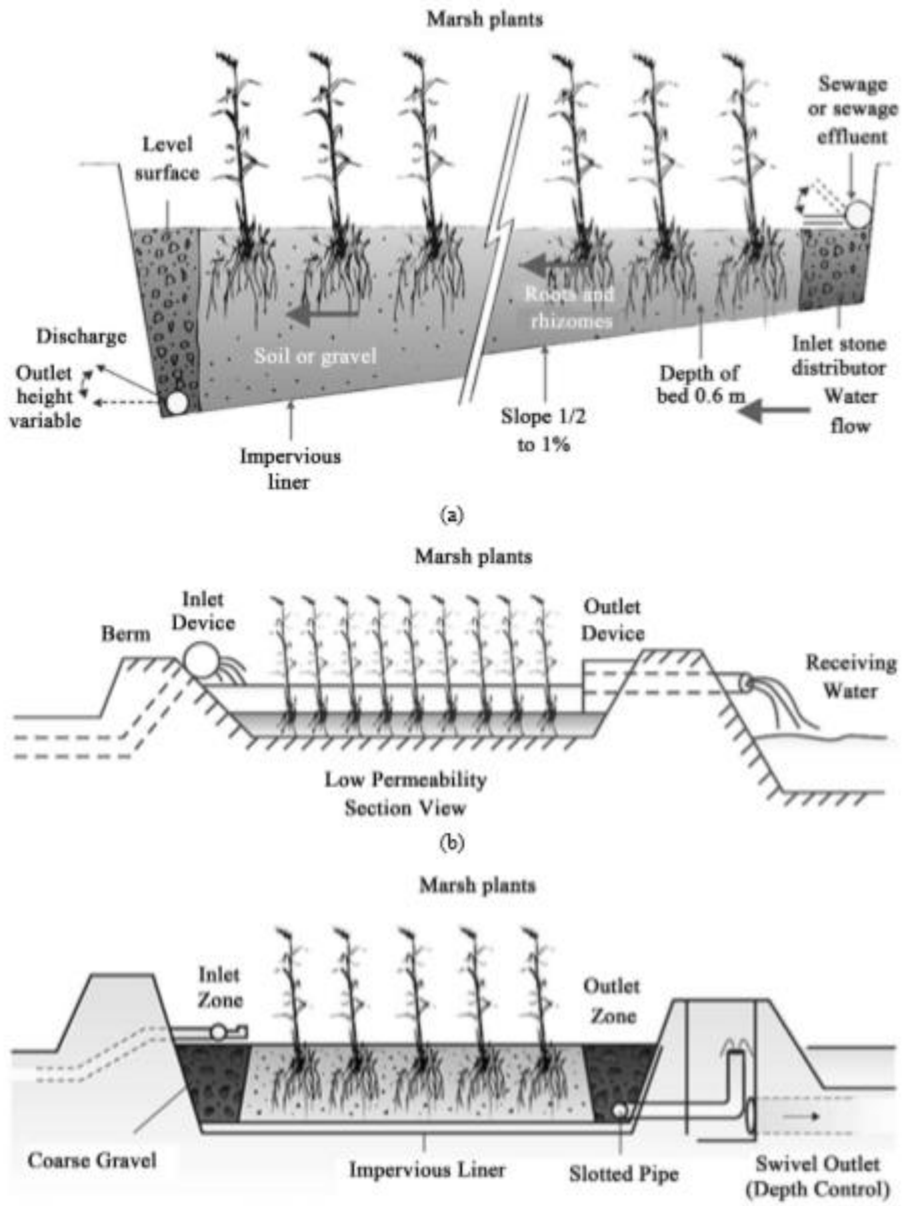


Figure 1: Typical configurations of (a) horizontal-flow wetland; (b) sub-surface flow wetland; (c) surface flow wetland system

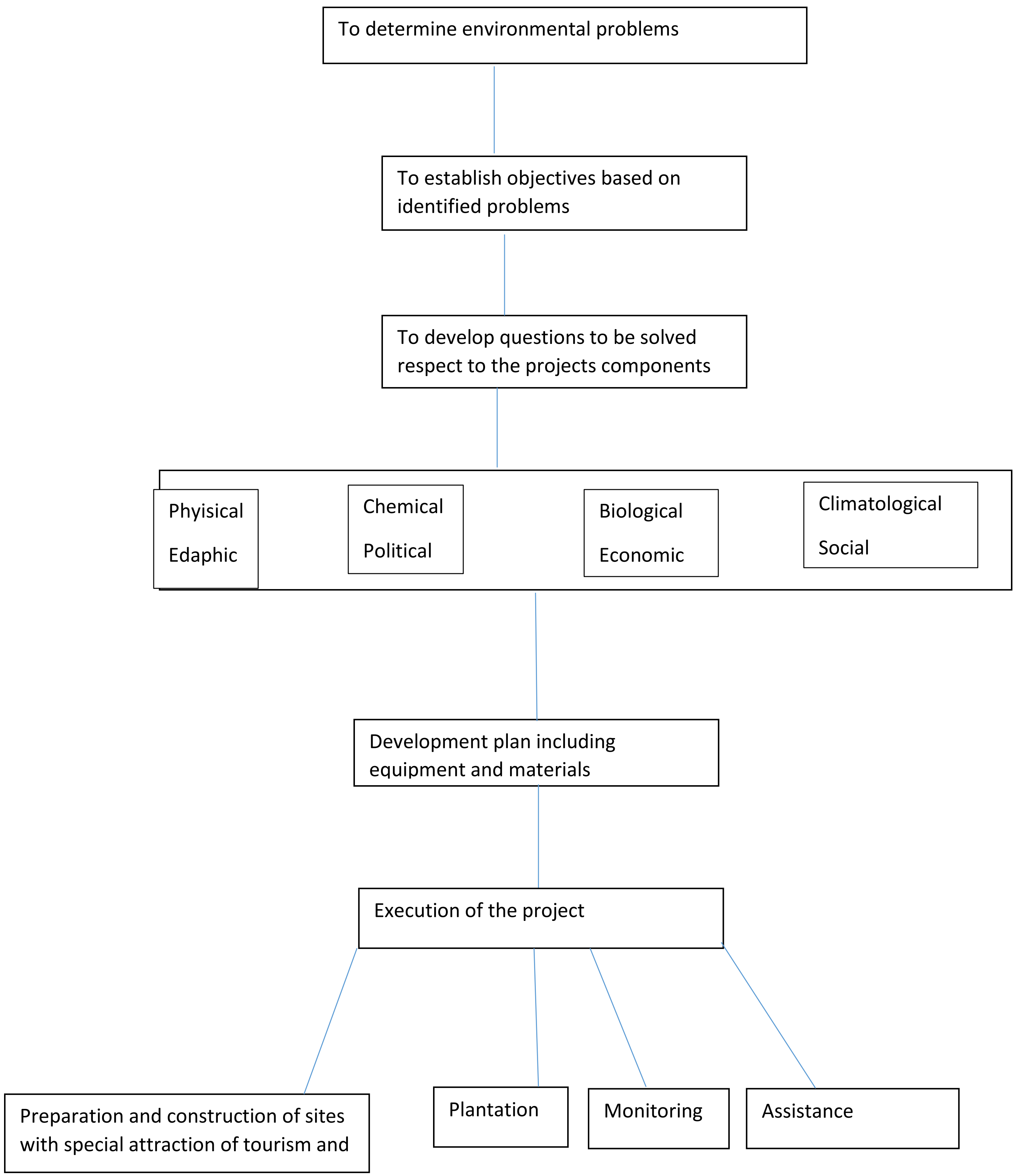


Figure 2: Outline of project development process.

Source: (Ezeah et al., 2015)

2.3.3 Hybrid systems for wastewater treatment

Lopez Zavalla et al presented a bio-energy so called hybrid system for wastewater treatment to enhance power generation by microbial fuel cells (MFC) (LÓPEZ et al, 2014). The hybrid system approach presented intends to enhance the power generation and reduce the costs of construction and operation of MFCs in such a way they might be scaled up to "real-world by generating electricity through electrochemical reactions.

2.4 Treated industrial waste water effluent standards

In Rwanda, government through its authorities and organizations in charge of wastewater management, here mentioned REMA, RURA, WASAC and RSB have together set rules, regulations and standard to consider, regarding the industrial wastewater discharge. RURA was established under the law "Law N° 09/2013 of 01/03/2013" determining its mission, powers, organization and functioning. However this authority, deals with licenses and authorizations, for liquid waste collection and transportation (RURA, 2016). Nonetheless, RSB established standards for the compliance of industrial wastewater treatment in the table 2. According to REMA, in its Environmental Impact Assessment Guidelines for Waste Management in Rwanda, in Article 33: Any waste, especially from hospitals, dispensaries and clinics, industries and any other dangerous waste, shall be collected, treated and changed in a manner that does not degrade the environment in order to prevent, eliminate or reduce their adverse effects on human health, natural resources, flora and fauna and on the nature of the environment (REMA, 2009).

Table 2: RSB and international treated wastewater industrial effluent standards (RSB, 2016)

Parameter	RSB Permissible limits	International limits
pH	5-9	6-9
Temperature increase	°C < 3	
Total suspended solids mg/l	50	50
Total Dissolved Solids mg/l	2000	2000
Oil and grease mg/l	10	10
COD mg/l	250	-
BOD5 mg/l (20°C)	50	50
Ammonia (as N) mg/l	20	2

Faecal Coliforms cfu /100ml	400	2000
Phosphates mg/L	<10	-
Arsenic mg/l	0.01	1
Free chlorine mg /L	<1.0	
Benzine mg/l	0.1	
Cadmium mg/l	0.01	<0.02
Hexavalent Chromium mg/l	0.05	<0.1
Copper mg/l	3	
Cyanide mg/l	0.1	
Iron mg/l	3.5	
Mercury mg/l	0.0002	
Lead mg/l	0.1	<1.0
Nickel mg/l	3	
Phenol mg/l	0.2	
Sulphide mg/l	1.0	
Zinc mg/l	5	
Selenium mg/L	<0.02	
Pesticides mg/L	Not detectable	

2.4.5 Heavy metals MCL standards and removal methods

As illustrated from the table 1, industrial wastewater contains heavy metals that are of a great concern during industrial wastewater treatment. Industrial sewage, which contains heavy metals treatment technique, involves the technologies to reduce toxicity to meet disposal standards (Gunatilake S.K, 2015).

Table 3: The MCL standards for the most hazardous heavy metals (Barakat, 2011; Gunatilake S.K, 2015)

Heavy metal	Toxicities MCL	MCL (mg/L)
Arsenic	Skin manifestations, visceral cancers, vascular disease	0.050
Cadmium	Kidney damage, renal disorder, human carcinogen	0.01
Chromium	Headache, diarrhea, nausea, vomiting, carcinogenic	0.05
Copper	Liver damage, Wilson disease, insomnia	0.25
Nickel	Dermatitis, nausea, chronic asthma, coughing, human carcinogen	0.20
Zinc	Depression, lethargy, neurological signs and increased thirst	0.80
Lead	Damage the fetal brain, diseases of the kidneys, circulatory system, and nervous system	0.006
Mercury	Rheumatoid arthritis, and diseases of the kidneys, circulatory system, and nervous system	0.00003

MCL: maximum contaminant level

2.6 wastewater treatment plant performance indicators

The compliance assessment of a system's performance requires the comprehensive assessment of its efficiency and effectiveness (Quadros S. et al, 2010).

According to Quadros et al (2010), the following performance indicators should be checked while assessing the performance of a wastewater treatment plant:

2.6.1 Treated wastewater quality indicators

Those included indicators to be considered while assessing the effluent wastewater after treatment.

2.6.1.1. Compliance with discharge permit regulation

This indicator defines the compliance requirement for a treated wastewater to be discharged into a receiving body under a permit regulation.

A. Quality tests carried out (discharge permit regulation) [%]

$$\text{WQtest} = \frac{\text{Tests carried out (discharge permit regulation)[No]}}{\text{tests required (discharge permit regulation)[NO]}} * 100$$

B. Compliance of wastewater quality (discharge permit regulation) [%]

$$\text{WQquality} = \sum_{i=1}^{n} \text{ji} * \frac{100}{n}$$

n = total of required parameters analysed

ji= compliance with parameter i (=0 , no compliance; = 1 compliance)

2.6.1.2. Quality of discharged water

This is an indication of quality standards of treated wastewater to be discharged off into the environment.

Compliance of water quality with other standards [%]

$$\text{WQ effluent} = \frac{\text{Tests complying with other standards for discharged water (NO)}}{\text{Tests carried out on discharged water (NO)}} * 100$$

2.6.2 Water reuse key performance indicators

Those include indicators to be considered while assessing the quality of water reuse for different purposes like irrigation

A. Compliance of water quality with reuse consents (%)

$$\mathrm{WQ, reuse} = \frac{\text{Tests complying with water reuse consents (NO)}}{\text{Tests carried out on reclaimed water(NO)}} * 100$$

B. Microbiological quality of reclaimed water at delivery points (%)

$$\mathrm{WQ, reclaimed} = \frac{\text{Average of the10\% higher values recorded at the delivery point with higher microbiological counts (concentration units)}}{\text{Maximum allowable value (concentrationunits)}} * 100$$

This indicates the reclaimed water quality at delivery point.

2.6.3 Treatment Plant efficiency

Those indicators are required to assess the efficiency and the capacity of the plant.

2.3.3.1 Overall efficiency

1. Volumetric efficiency (%)

$$\mathrm{VE} = \frac{\text{treated wastwater (m3)}}{\text{raw wastewater(m3)} + \text{fresh water(m3)}} * 100$$

2. COD mass removal efficiency (%)

$$\mathrm{MREcod} = \frac{[\text{inflow COD mass} - \text{Outflow COD mass (effluent þ by– pass)}](\text{kg})}{\text{inflow COD (kg)}} * 100$$

2.3.3.2. WWTP capacity

This indicator is used to assess the adequacy of the treatment plant.

A. Flow equalization (%)

This is defined as a method used to overcome the operational problems and flowrate variations to improve the performance of downstream processes and to optimize the cost of downstream treatment facilities. It is calculated by:

$$\mathrm{FE} = \frac{\text{volume of equalisation basin (m3)}}{\text{volume required for daily flowrate equalisation(m3)}} * 100$$

CHAPITER 3. MATERIALS AND METHODS

3.0 introduction

This chapter describes the methods and principles that were used during this study. It is consisting of the description of the study area, sample collection and preservation process, study, research materials, and data analysis methods.

3.1 Description of the study area

Three industries and Kigali special economic zone (KSEZ) were selected to assess the individual industrial wastewater characteristics and quality of their effluents. Two industries and KSEZ are located in Kigali city, 2 in Gasabo and one in Nyarugenge districts. The remaining industry is located Musanze District in the Northern province. The codes of selected industries are Kigali special Economic Zone (KSEZ) [industry 1] in addition to four selected industries which are: UTEXTRWA (industry 2), SKOL (industry 3), Horizon SOPYRWA (industry 4).

Rationale of selection

The reason for selection of those industries is that they are of different functions as illustrated in the table 4 thus make a good representative of Industries that use water in their production process in Rwanda. The selected industries are all locate near water resources, which expose these natural resources to pollution in case of poor wastewater management from the industries

Table 4: Selected industries and their functions

industry	Function
1	Multifunctional
2	A textile and garment producing company
3	A beer producing industry
4	Extraction of pale from the raw material of dry pyrethrum flower
5	House-hold cleaning detergents and soap in Rwanda

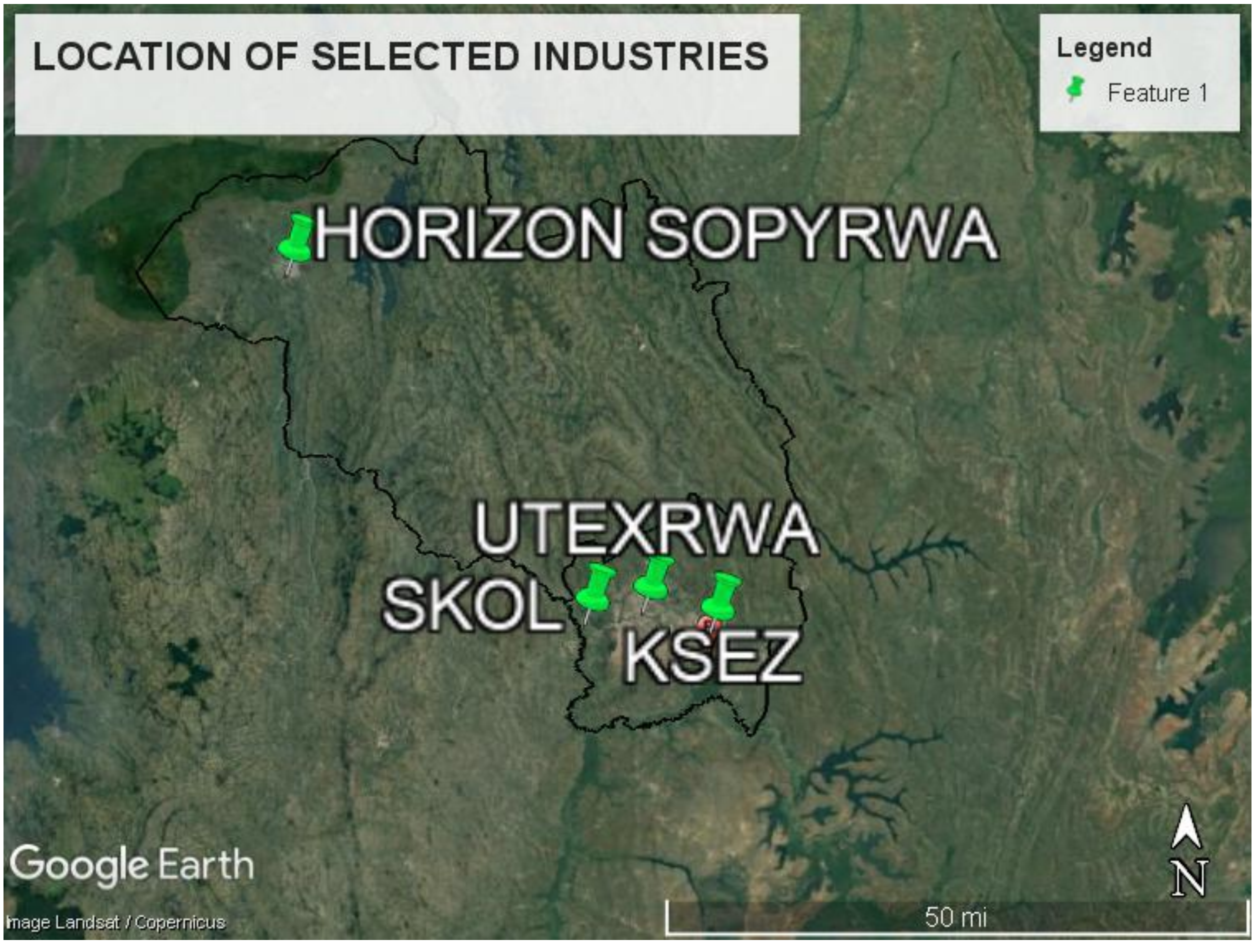


Figure 3: site location and description

3.1.1 Site localization and industrial flowchart characteristics

There sample points were selected for every industry, one point at the inlet to the treatment plant, the second point was outlet of the treatment plant where the treated wastewater is discharged into the environment and the third one was where a treated effluent is discharged into a nearby water body or wetland where sediments was collected for heavy metals analysis as illustrated on the figure 3

1. **Kigali special economic zones (KSEZ)**

The Kigali special economic zones phase 1 is located Munini village, Masoro cell, Ndera sector, Gasabo district on the outskirts Kigali city, just 4 kilometers from the Kigali international airport and 12 kilometers from the city center along the central transport corridor (to dares salaam). It occupies a total area of 159 hectares of which over 131 are for industrial use and 28 are for the green belt. However, this industrial zone combines a large number of industries, there are individual flow charts according to the processing purpose

2. UTEXRWA

Utexrwa is located in Kigali, Gasabo District, in the Rwampara wetland, on the Utexrwa- kinamba road. Rwampara wetland is used mainly for cultivation of vegetables mostly supplied to markets in Kigali.

Selected points for sample collection are:

- Inlet: U1(S 01.92640, E 030.07661),
- Outlet: U2(S 01.92640, E 030.07661),
- At Rwampala wetland: U3(S 01.92564, S 030.07507)

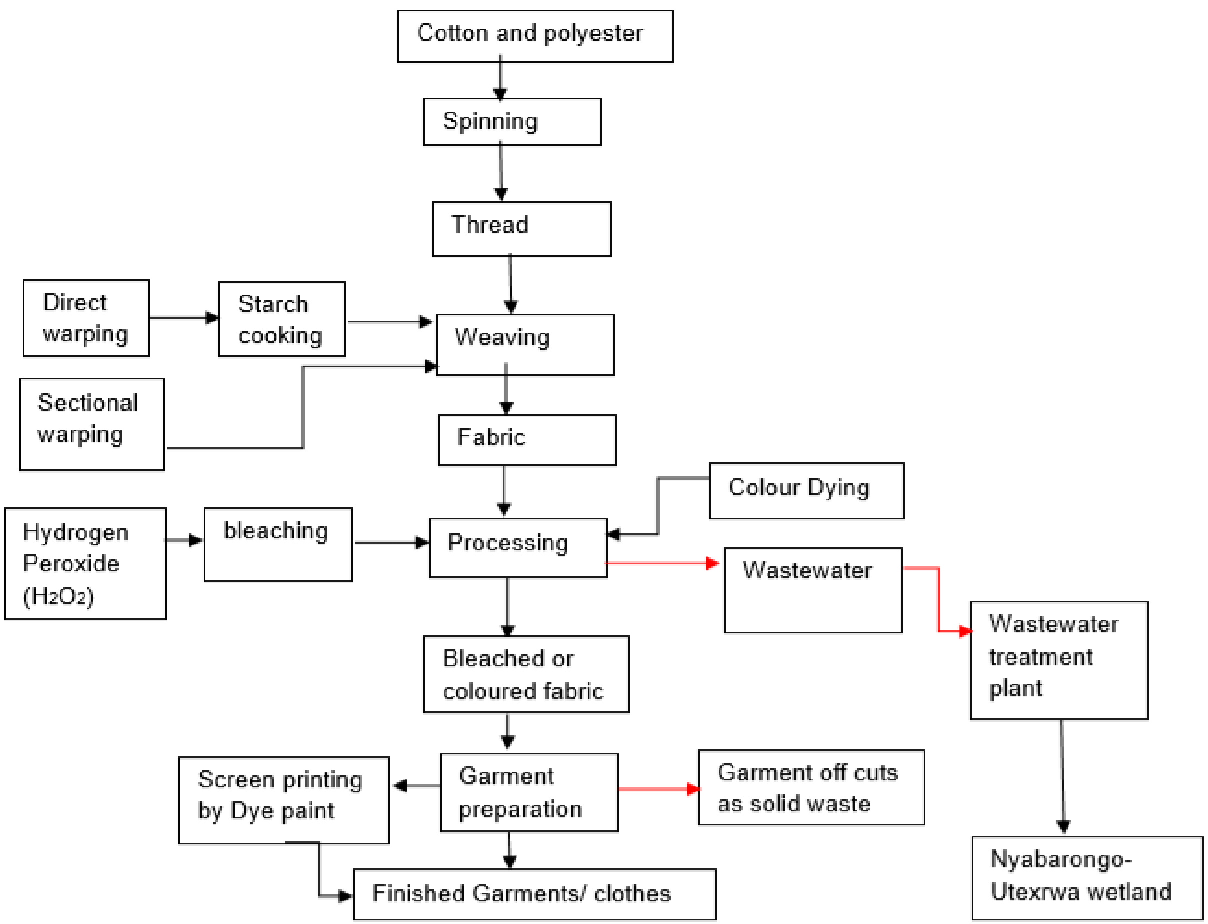


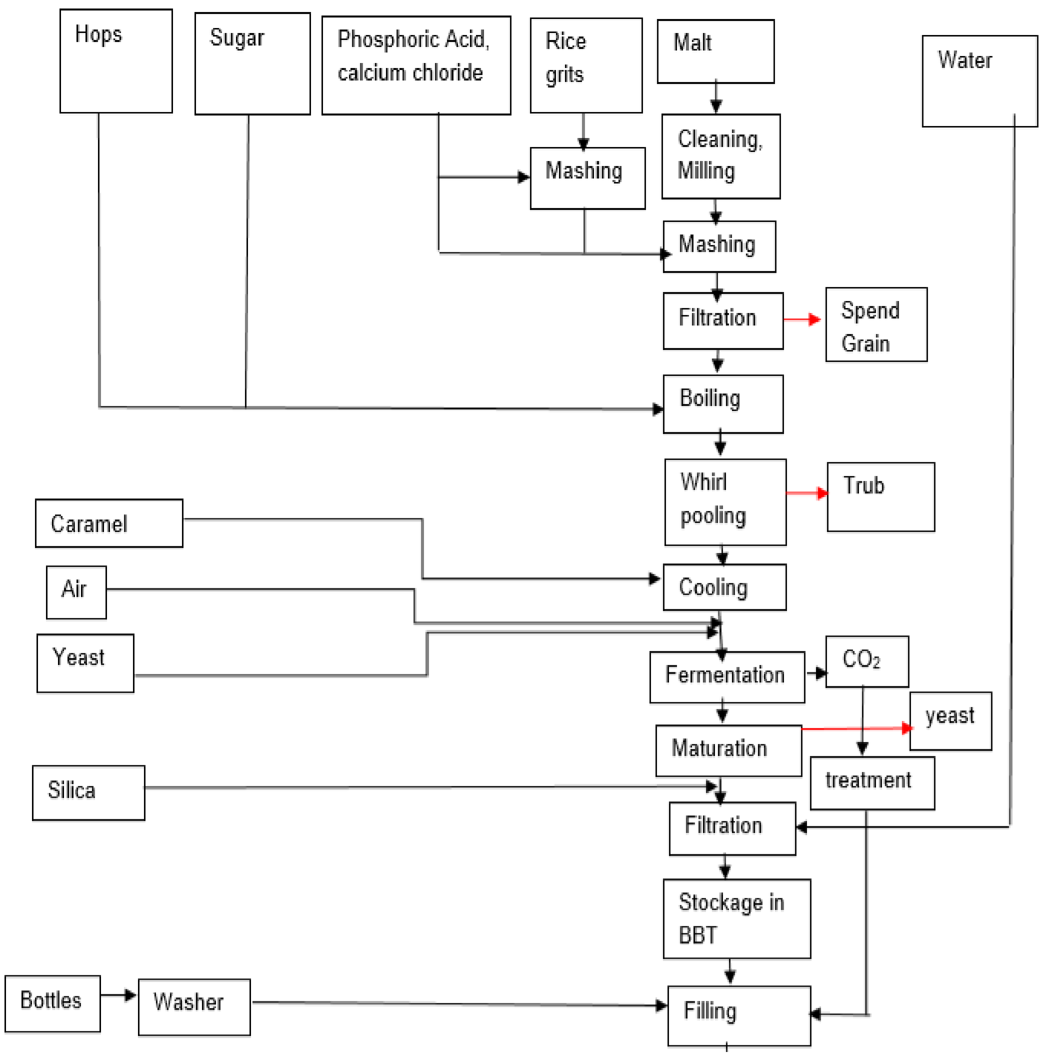
Figure 4: UTEXRWA process flow chart , source: UTEXRWA

3. SKOL

SKOL located in Kigali city, Nyarugenge District, Kanyinya sector, Nzove cell. The key features in its neighbourhood is the Drop water factory, Nzove I and II water treatment plants, Nyabarongo wetland and river.

Selected points:

- Inlet : S1(S 01.94332, E 030.00451)
- Outlet: S2(S 01.94332, E 030.00451)
- At treated wastewater point of discharge in the water body, at Nyabugogo wetland**:** S3(S 01. 94433, E 030.00323)



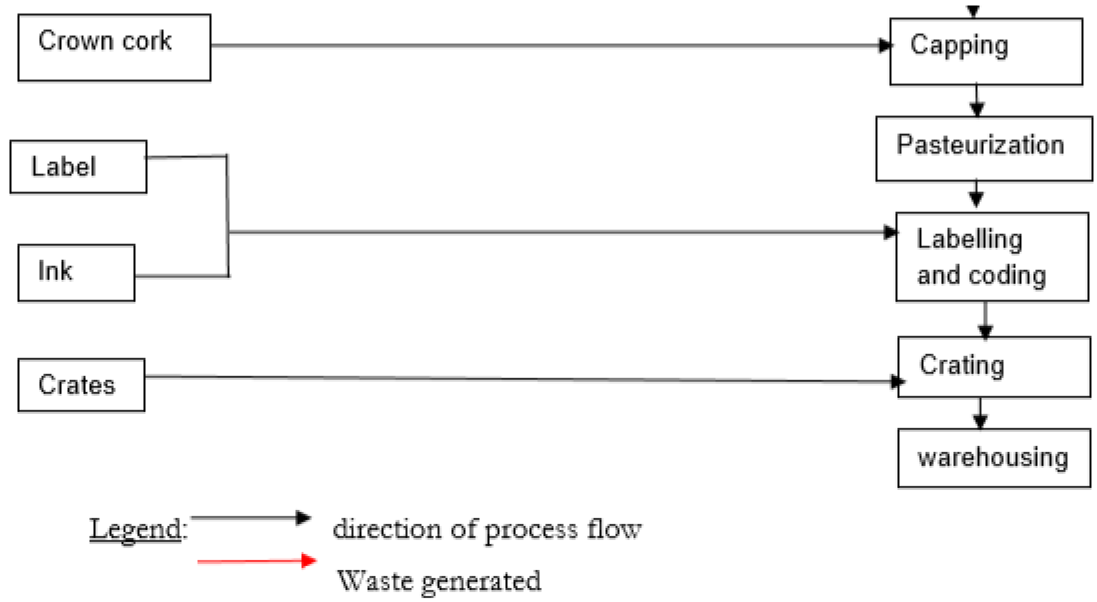


Figure 5: Process Flow chart. Source: Skol Brewery ltd

4. Horizon SOPYRWA

Horizon Sopyrwa ltd is located in Musanze district

Selected points are:

- Inlet: H1(S 01.51221, E 029.63657)
- Outlet:H2 (S 01.51214, E 029.63679)
- Downstream of Kigombe river: H3(S 01.51214, E 029.63679)

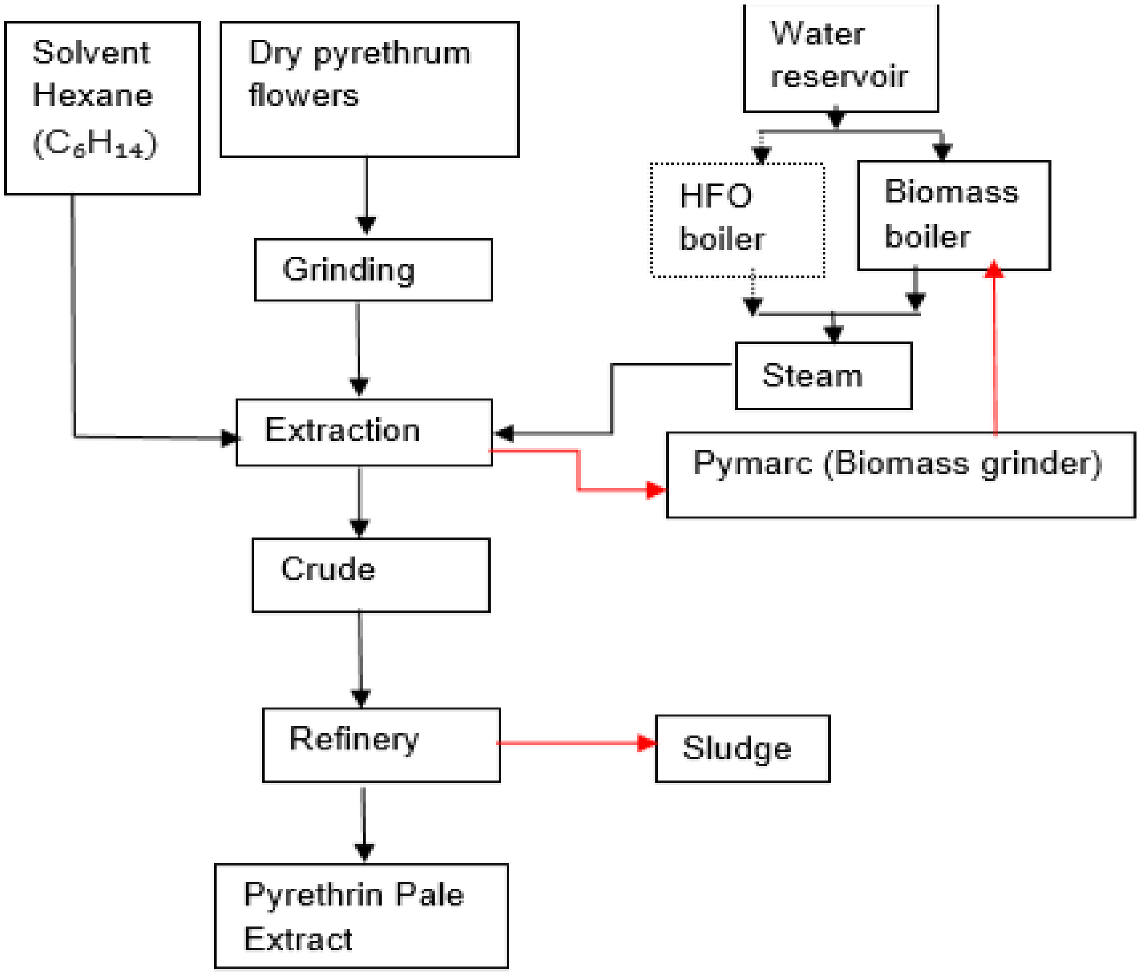


Figure 6 : Process flow chart. Source: Horizon Sopyrwa

3.2 Sample collection and preservation

3.2.1. Collection of samples and wastewater quality parameters

The samples that was used in this study were taken in the year 2020.Three wastewater samples were collected in different 3different months of the year using a systematic method in order to be representative of the wastewater management in the different periods in a manner that is reproducible, defensive and useful, one at inlet to the WWTP, and effluent wastewater sample at outlet of the treatment system and the remaining at discharge point to the water body or a wetland as described in sub-unit 3.1.1.

The samples were collected 3 times for all industries in a period of 3 months (December, February and June), 3 times (before treatment, near and far from the treatment site). This makes a total of 9 samples for every parameter tested

Collection purpose of those samples was to make physic-chemical, microbial and heavy metals analysis.

Wastewater quality parameters to be monitored as according to industrial flowcharts are: pH, Conductivity, TDS, DO, COD, BOD, TSS, Color, nutrients (TN, TP, NH_3, PO_4), Oil & Grease, Heavy metals (Pb, Cd, Cr) and Fecal Coliforms.

3.2.2 Preservation of samples

Collected samples designated for physical-chemical analyses were taken in plastic containers. Before collecting a sample and in order to avoid any contamination, the plastic containers were cleaned and rinsed three times properly using the wastewater to be sampled.

For microbiological analysis, the samples were collected in sterilized bottles and all samples collected were kept in an ice Box (4^oC) to avoid any change in targeted parameters.

The samples designated to heavy metals analysis were taken in bottles containing nitric acid of high purity (65%) to prevent metal precipitation such as hydroxide and stop redox reactions that could occur on metal at alkaline pH.

All the samples were placed in cooler box with ice for transportation to the Laboratory of the School of Science/College of Science and Technology of the University of Rwanda (UR) and stored in fridge at 4^oC.

Figure 7: Cooler box

3.3 Research materials

During this study, primary and secondary data were used. To obtain primary data, materials used during this study are classified into 3 categories, the category one is sample collection and preservation materials, the second is in situ or onsite wastewater quality parameters measurement materials and the third one are offsite measuring instruments i.e. at CST Chemistry and Biology laboratories and WASAC central laboratory. The table: 5 illustrate those categories, parameters measured and materials used.

Secondary data include on-desk reviews about wastewater management in Rwanda, regulations and institutions in charge of wastewater management, treated wastewater industrial effluent standard and developed key performance indicators.

Table 5: Materials

Sn	category	Measured parameters	Materials
1	Sample collection		plastic containers, ice Box (4^{o}C) sterilized bottles,
2	In-situ	pH, Conductivity, Salinity, TDS, Dissolved Oxygen (DO)	Sensitive electrodes sensors that comprised of; HQ40d Portable Multi Meter pH, Conductivity , Salinity, TDS, Dissolved Oxygen (DO), ORP for Water and Wastewater measurement
3	Offsite/in laboratory	Heavy metals Physio – chemical BOD&COD	Atomic Absorption Spectrometer (AAS UV Spectrophotometer 20oC incubator (Potassium Dichromate)

3.4 Primary data collection

3.4.1. In situ data collection

HQ40d Portable Multi Meter is a portable calibrated sensitive electrode that was used to measure in situ wastewater quality parameters that are mentioned in the table 5 . This multi meter is used by connecting a probe. A probe is immersed into the wastewater so that a multi meter records a parameter instructed and Id- coded by the user. the recorded data are downloaded on a PC thereafter by using a USB connection.

3.5 Results analysis methods

The results obtained were analyzed using Microsoft excel, and Statistical Package for Social Sciences (SPSS) program from international business machine (IBM) Armonk, New York, USA. This software was used to analyze the management practices of plants during operations.

CHAPTER 4. STUDY RESULTS, ANALYSIS AND DISCUSSION

4.0 Introduction

This chapter presents the results obtained, their analysis and discussions on the study that was aimed at assessing in details the industrial wastewater treatment systems at selected industries in Rwanda. The results presented are influent wastewater characteristics generated from industries to the treatment plants, treated effluent wastewater characteristics and their comparison with national and international standards, and the presence of wastewater treatment plants as well as their management practices during operation. Wastewater parameters that are being discussed are wastewater physic-chemical characteristics of industrial wastewater that was originated from four industries namely: KSEZ, UTEXRWA, SKOL and Horizon SOPYRWA that are coded industry 1, industry 2, industry 3 and industry 4 respectively.

With reference to the industrial wastewater substances presented (Alturkmani, 2014) and researcher's assessment depending on the nature of industries, the industrial wastewater parameters that were monitored are: pH, Conductivity, DO, TDS, COD, BOD, TSS, Color , nutrients (TN, TP, NH_4-N, PO_4-P), Oil & Grease, and Heavy metals (Pb, Cd, Cr). However, the parameters was chosen according to the type of industry and its waste stream constituents

4.1 Presentation of study results

4.1.1 Influent wastewater characteristics at selected industries in Rwanda

Measuring the raw wastewater characteristics from the industries to their treatment plants help us to know if the extent of the treatment required and will help us to know treatment performance of the plants.

Nature also have a great intervention in wastewater treatment. The efficient of nature treatment also is measured by comparing the results of wastewater quality monitoring near the generation site and far from that site. The results obtained during the monitoring before being treated are presented in the table 6.

Table 6: Influent wastewater characteristics from selected industries

		Industry1			Industry 2			Industry 3			Industry 4			PL(RSB-2017 &ES-RQ-2008
Wastewater quality parameter		Dec	Feb	Jun	Dec	Feb	Jun	Dec	Feb	Jun	Dec	Feb	Jun	
pH		8	9.2	11.3	4.41	4.82	12.31	7.49	7.82	7.17	8.25	8.43	7.48	5-9, 6-9
Ec		4820	2800	2100	1052	1424	2900	2220	1870	1864	971	1000	911	-, -
TDS (mg/l)		1500	2100	2580	345	560	1500	971	941	1302	462	485	442	2000 2000
DO		4.31	3.62	2.41	4.14	3.64	0.55	3.69	1.67	0.29	4.28	5.37	3.84	- 1
Nutients:	NH_4-N	22.7	21.5	18.6				2.19	3.02	1.21				20, 2
(mg/l)	TN	62	53.7	45.2				15.4	10.9	7.07				-, 5
	PO_4	18	22.1	26.2				3.25	3.47	3.71				10

	TP	70	75.3	68.7				3.51	5.17	3.24				- ,<2
COD		400	815	1350	489	1049	1664	702	1184	1514	65	34	34	<250, -
BOD		62	412	681	99	576	738	655	792	748	32.4	12.4	16.6	<50, 50
TSS		180	215	287	40	111	123	195	119	279	1	3	1	50, 50
Oil&grease (mg/l)		38	137	14	48	178	43	42	48	18	11.8	46	ND	10,10
FC(cfu/100 ml)		20100	26500	27340	23×10^{1}	55x10^{1}	21x10^{2}	61X10^{1}	32X10^{1}	81X10^{2}	14X10^{1}	24X10^{1}	66X10^{2}	400,200
Chromium(Cr) (mg/l)		0.06	0.061	0.76	0.054	0.084	0.072	<0.01	<0.01	<0.01	<0.001	<0.01	<0.01	0.05, 0.1
Cadmium(Cd)		<0.2	<0.02	<0.02	ND	<0.01	<0.01	0.011	<0.01	0.012	0.002	0.026	0.021	0.01
Lead (Ld)		0.45	0.62	0.32	0.05	0.06	0.02	0.49	0.05	0.08	0.05	0.05	0.045	0.01, 0.01
µg/l Pesticides											<0.01	<0.01	<0.01	ND

4.1.2 Effluent wastewater characteristics

Effluent is defined as wastewater, treated or untreated, that flows out of a treatment plant, sewer, or industrial outfall.

Here, the presented results are effluent characteristics from the treatment plants (industry 1, 2, and 3) , untreated or treated by unconstructed nature from industries 4 and 5. Two points near and far from the treatment sites was chosen, and the results of wastewater quality parameters was compared by national and international standards. The laboratory results obtained for the samples collected near and far from the treatment sites are presented in table 8 and 9.

Table 7: Industrial effluent wastewater characteristics near the treatment site

		Industry1			Industry 2			Industry 3			Industry 4 (no WWTP), Kigombe upstream point was selected.		
Wastewater quality parameter		Dec	Feb	Jun	Dec	Feb	Jun	Dec	Feb	Jun	Dec	Feb	Jun
PH		7.5	6.8	8.1		9.82	9.41	8.17	7.9	8.9	7.54	7.53	6.93
Ec (µs/cm)		2800	3450	4210		2112	1946	2590	1602	2730	940	903	812
TDS (mg/l)		1203	1380	1430		980	886	1134	773	895	490	486	449
DO(mg/l)		5.1	4.2	2.8		6.88	1.99	5.45	3.51	3.39	6.28	5.86	6.32
Nutrients(mg/l)	NH4-N	25.4	19.8	18.2				2.47	2.15	1.18			

	TN	61.917	53.5	44.9				1.4	1.4	1.15			
	PO4	8.9	9.7	7.4				2.01	2.57	3.21			
	TP	55.4	45.1	48.6				1.96	2.36	2.88			
COD(mg/l)		399	816	1355		314	449	65	194	379	29	14	4
BOD(mg/l)		5.4	45.5	38.6		43.5	97.8	3	118.2	64.8	2.7	2.7	1.79
TSS(mg/l)		123	195	220		31	32	26	13	173	0	0	0
Oil&grease		35	71	15		150	35.5	ND	26	14	0	0	0
FC(cfu/100ml)		2419.6	26731.5	28513		$47x10^{1}$	$1x10^{3}$	$47x10^{1}$	11	$31x10^{1}$	$7x10^{1}$	$5x10^{2}$	$12x10^{3}$
Chromium(Cr) (mg/l)		<0.05	<0.05	<0.05		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadimium(Cd) (mg/l)		<0.003	<0.004	<0.003		<0.01	<0.01	0.005	<0.01	0.004	0.004	0.03	<0.01
Lead (Ld) (mg/l)		<0.0178	<0.02	<0.011		0.02	0.01						
Pesticides ($\mu g/l$											<0.01	<0.01	<0.01

Table 8: Effluent wastewater characteristics far from the treatment site

		Industry 1			Industry 2			Industry 3			Industry 4(No WWTP, Kigombe downstream point was selected			Permissible limit
Wastewater quality parameter		Dec	Feb	Jun	Dec	Feb	Jun	Dec	Feb	Jun	Dec	Feb	Jun	
PH		7.5	7	8.2	8.52	9.48	8.06	9.61	8.5	8.08	7.85	7.97	7.45	5-9,6-9
Ec ($\mu s/cm$)		3230	3410	3950	752	702	563	2550	1736	2210	919	910	823	-,-
TDS (mg/l)		1206	2400	1390	320	332	256	1110	789	1064	495	496	452	2000, 2000
DO(mg/l)		4.2	3.5	2.1	3.77	5.58	6.54	5.74	5.66	5.82	7.08	6.82	7.04	-,1
Nutrients(mg /l)	NH4 -N	16.2	12.1	15.7				0	0.08	0.01				20,2
	TN	56.816	51.925	41.702				0.7	3.7	7.58				-,5

	PO4-P	8.1	9.3	6.8				2.84	2.26	3.12				10
	TP	54.9	42.1	41.9				2.87	2.39	3.38				-,2
COD(mg/l)		529	830	1367	109	74	59	145	254	344.9	32	14	4	250,-
BOD(mg/l)		26.4	45.6	40.7	46.2	36.9	17.7	84.9	159	168.9	7.8	8.8	1.64	50,50
TSS(mg/l)		93	120	150	4	19	23	129	81	132	0	0	0	50,50
Oil&grease		9	8	5	0	8	22.8	0	0	8	0	0	0	10,10
FC(cfu/100ml)		>2419.6	>2673.5	>2851	820	4300	8200	7000	200	540	71	700	16000	400,200
Chromium(Cr) (mg/l)		<0.05	<0.05	<0.05	<0.01	<0.01	<0.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05, 0.1
Cadimium(Cd) (mg/l)		<0.003	<0.002	<0.003	0.008	<0.01	<0.01	0.001	<0.01	0.001	0.008	<0.01	0.002	0.01
Lead (Ld) (mg/l)		<0.01	<0.01	<0.01	<0.01	0.03	0.013	0.04	<0.01	<0.01	<0.01	0.07	0.06	0.01,1
Pesticides µg/l											<0.010	<0.010	<0.010	0

4.1.3 Management practices of wastewater management systems during operation

The results of treatment systems management during operation was obtained by questionnaire survey that was carried out at the industrial organizations. 15 participants were randomly selected and responded questions under assistance and invigilated by the researcher.

The sociodemographic characteristics of the study participants illustrates that 53.33% are females and 46.67% are males. Those include participants of different posts, experience and level of education as illustrated in the figure 7

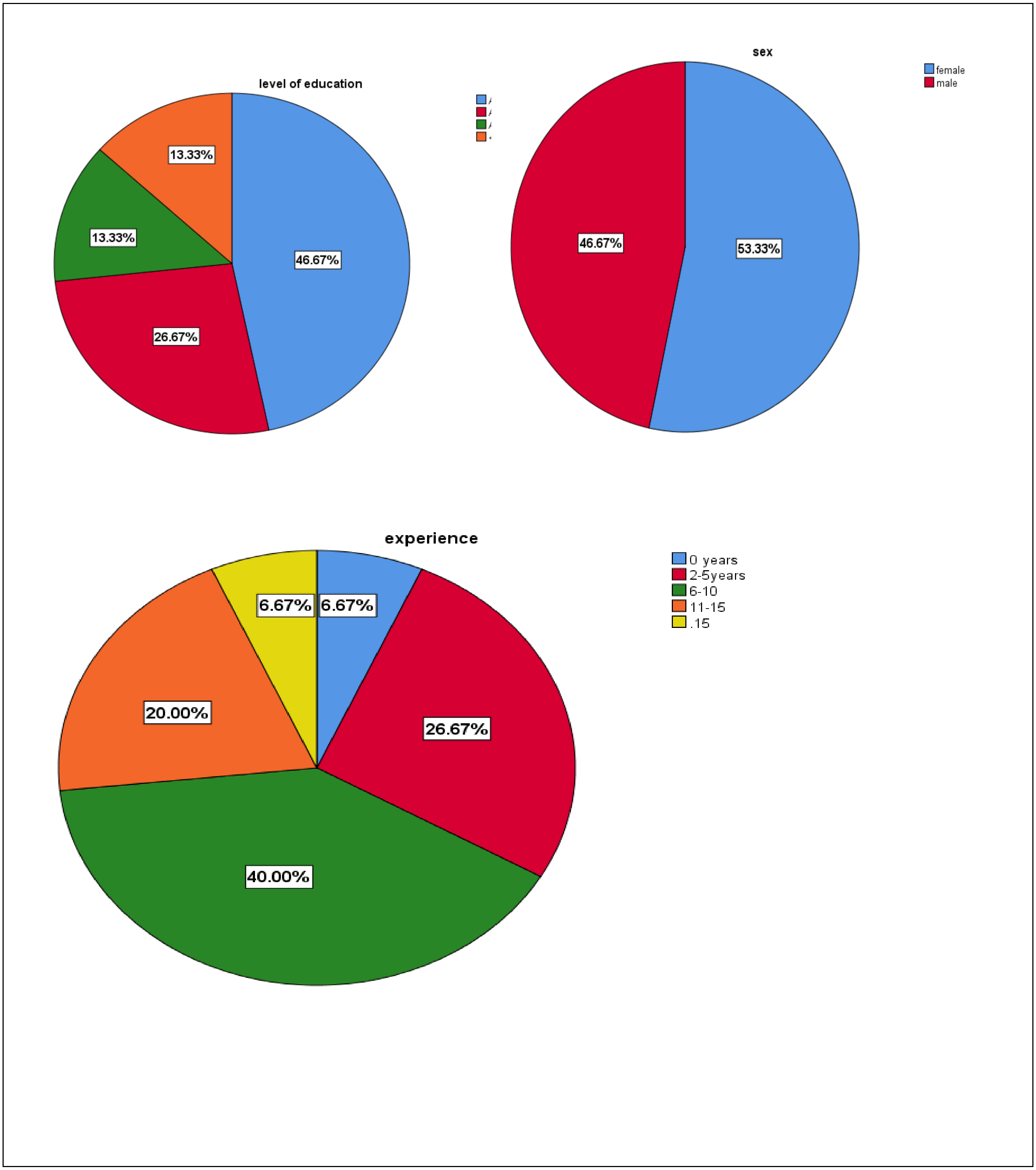


Figure 8: Socio-demographic characteristics of the study participants

According to the observation of the researcher and 15 respondents from 4 surveyed industries, apart from the industry 1,2, and 3, the remaining industry 4 have no well-defined treatment systems for treatment of industrial effluent waste stream. Industry 4 has no treatment system. However, there is no inspection procedures for all industries that can guide industries for the management of their treatment systens.

The management practices of treatment plants during operation are poor. No reference protocols for the plants management for industries. They survey the performance of treatment facilities and units when there is a problem. According to the national and international standards of wastewater quality effluents, the survey of quality of discharged industrial waste stream is done when required. The missing value of 40% is due to industries 4 and 5 that have no WWTP, hence no plant inspection procedures. Approximately ¾ of the study participants justified that industries have no training program for employees about WWT as illustrated on the table 11.

Table 9: Management practices of wastewater management systems during operatio

		Frequency	Percent
Presence of plant inspection procedures	no	9	60.0
Missing	System	6	40.0
Total		15	100.0
Properly working	no	5	33.3
	yes	4	26.7
	Total	9	60.0
Missing	System	6	40.0
Total		15	100.0
Inspection of outside facilities	daily basis	5	33.3
	when required	4	26.7
	Total	9	60.0
Missing	System	6	40.0
Total		15	100.0

Inspection of pre-treatment facilities	annual basis	1	6.7
	when required	8	53.3
	Total	9	60.0
Missing	System	6	40.0
Total		15	100.0
Inspection of pump control devices	when required	9	60.0
Missing	System	6	40.0
Total		15	100.0
Inspection of WWTP control system	when required	9	60.0
Missing	System	6	40.0
Total		15	100.0
Inspection of wastewater quality for compliance	when required	9	60.0
Missing	System	6	40.0
Total		15	100.0
Inspection of collecting system	when required	8	53.3
	55	1	6.7
	Total	9	60.0
Missing	System	6	40.0
Total		15	100.0
training of employees about WWT	no	11	73.3
	yes	4	26.7
	Total	15	100.0

4.2 Analysis and discussion of laboratory results

This sub-unit aims at analyzing and discussing of wastewater quality results obtained after in-situ and laboratory measurements. Wastewater quality parameters at each sampling location and industry was assessed for their compliance with national and international standards. Their compliance are analyzed and discussed here in this sub-section.

The missing results of December at industry 2 are because there was no effluent wastewater in the final clarifier tank. Others are due to the nature of treatment and inputs chemicals at the industry.

4.2.1 Hydrogen potential (pH)

pH of wastewater during treatment is essential for the removal of organic compounds and heavy metals. Alkaline pH favors the precipitation of most metals I form of insoluble solids (Edokpayi & Odiyo, 2015)

Results showed that Ph values at industry 2 and 3 are slightly higher than the standard value of Ph in December and February . For other periods and industry 1 and 4 industries pH values complies with national and international wastewater quality standards. Industrial sewage outflows before treatment at industry 2 was alkaline during June (12.31) and acidic in the months of February and June (4.41 and 4.82) and alkaline (9.61) far from the treatment site for industry 3 at Nyabugogo wetland. It was continuously being alkaline (near the treatment site and at farm area during the month of June for industry 2. This indicates that there is no treatment of Outlet wastewater from industry 2 as illustrated on the Fig.9. However, the constant pH (7.5, 8) level near and far from the treatment site at industry 1 and 5 indicates that they have no adverse impacts on the environment whereas the increase in pH from Kigombe upstream (6.93-7.54) and downstream (7.45 – 7.97) indicates that there is no adverse impact on kigombe due to industry 4. High of pH effluent affect the soil fertility, and hence affect the agricultural yield.

Alkalinity and acidity of sewage at industry 2 is a result of chemical applied with reference to table 1.

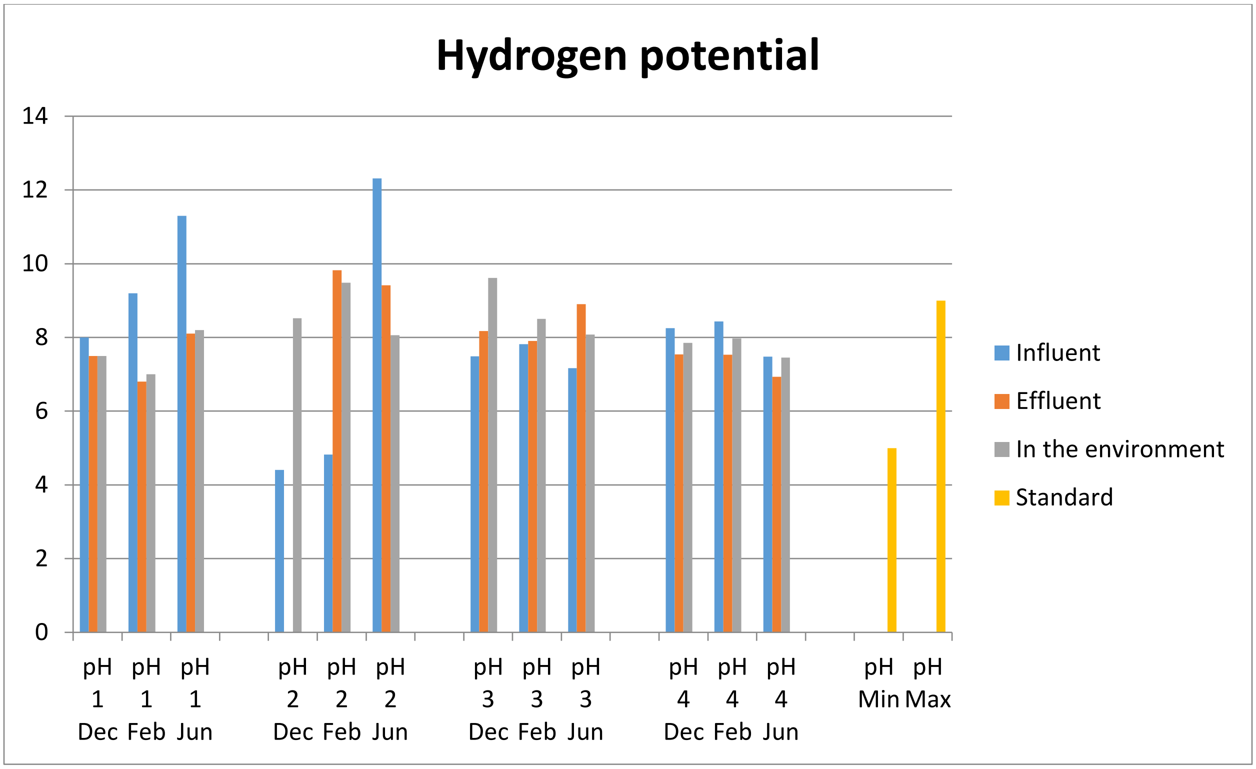


Figure 9: pH variation at selected industries

4.2.2 Electric conductivity

The highest value of Electric conductivity ($571000 \mu S/cm$) was obtained during the month of December at industry 1 as influent to the wastewater treatment plant and the lowest one ($563\ \mu S/cm$) also was obtained in June at industry 2 at a point where the effluent from wastewater treatment has mixed with the open environment. There is no standard limit for wastewater effluent in the considered standards of Rwanda standards board, East African Community (EAC) standards and International standards. However the standard limit for portable waster is 2500 $\mu S/cm$ indicating a high maximum value and minimum value that is in range. Electric conductivity is a measure of the ability of water to conduct electric current. This is greatly dependent on the availability of ion species (Julian et al, 2018). Higher values of Electric conductivity show that inorganic ions are in abundance in wastewater and thus high total dissolved solids concertation. A failing sewage system would raise the conductivity due to the presence of chloride, phosphate and nitrates (Uwidia et al, 2013).

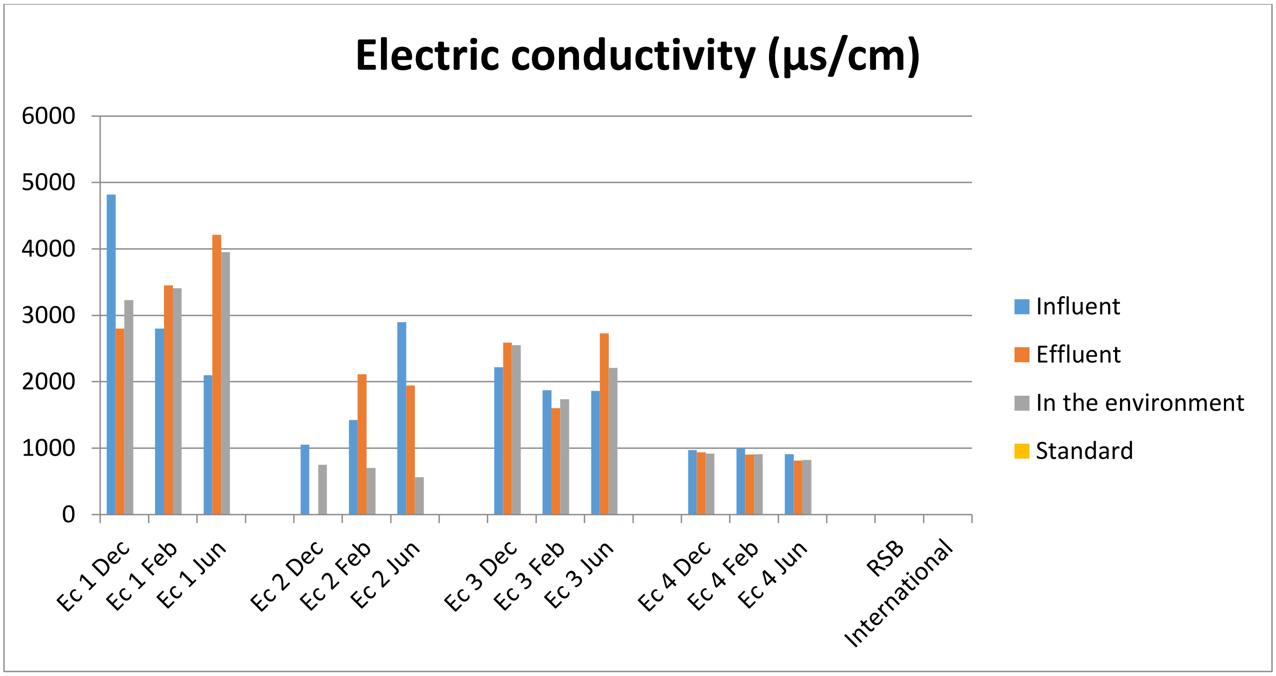


Figure 10: Electric conductivity variation

4.2.3 Total dissolved solids

TDS indicate a measure of all solids that are dissolved in water (Aniyikaiye, 2019). Results from laboratory testing indicate TDS varying from 14300 mg/l to 256 mg/l for the treated and after mixture in environment. All values before, after treatment and after mixture with the environment for all industries are compliant with the standard values that is national and international tolerable limits (2000 mg/l) of industrial effluent. There was no significant variation between the wet and dry season.

Wastewater disturbances can increase the number of dissolved solids. Increase of TDS in February from 560mg/l at the ETP inlet up to 980mg/l at the ETP outlet, could be due to water that was drained into the final clarifier tank of the ETP, which caused mixture of the previously settled solids with the effluent resulting in an increment in TDS in the sample effluent that was collected for analysis at the Final tank outlet

At industry 1, the TDS variation near (544 mg/l) and far (1206 mg/l) from the WWTP indicates that this zone has no adverse impacts on environment, the increase in TDS might be caused by other human activities whereas at industry 4, TDS variation is constant there. At industry 2, and 3

TDS varied in a decreasing manner, this indicates the nature treatment capacity from ETP outlet to the agricultural area, far from the treatment plant.

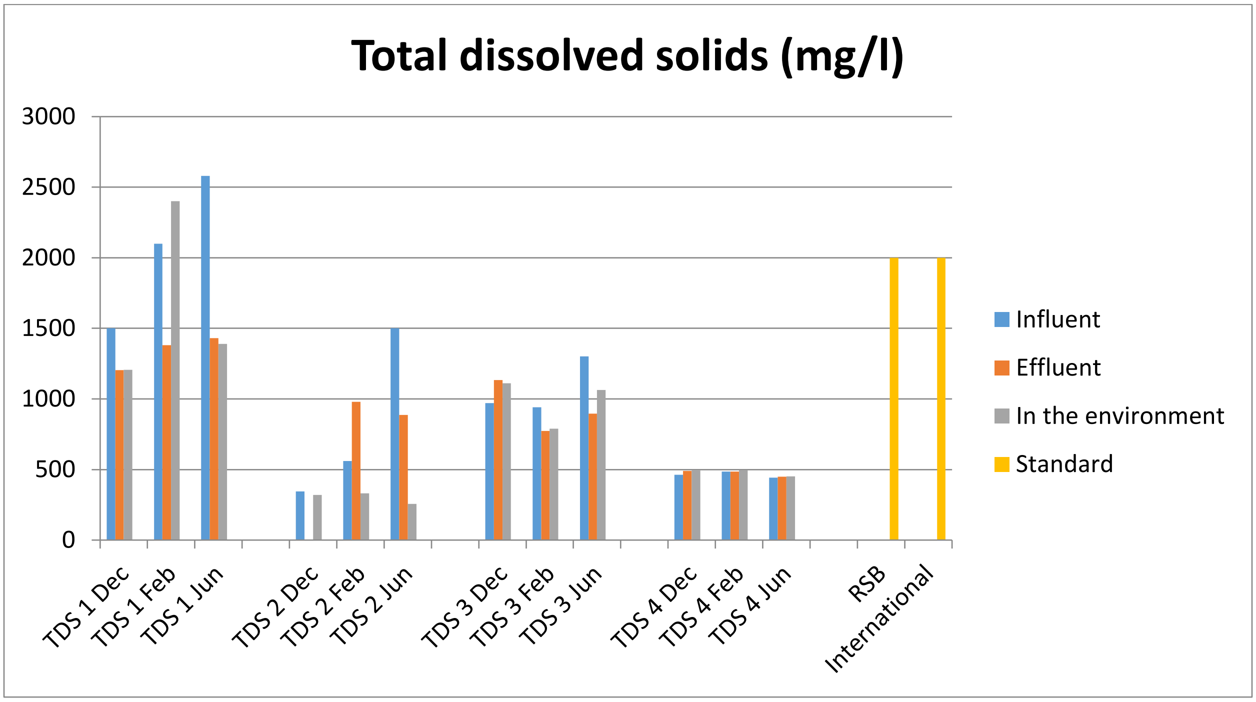


Figure 11: Total dissolved solids

4.2.4 Dissolved oxygen

Dissolved oxygen indicates the amount of oxygen available to the living organisms and is important for the survival of aquatic life. It is an important parameter to asses due to its influence on organisms present in water bodies (Rubel, 2019). Dissolved oxygen is partially dependent on physical, chemical and biological activities occurring in water. Oxygen concertation in water is dependent on oxygen generation through photosynthesis and consumption by living organisms mostly bacteria (Vyankatesh, 2014)

Apart from industry 2 (0.55 mg/l) and 3 (0.29 mg/l) during the month of June that falls below international recommended tolerable limit (>1mg/l), the level of oxygen demand obtained during in-situ measurements at selected industries complies with limits of dissolved oxygen in industrial wastewater. The higher the dissolved oxygen indicates the lower number of organic matters hence less pollution. The gradual reduction in three consecutive months at industry 2 and 3indicates that there were activities that increased the amount of organic matters.

Dissolved oxygen depletion, indicates the poor quality of wastewater, and it is known to be a common cause of aquatic life problems like fish kills.

The amount of oxygen needed, varies according to the living organisms requirements for example, bottem feeders,oysters,,and worms require (1-6mg/l) whereas shallow water fishes needs (4-15 mg/l) (Fondriest, 2013).

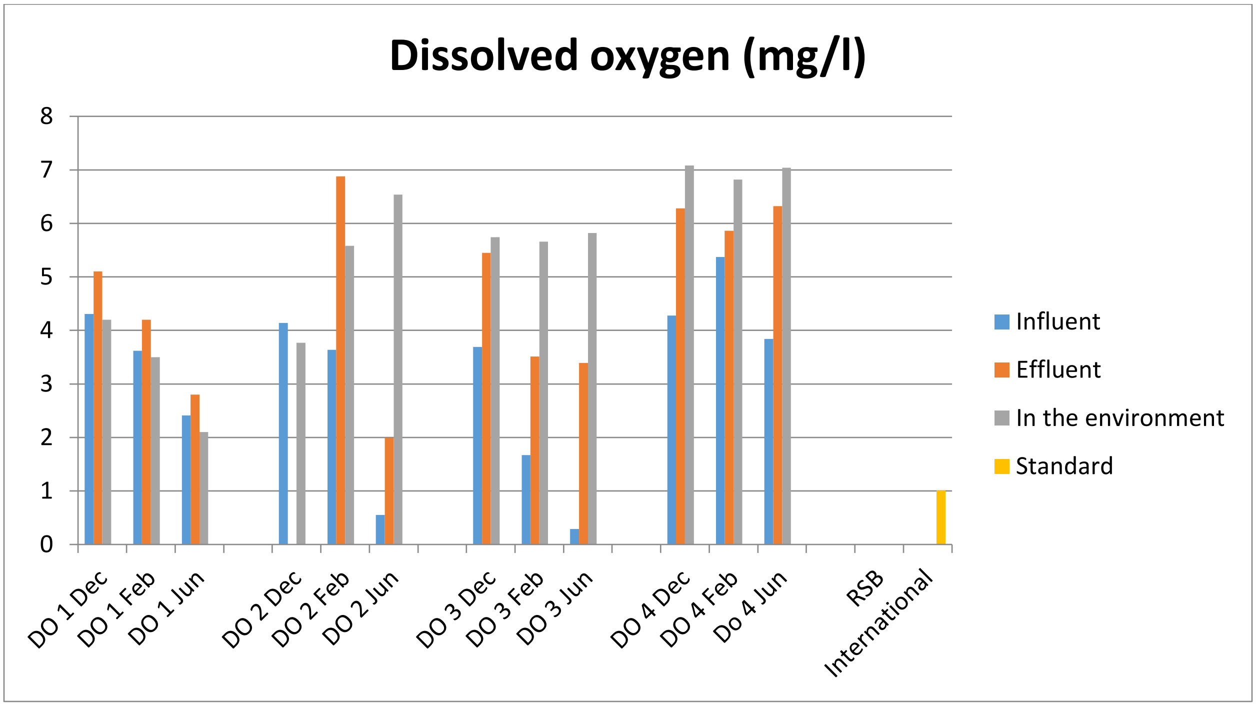


Figure 12: Dissolved Oxygen variation

4.2.5 Nutrients

Nutrients have been assessed at industry 1 ,2and 3 according to their functions, input materials and materials including in their effluents with reference on the table 1. The assessed nutrients are : nitrogen, phosphorus, ammonia nitrogen, phosphates and sulphides

Nutrients are essential for human and plants growth. It is in the same way that the amounts of nutrients present in wastewater indicate the nuisance of microorganisms and plant growth in water ways. It is also known than the higher amount of nutrients enhances the creation of algal blooms which very toxic. However, treated wastewaters rich in nutrients are suitable for irrigation.

4.2.5.1 Total nitrogen (mg/l)

The results of total nitrogen from the monitoring of wastewater at Skol Brewery Ltd, varied at the inlet between (7.07 – 15.40 mg/l) and averaged 1.32 mg/l at the outlet. At inlet to the treatment plant, TN didn't comply with international standard (5mg/l) where as it falls below the tolerable limit at outlet. Total nitrogen gradually increased in the months of December, February and June at Nyabugogo wetland. This indicates that there are external contributors. Hence industry 3 has no adverse impacts on the environment, therefore a good treatment system for removal of total nitrogen.

At industry 1, the industrial outflows are rich in total nitrogen at every selected point, (61.917 mg/l) before treatment,(61.917 mg/l) near the treatment site, (56.816 mg/l) far from the treatment site. This indicates that there is no compliance with standards and no treatment of industrial wastewater to comply with international standards . therefore industry 1 has adverse impacts on the environment

4.2.5.2 Ammonia nitrogen

Results of ammonia nitrogen (NH3-N) from monitoring wastewater at industry 3 varied at the inlet and outlet between (1.21 – 3.02 mg/l) and (1.18 – 2.47 mg/l), respectively.

At the discharge outlet from the wastewater treatment system, values of ammonia nitrogen in the effluent are slightly higher in December and February (2.47 mg/l and 2.15 mg/l) than the standard, implying effluent did not comply with International Standards of discharged industrial wastewater, however in June the NH3-Nvalue found was complying with International Standards of discharged industrial wastewater (2mg/l). There is no collected sample of NH3-N collected from industry 5

4.2.5.3. phosphates (mg/l)

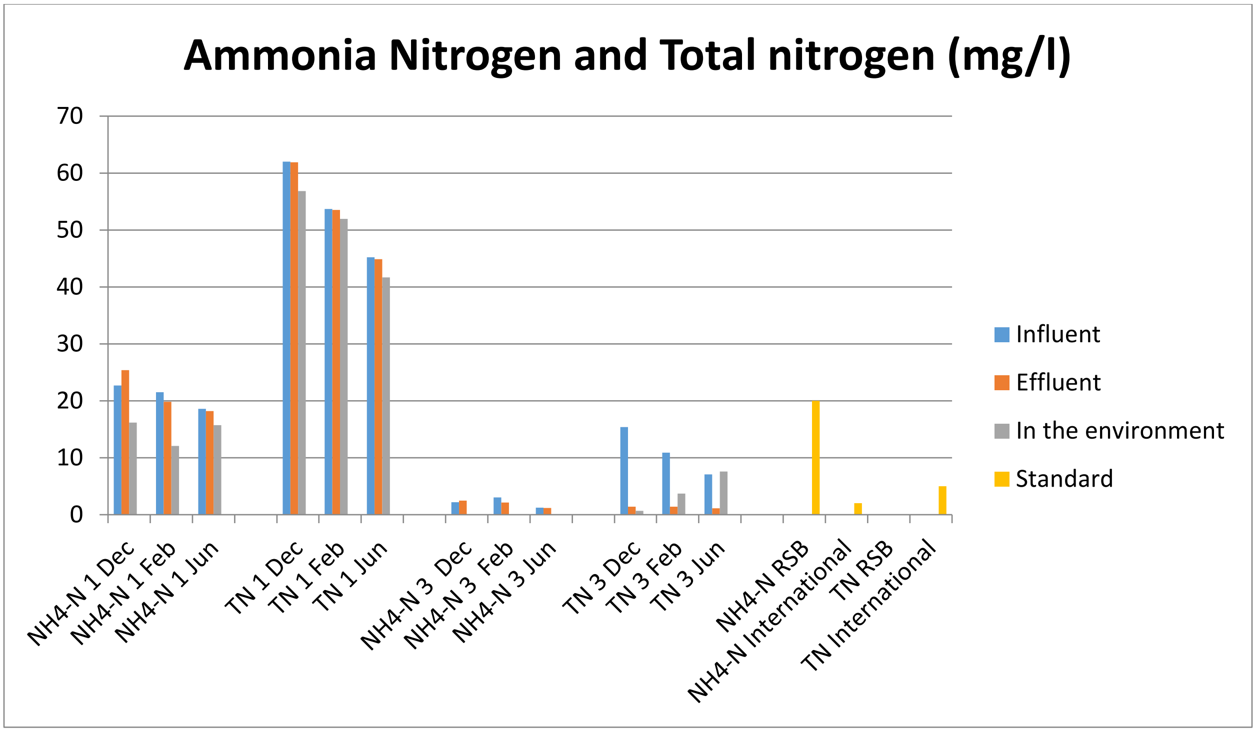
Phosphates as phosphorus obtained at industry 3 was 3.48mg/l at the inlet and varied at the outlet between (2.01 – 3.21 mg/l). although there is no national and international standards to compare in order to assess the compliance, those values fall within the tolerable values of treated domestic sewage standards.

4.2.5.4. Total phosphorus

The results of total phosphorus from the monitoring of wastewater at industry 3, varied at the inlet and outlet between (3.24 – 5.17 mg/l) and (1.96 – 2.88 mg/l) respectively.

Compared to Rwanda and International standards of discharged industrial wastewater (2 mg/l), effluent at the outlet from WWTP were higher in February and June (2.36 mg/l and 2.88 mg/l) and also all samples for the effluent at point of discharge to the wetland, implying therefore that the effluent at the discharge does not comply with both Standards. In December, however, effluent at discharge complied with the two standards (1.96 mg/l).

At industry 1, total phosphorus before treatment , near WWTP and far from the treatment sites are higher (55.4) than domestic effluent standard (10).



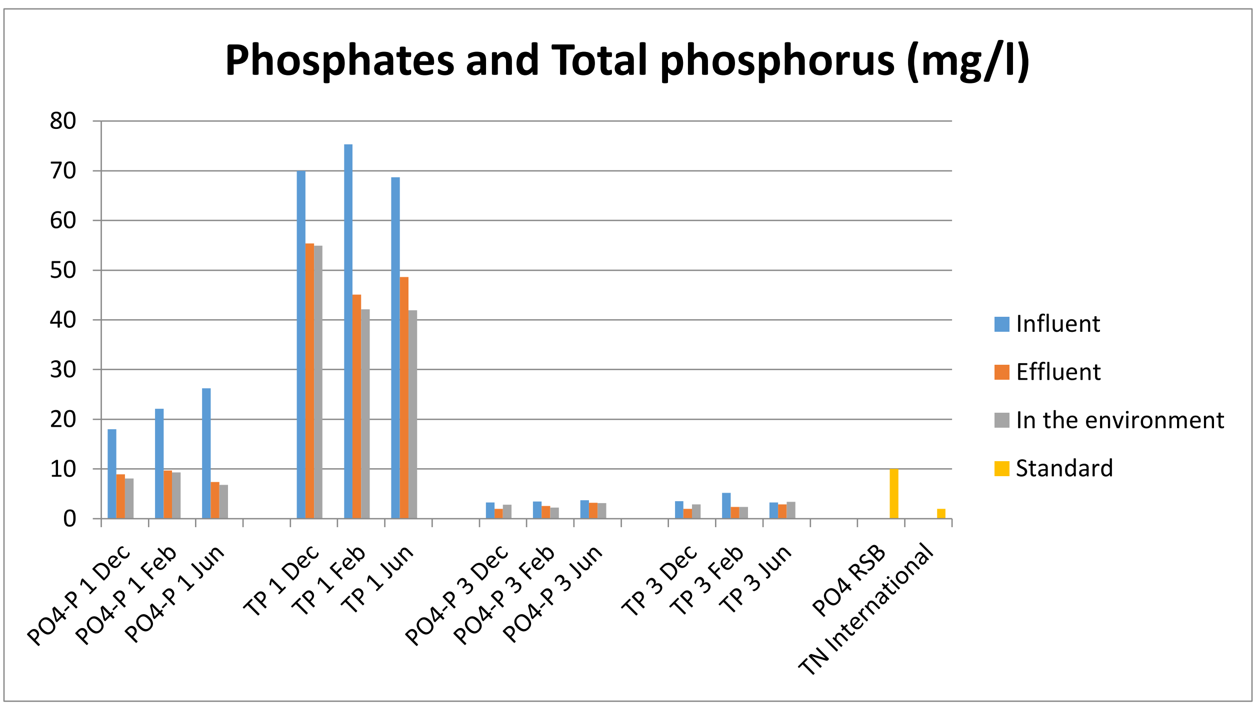


Figure 13: Nutrients variation

4.2.6 Chemical oxygen demand

COD is a measure of oxygen equivalent of the organic content of the sample that is susceptible to oxidation by a strong chemical oxidant. COD is an evaluation used to measure the level of water contamination by organic matter (Sulaiman, 2016). The measurements of COD can be done in a few hours while BOD measurements usually take five days (BOD_5) (Ram, 2011). COD and BOD values are both a measure of the relative oxygen depletion effect of waste contaminants. They are all a measure of pollution effect in water (Sasamal, 2007)

Except industry 4 with (65 mg/l) COD wastewater effluent, other remaining selected industries wastewater outflows to the treatment plants or environment are characterized by high level of chemical oxygen demand. Industry 2 COD outlet was very high during the month of June (1666 mg/l) from 498 in December and 1049 mg/l during the month of February. Industry 3 outflows to the treatment plant also were very high during the months of December (1515 mg/l) from 1184 and 702 mg/l in the months of February and December respectively. hence, industries 1, 2, 3, and 5 outflows do not comply with Rwanda standard board tolerable limits of COD for industrial wastewater outflows of 250mg/l.

COD variations near the treatment sites.

Looking at the treatment systems capacities of COD removal, there is a failure to meet national standards of COD in industrial wastewater discharge at industries 1,2, and 3. COD variation near the treatment sites for these industries are 399 mg/l, from 314 to 449 and 65 to 379 mg/l in the months of October, February to June and December to June respectively. nonetheless, December and February results (65 and 194 mg/l) shows the compliance with RSB standards at industry 3

At industry 1 and 5, the value of 599 mg/l far from the treatment site, indicates that there are other external contributors to the values of COD in addition to its treated effluent that is not meeting the standards, whereas there is a valuable difference in COD changes for industry 5 from the point near the release and far from that point.

High COD indicate presence of all forms of organic matter, both biodegradable and non-biodegradable. High levels of organic matter in water, imply increased oxygen consumption by organic matter decomposers and therefore decreased oxygen content of the receiving water body, a sign of water pollution, causing depletion of fish and aquatic life from

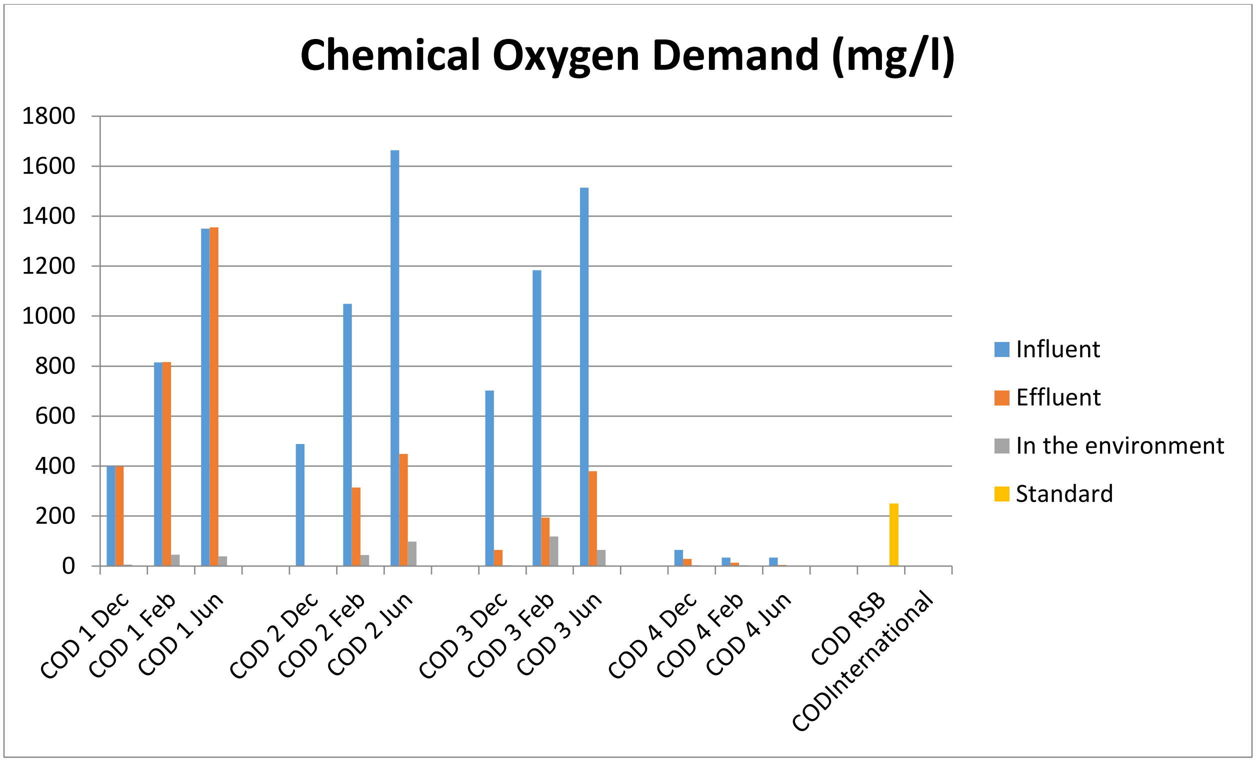


Figure 14: Chemical oxygen demand variation

4.2.7 Biological oxygen demand (mg/l)

BOD is considered as the amount of oxygen used by microorganisms to decompose organic compounds in water. BOD in water is determined by the difference in the dissolved oxygen (DO) levels of water samples prior to incubation and compare them after 5days of incubation (Sperling, 2007). Dissolved Oxygen (DO) is greatly influenced by BOD level in wastewater.

Results from laboratory tests showed that the values of BOD influent to the wastewater treatment systems at industry 1,2 and 3 are very high compared to Rwanda and international standards of wastewater quality(50mg/l). The highest BOD values was obtained during the months of June (681) for industry 1, June (738) for industry 2 and February (792) for industry 3 respectively. This led to the failure of wastewater treatment systems for industries 2 and 3 where values still remained higher than the required standards after treatment with June (97.8) for industry 2, Feb (118.2) and June (64.8) for industry 3. Samples taken far from the treatment site, all the measurements taken for effluent from industry 3 were higher than the permissible standards. The increase could have been due to increase of organic matter from open environment. There is a positive difference between the maximum value of BOD (64.8 mg/l) found in treated effluent at industry 3 near the treatment site and at Nyabugogo wetland (168.9 mg/l) that indicates the presence of external contribution.

BOD refers to the amount of oxygen required for the biotic degradation of organic matter in bodies of water. When BOD levels are high, dissolved oxygen (DO) levels then decrease because the oxygen that is available in the water is being consumed by the bacteria. Since less dissolved oxygen is available in the water, fish and other aquatic organisms have inadequate oxygen and may not survive (Bhateria, 2016)

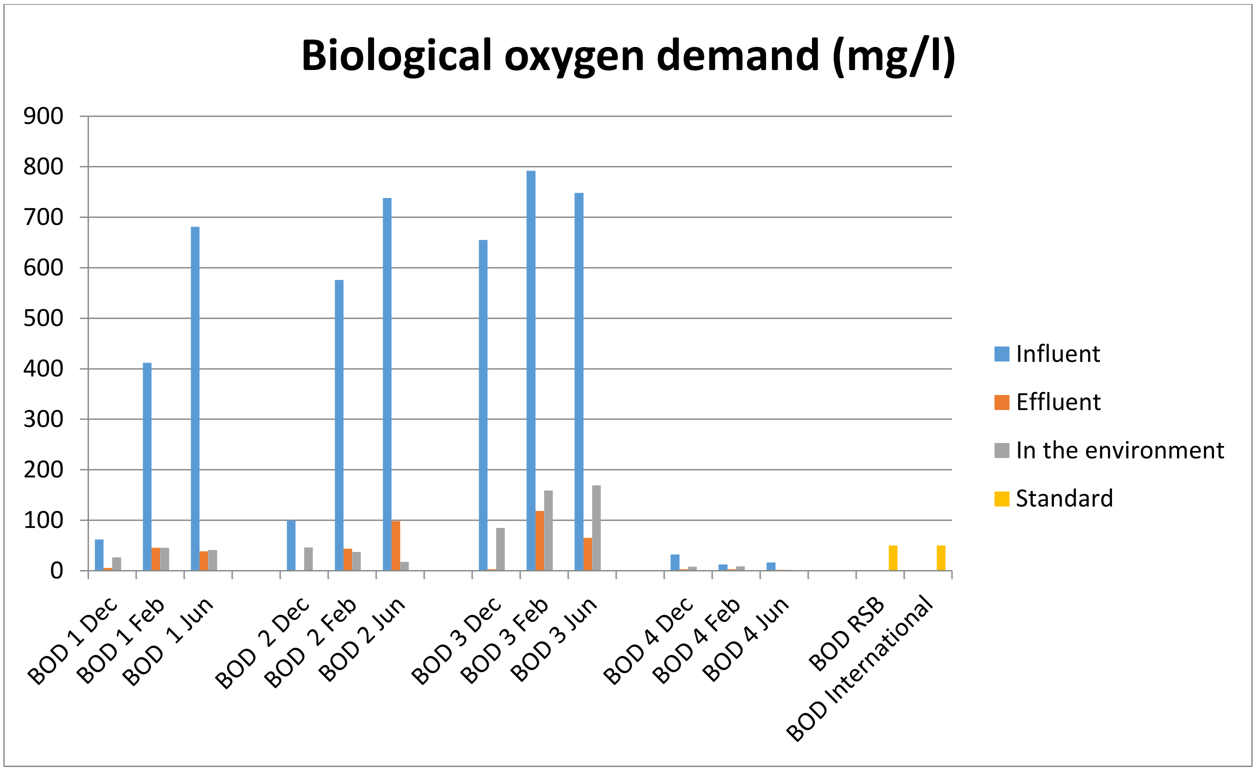


Figure 15: Biological oxygen demand variation

4.2.8 Total suspended solids (mg/l)

Total suspended solids (TSS) are a measure of particulate matter suspended in water. TSS also used to describe the extent of pollution in wastewater. It is a good indicator of turbidity of the wastewater (Sulaiman & Attalla, 2016). Human beings exposed to water with high concentrations of TSS and TDS are at risk of having health problems related to cancer (Waqas & Arshad, 2015)**.** Apart from industry 4 which has a compliant outflow wastewater effluent with a maximum value of 3 mg/l, other remaining industries wastewater discharges requires treatment to meet RSB and international standard (50mg/l) of TSS in treated wastewater. TSS values in effluent wastewater was varied from 40-123 mg/l at industry 2 and 195-279 mg/l at industry 3 in months of December to June.

TSS values of 173 and 123 that was found in the months of June and October at industries 3 and 1 indicates the failure of treatment systems to comply the wastewater quality to the national and international tolerable limits. However, in months of December and February, wastewater quality's TSS Were below national and international tolerable limits of TSS in industrial effluent wastewater.

TSS variations from the treatment sites to the points far from the treatment sites (123-145mg/l) indicate that there is negative external contribution to the wastewater quality.

The most visible environmental impact that TSS has on the environment is siltation and sedimentation. Suspended solids transported into rivers, lakes and oceans eventually settle on the bottom, and over time this accumulated sediment can clog and alter the topography of bodies of water.

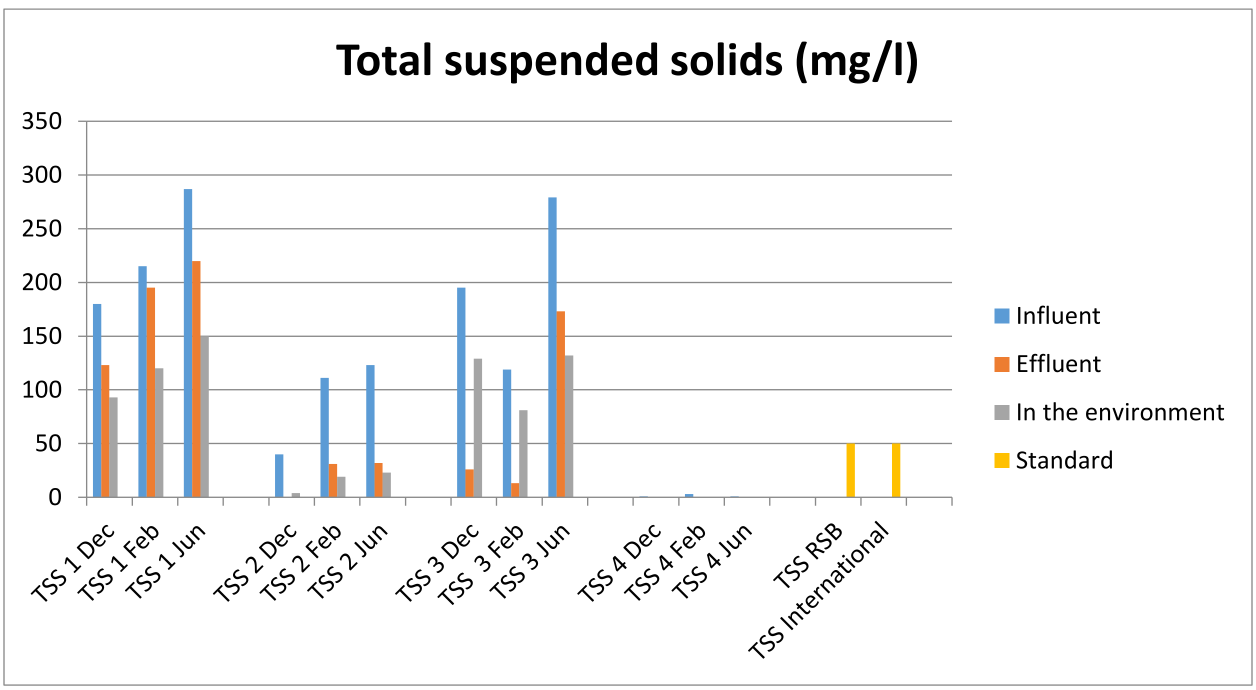


Figure 16: Total suspended solids variation

4.2.9 Oil and grease (mg/l)

Oil and greases results were found to be very high (178, 150 mg/l) by comparing to RSB and international standard (10mg/l) at industry 2 before and after treatment during the month of February. The result in the remaining months (December and June) also indicates that the values of oil and grease in industrial waste water do not comply with provided standards. Therefore, it is indicated that the treatment system at this industry is not efficient for removal of oil and greases. The results obtained from the sample collected at agricultural area 22.8 in the months of June, implies that this treatment failure can affect that environment.

At industry 3, the values of oil and greases before treatment were found to be 42, 28 and 18 mg/l in the months of December, February and June respectively. Comparing those results to those found near the treatment site, 0, 26 and 14 mg/l, there is a great difference where the treated effluent complied with RSB and international standards in the month of December. However, there is a failure to meet the standards in months of February and June. However, the results found at Nyabugogo wetland shows that there is environmental self-treatment that resulted to 0 oil and greases in the months of December and February and 8 in June which below tolerable limits by RSB and international standards.

The results of oil and grease found at industry 4 was found to be 11.8, 46 and not detected. The first two results in the months of December and February are not complying with standards. At Kigombe upstream and downstream, oil and greases was not detected, implying that the treatment system at industry 4 is efficient and hence no adverse impacts on Kigombe river.

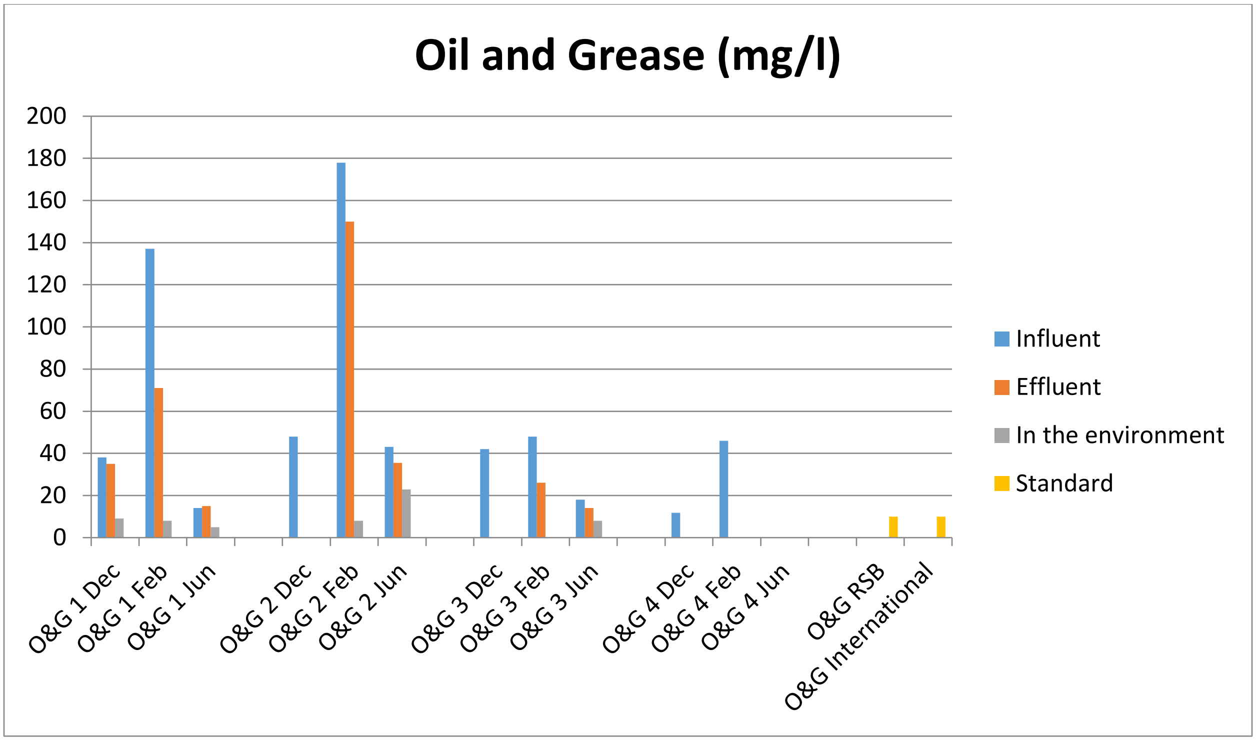


Figure 17. Oil and grease variations at selected industries

4.2.10 Fecal coliforms

As it is illustrated on the figure 16, the number of fecal coliforms at selected industries wastewater outflows exceeds the RSB and international wastewater quality discharge tolerable limits, 400 cfu/100ml and 2000 cfu/100ml in months of December and October. It is very high at industry 1 (20100), followed by industry 3 (8100), industry 4 (6600) and industyr2 (2100). However, in the remaining months (December and February), the wastewater laboratory results complied with international standards for industries 2, 3, and 4.

For wastewater quality after treatment near the treatment site, only industry 3 has treated its effluent to 310 cfu/100ml (maximum) that complies with national standard and international standards. The remaining industries 2 (1000 *mg/l*), and 4 (1200 *mg/l*) fecal coliforms in industrial effluent complies with only international standards. The remaining results (2419.6, 1000, and 1200 *mg/l*) are not complying with RSB standards for industries 1, 2, and 4 respectively. This indicates the failure of treatment systems to reduce feacal coliforms to the required standards.

Fecal Coliform bacteria indicate the presence of sewage contamination of a waterway and the possible presence of other pathogenic organisms. Levels of FC beyond tolerance limits may indicate a higher risk of pathogens being discharged in the water. Some waterborne pathogenic diseases that may coincide with fecal coliform contamination include dysentery, typhoid fever, viral and bacterial gastroenteritis, and hepatitis A.

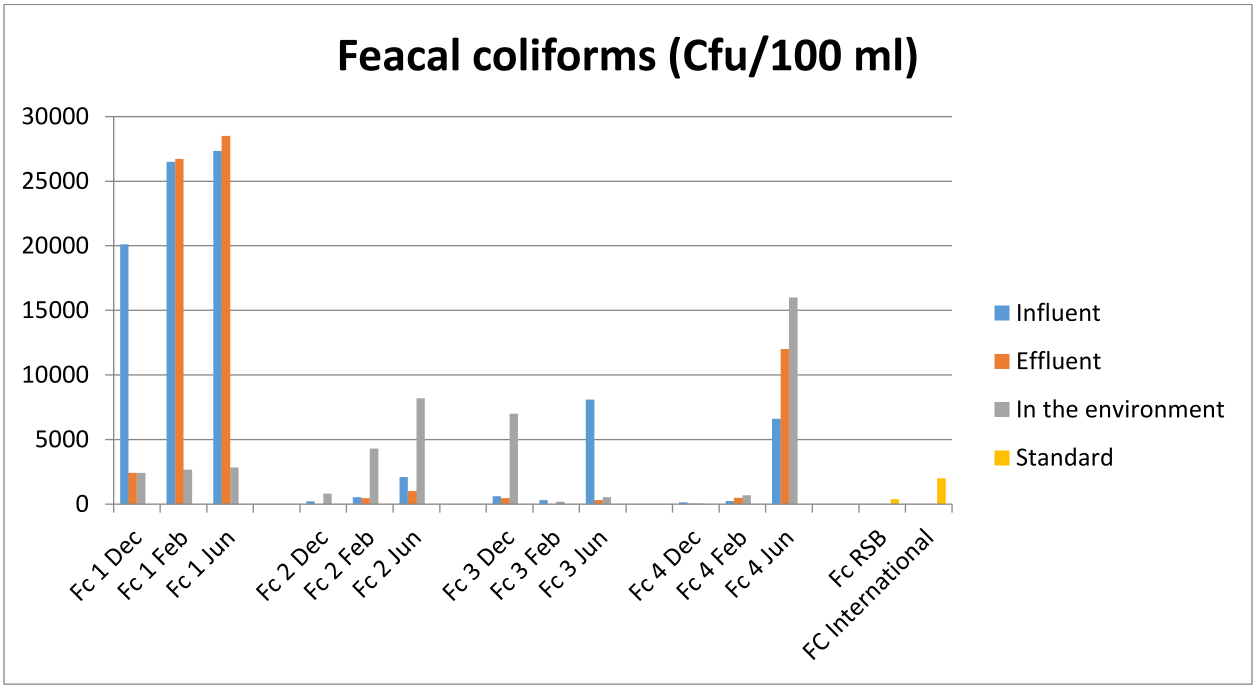


Figure 18. Feacal coliforms variation at selected industries

4.2.11. Heavy metals (mg/l)

Heavy metals are key parameters to consider while assessing the industrial wastewater treatment performance of industrial wastewater treatment performance. The failure of compliance with standards for heavy metals can be a results of environmental and life problems with reference on Table 3 by Barakat and Gunatilake**.**

4.2.11.1 Chromium (mg/l)

The AAS results of chromium found in industrial wastewater outflows before treatment was found to be 0.06 *mg/l* which not complying with RSB (0.05 *mg/l*) but complies with international standards limited to 0.1. however, it was found complying with standards after treatment with 0.05 *mg/l* near the WWTP. This implies that the treatment system at industry 1 is efficient for removal of Chromium.

The Chromium results obtained at industry 2 were: 0.054, 0.072 and 0.084 before treatment that are not compliant with RSB standard but with international standards. After treatment, the values of chromium were found to be <1 *mg/l* in months of December and February. Those results were also that obtained at agricultural area, far from the treatment site apart from 0.12 in June that was raised by external contributors. Therefore, this is a clear indication that industry 2 has efficient treatment system is efficient for removal of chromium and this industry has no adverse impacts on the environment.

Chromium values in industrial effluents from industries 3 and 4 was found to be <0.01 and continued to be this after sewage treatment and far from the treatment at Nyabugogo wetland and Kigombe downstream.

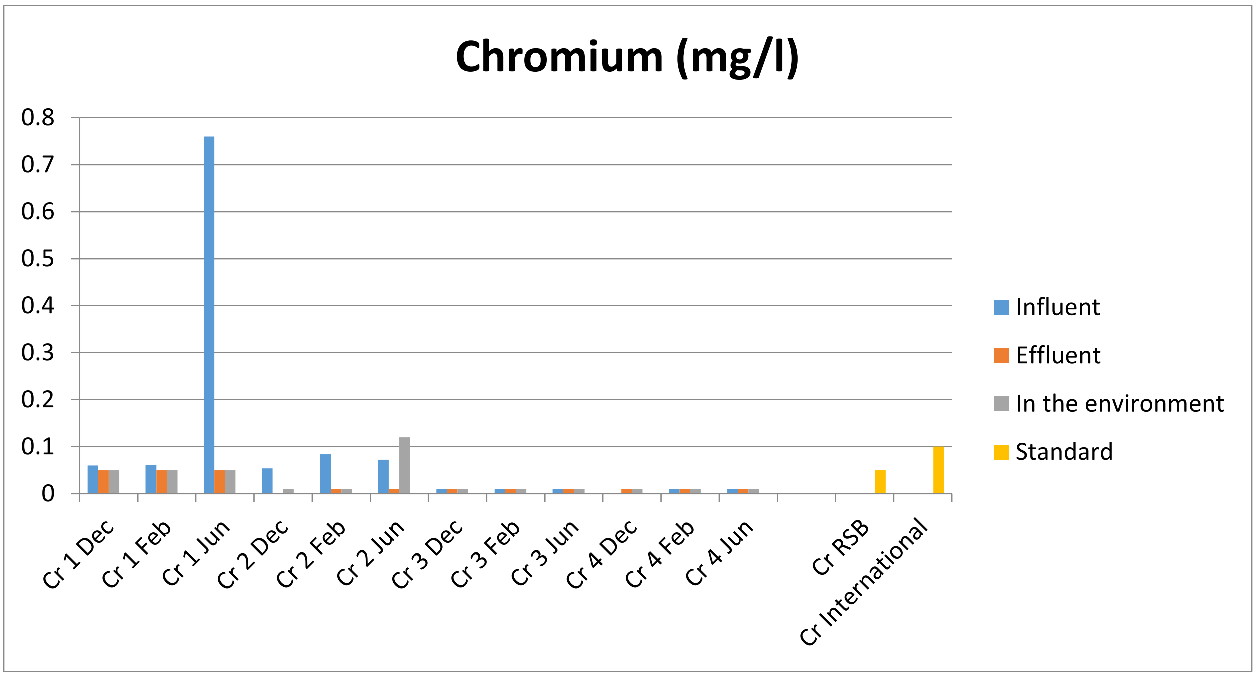


Figure 19.Chromiun variation at selected industries.

4.2.11.2 Lead (mg/l)

The values of lead obtained at selected industries before treatment, near the treatment sites and far from the treatment sites are compliant with Lead international standard (1mg/l). However, they are not compliant with MCL by Barakat and Gunatile (0.006mg/l).

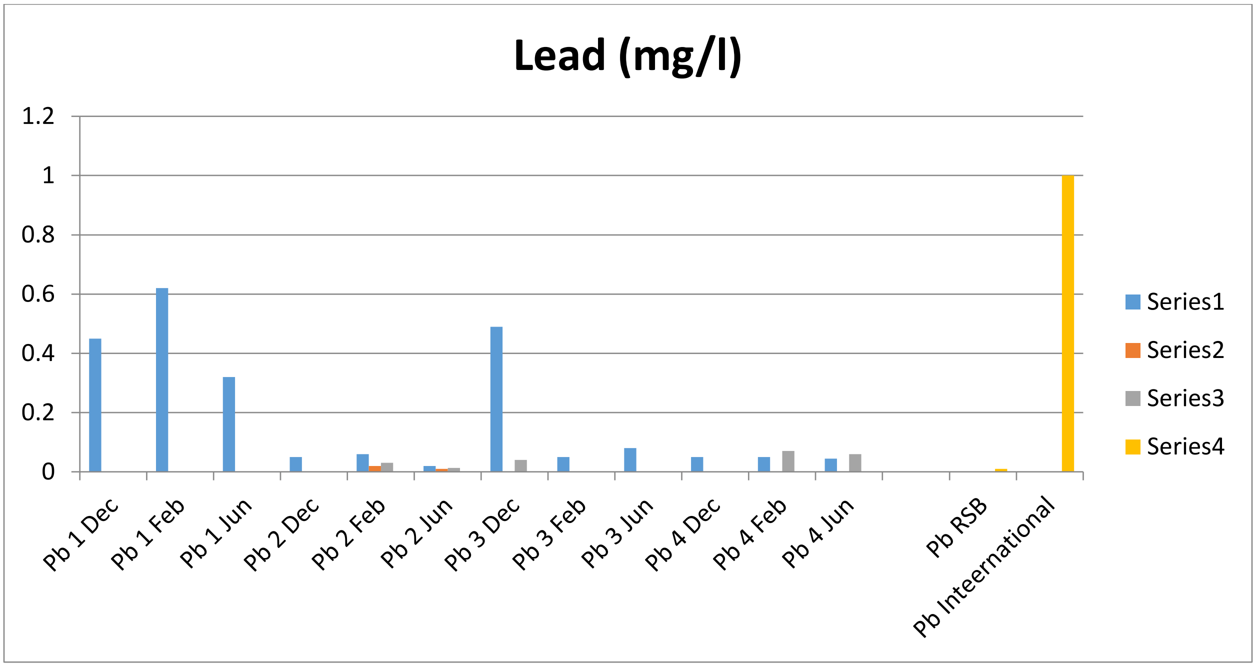


Figure 20. Lead variations at selected industries

4.2.11.3 Cadmium (mg/l)

The level of cadmium in the effluent from industry 4 during the months of February (0.026 *mg/l*) and June (0.021 *mg/l*) was obtained not complying with international standard (0.02 *mg/l*) at the point of generation. At Kigombe upstream, the value of Cadmium is slightly high (0.03 *mg/l*) during the month of February. This implies that there is no treatment system for Cadmium removal. The remaining industrial effluents cadmium results complies with international and MCL.

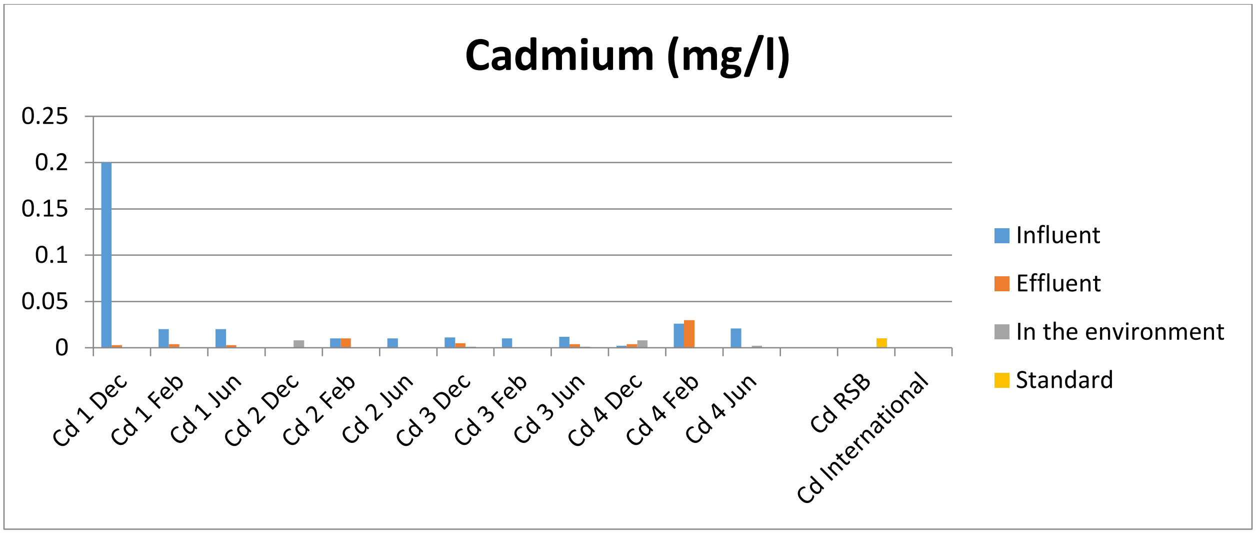


Figure 21. Cadmium variations at selected industries

4.2.12 Pesticides

Pesticide levels of effluent at Sopyrwa Horizon Ltd, Kigombe upstream and downstream were not detected (all at <0.01$\mu g/l$ =0.00 mg/l).

4.3 Management practices of treatment systems during operation

An effective management of the plant during operation plays an important role in the plant efficiency as it ensures nonviolent and adequate operation of treatment facilities. Assessment that was carried out and four selected industries illustrated that there is no inspection procedures for all industries that can guide industries for the management of their treatment systems. The missing systems, stands for the respondents who have not answered because there is no defined treatment system.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.0 Introduction

This study was based on the detail assessment of industrial wastewater treatment systems at selected industries including the centralized system of Kigali special economic zone in Rwanda. It was aimed at determining the influent industrial wastewater characteristics to the treatment systems, treated effluent wastewater characteristics near and far from the treatment sites, comparison of results to the national and international standards, to assess the management practices of treatment systems during operation and to suggest possible improvements where a problem is found. This chapter illustrates the conclusions and recommendations drawn by researcher according to the findings.

5.1 Conclusion

Nowadays, the most pressing environmental problems in Rwanda is pollution associated with water, air, and soil. What is worrisome is the discharge of untreated or inadequately treated industrial wastewater to the environment that result to the water resources and land degradation as well as air quality deterioration.

The findings of this study conclude that, non-compliance of industries for the treatment of their effluents are comprised of the following:

- Failure of industrial treatment systems to treat their effluent within the required national and international tolerance limits of wastewater quality compliance. The parameters are namely: PH, nutrients (TN, TP), COD, BOD, TSS, O&G, FC, and heavy metals.
- Industry 1 areas of non-compliance in some areas include the highest levels of nutrients (TN and TP), COD, TSS, FC.
- Industry 2 have failed to meet the compliance on: pH, COD, BOD, O&G, FC, and heavy metals (Pb, Cr, and Cd) where the treated effluents include those wastewater quality parameters in excess
- Areas of noncompliance at industry 3 include inadequacy of industrial effluent treatment to meet national and international tolerable limits on the following parameters: TP, COD, BOD, TSS, O&G, FC, and lead.
- At industry 4, treatment system is not adequate to treat their industrial effluents to meet national and international tolerable limits on the parameters: FC, Cd, and Pb.

- The treatment system at industry 5 is inadequate to reduce COD, TSS, wastewater parameters in their industrial effluents.

From the survey, most respondents have illustrated that there are no guidance protocols to be referred on while doing plants inspection. Most areas of the treatment systems are inspected only when required or when there is a problem. Wastewater quality inspection against the compliance of national and international limits also is done only when required.

5.2. Recommendations

This sub-unit includes the corrective actions proposed by the researcher to overcome the mentioned non-compliances in 5.1 to meet adequate treatment of industrial sewage. It also includes possible solutions to increase the performance of treatment systems.

5.2.1 Recommendations on industrial organizations

For effectiveness of industrial wastewater treatment at selected industries:

- ❖ Industries 3 and 4 (as codified) are recommended to install effluent treatment plants.
- ❖ The management of Industry 1 (Kigali Economic Zone) should ensure that all industries conduct pre treatment of their wastewater before release to the centralized wastewater treatment system in order the reduce the pollution load received at the treatment plant.
- ❖ All industries are recommended to perform wastewater quality tests not only when it is required by institutions in charge of wastewater management but also at a quarterly basis and submit the reports to the authorities in charge of wastewater management namely: REMA, WASAC and RSB.
- ❖ All Industries must promote the reuse of effluent water to ensure water efficiency. This could be done by improving the treatment level through tertiary treatment methods including cost effective methods like installation of a two-stage filtration process comprising of; coarse filtration followed by ultrafiltration, use of constructed wetlands so as to boost the performance of their treatment systems.
- ❖ To improve the management practices of wastewater management through regular maintenance of the wastewater treatment plants. This should be done by contracted professionals in wastewater management

5.2.2. Recommendations on the authorities in charge of wastewater management

For adequacy of industrial wastewater treatment systems at selected industries, institutions in charge wastewater management should do the following:

1. To establish regulations on industrial management, inspection protocols and plans for wastewater quality inspections to ensure compliance with industrial wastewater national and International effluent tolerance limits.
2. To ensure that all Industrial parks in Kigali and other Secondary and satellite Cities have standard centralized wastewater treatment systems. The regulatory institutions should also ensure that all industries likely to release wastewater should have a pre treatment at their premises before release the Centralised system.
3. Regulatory Institutions through monitoring should ensure full compliance of all industries to the existing wastewater effluent standards before release to the open environment
4. To promote the establishment of cost effective wastewater treatment technologies such as nature-based treatment solutions (constructed wetlands, filtration methods using local materials) to boost the efficiencies of the industrial treatment systems.
5. To promote research in exploring up to date cost effective wastewater treatment technologies. This should be done by providing research grants and incentives to researchers and academic institutions.

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Appendix

Appendix 1

RESEARCH QUESTIONNAIRE

RESEARCH TOPIC: comprehensive assessment of industrial wastewater treatment at selected industries in Rwanda

Relationship between questionnaires and study objectives

This questionnaire is composed by 3 sections, A, B, and C. SECTION, A will assess demographic data of the participant, SECTION B composed by 4 questions which are supposed to assess the presence of a wastewater treatment plants. SECTION C is characterized by7 questions, which will assess the management of the plants during operation.

Instructions:

1. The questionnaire is addressed to you individual do not consult with another provider.
2. No name must be mentioned on the questionnaire.
3. Select the appropriate responses by circling the letter which corresponds to the best answer

5. it is allowed to circle more than one letter, if both corresponds to the best answers

6. You can ask if question is not well understandable.

SECTION A: DEMOGRAPHIC INFORMATION

1. Age : a. 20-29years b. 30-39years C. 40-49years d. >50 years

2. Sex: a. M b. F

3. Education level: a.A2 b.A1 c. A0 d.0 level e. Primary school f. None…

g. Other ,specify………………………………………………………………….

5.Post: a. consultant b. chemical engineer c. labolatory technician d. maintenance 6. Sanitation engineer e. Manager f. supervisor g. manpower

Experience: a. 0 years b.2-5years c. 6-10 years d.10-15 years e. >15 years

7. What industry do you work in?

a. Kigali special economic zone b. UTEXRWA c. SKOL d. HORIZON SOPYRWA

e. catchup investments ltd

SECTION B: questions regarding the presence of wastewater treatment plants

1. Do you know that the discharge of untreated industrial wastewater is harmful to the environment and human life a. yes b. no
2. Do you have wastewater quality standards to be considered while discharging industrial wastewater to the environment? a. yes b. no
3. Do you have a wastewater treatment plant before discharging them? a. yes b. no
4. If yes,

   A. Is it working today? a. Yes b. no

SECTION C: questions regarding the management practices of plants during operation

A good performing wastewater treatment plant requires inspection procedures according to the treatment facilities.

5. Do you have any plant inspection procedures to be referred on? a. yes b. no
6. On which basis do you do a survey on industrial sewage treatment facilities like plant fence , plant area before pre-treatment?

   a. daily basis b. weekly basis c. monthly basis d. annual basis.
7. On which basis do you do pre-treatment facilities inspection?

   A Daily basis b. weekly basis c. monthly basis d. annual basis
8. On which basis do you clean pump control devises and check pump sumps?

   a. Daily basis b. Weekly basis c. monthly basis d. annual basis
9. A wastewater treatment plant is composed by valves and gates, control control system , flow measuring devices. How do you manage their inspection?

   a. Daily basis b. weekly c. monthly d. yearly e. as necessary

10. When do you use to test the quality of effluent to check its compliance?
    a. Daily b. weekly c. monthly d. yearly f. as necessary

11. When do you check the working behavior of collecting systems (sewer lines and manholes)?
    a. Daily b. weekly c. monthly d. annually e. as necessary

Appendix 2

INFORMATION SHEET

I am Rachael BUSINGE, student at the University of Rwanda, College of Science and technology, in Master's program. One of the requirements in this program is to do a research. My study is about "comprehensive assessment of industrial wastewater treatment systems at selected industries in Rwanda".

The aim of this study is to assess in details the wastewater treatment systems at selected industries in Rwanda. My study thesis is comprised by laboratory activities to assess the compliance of discharged industrial wastewater quality with recommended standards and measure the wastewater treatment efficiency for every selected industry. It also involves the data that are collected by the use of questionnaires admitted by interviews to assess the management practices of plants during operation. Five selected industries are: Kigali special economic zone (KSEZ), UTEXRWA, SKOL, HORIZON SOPYRWA and catchup investment ltd, in addition to 15 Personal participants there to answer the written questions.

The information obtained from this study will be helpful in different aspects including to know the presence of treatment plants and their management practices. You are being asked to take part in this study and to respond genuinely. This questionnaire focuses on assessing on management and inspection procedures of wastewater treatment system at your industry. Your cooperation and willingness is greatly helpful in this study. Your name will not be written in this questionnaire and will never be used in connection with any information you provided.

This questionnaire may take 5 to 10 minutes to complete. There is no possible risk associated with participating in this study except the time spent for completing the questionnaire. All information you give will be kept strictly confidential. Your participation is voluntary and you are not obligated to answer any question you do not wish to answer. If you feel discomfort with any of the questions, it is your right to drop it any time you want. If you have questions regarding this study or would like to be informed of the results after its completion, please feel free to contact the principal investigator. Address of the principal investigator: Mrs.Rchael BUSINGE Cell phone: +250 781 577 328, Email: burachael@gmial.com.

In the event of any problem or concerns/questions you may contact the researcher or the CST/UR Research Ethics Committee. If you are willing to participate in the study, please proceed to the consent form on the next page

Appendix 3

CONSENT FORM

In signing this document, I am giving my consent to participate in the study titled “comprehensive assessment of wastewater treatment systems at selected industries in Rwanda”.

I have been informed that the purpose of this study is to assess in details the industrial wastewater treatment systems at selected industries in Rwanda. I have understood that participation in this study is entirely voluntarily. I have been told that my responses to the questions will not be given to anyone else and no reports of this study ever identify me in any way. I have also been informed that my participation or non-participation or my refusal to answer questions will have no effect on me. I understood that participation in this study does not involve risks. I understood that Mrs. Rachael BUSINGE is the contact person if I have questions about the study or about my rights as a study participant. The following is her contact address. Address of principal investigator: Rachael BUSINGE, Cell phone: +250 781 577 328, E-mail: burachael@gmial.com.

After reading and understanding the aim of this study, I agree to participate. Date21/11/2021

Signature…………………………