ASSESSMENT OF WASTEWATER QUALITY IN NYABUGOGO STREAM/ KIGALI-RWANDA

A Thesis

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DECLARATION A

This thesis is my original work and has not been presented for a Degree or any other academic award in any University or Institution of Learning.

BONANE B. SERGE

April 11th, 2012

DECLARATION B

I confirm that the work reported in this thesis was carried out by the candidate under my supervision.

Dr. SEKABIRA Kassim

April 11th, 2012

APPROVAL SHEET

This dissertation entitled" **ASSESSMENT OF WASTEWATER QUALITY IN NYABUGOGO STREAM/KIGALI-RWANDA**" prepared and submitted by **Bonane Bahati Serge** in partial fulfillment of the requirements for the degree of **MASTERS OF SCIENCES IN ENVIRONMENTAL MANAGEMENT AND DEVELOPMENT** has been examined and approved by the panel on oral examination.

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DEDICATION

To my lovely parents, brothers, sisters and friends who supported me during my studies.

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ABSTRACT

The study assessed the characteristics of wastewater of Nyabugogo stream highlighting on their sources and the nature of contaminants they constitute as Chemical and Physio-chemical. It was anticipated that the water in the stream had high levels of both solid and liquid contaminants originating from domestic and industrial activities and wastewater discharges into the stream. The objectives of the study were to assess the nature of contaminants in the wastewater discharged into Nyabugogo stream and to identify the composition of contaminants by chemical and physio-chemical characteristics.

The study employed both quantitative and qualitative experimental designs to arrive at the results. Water samples from four sites along Nyabugogo stream through Kigali city were collected in well illuminated containers and taken to Energy and Water Sanitation Authority (EWSA) laboratory for analyses. At the sites, many reactive were done directly on the stream waster using conductivimeter and thermometer to determine Electrical Conductivity, Temperature and pH respectively. The results of the study were analyzed using Stata version 8.0 and Pearson correlation coefficient was compulated to establish the relationship between metal concentration and physico-chemical characteristics.

The results showed that a lot of water contaminants such as Copper, Magnesium, Iron, Potassium, Calcium, Nickel, Chloride, Sulphate, and Zinc were contained in the wastewater and once they reach the stream, the characteristics of the stream water change. Thus the stream water constituted contaminants from both domestic and industrial/commercial origins. On average, the water pH of 7.94, temperature of 21.6°C, total dissolved solids 164mg/l, conductivity 318.9µs/cm/l, turbidity 67.93NTU/L and hardness 978mg/l/$CaCO_3$. Ions present in the stream water varied in their average concentrations as Mn^{2+}(0.27±0.0mg/l), Cu^{2+}(0.09±0.0mg/l), Fe^{2+}(0.6±0.2mg/l), K^+(6.5±1.6mg/l), Ca^{2+}(46±26.8mg/l), Zn^{2+}(0.13±0.1mg/l), Ni^{2+}(0.04±0.0mg/l), Cl^-(63.64±7.6mg/l) and $SO4^{2-}$(19.9±7.5mg/l). A Pearson correlation test (r, at 0.05), was used to determine the relationships of interdependences amongst the ions present in the stream water. In dry/wet season, the interactions were Mn/Cu,r =0.94; Mn/K ,r=0.87; K/Ca r=0.96, and Fe/Ni, r=0.98.

In conclusion, water in Nyabugogo stream is polluted by some elements such as potassium, calcium and chlorides due to the increasing discharges of wastewaters from Kigali city activities of both organic and inorganic contaminants. This makes the water unsafe for human consumption as it contains heavy metals. Therefore, proper water treatment before use is vital to reduce or avoid any harmful effects of this water to the Kigali inhabitants. Management of the wastewater at the generation sources can reduce the volumes received by Nyabugogo stream. Further studies are required to look at other sources and preventive innovations of water pollution on Nyabugogo stream.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ACRONYMS

AIDS	:	Acquired Immune Deficiency Syndrome
BOD	:	Biological Oxygen Demand
COD	:	Chemical Oxygen Demand
EPA	:	Environment Protection Agency
EWSA	:	Energy and Water Sanitation Authority
KCP	:	Kigali Central Prison
NTU	:	Nephelometric Turbidity Unit
RDG	:	Rwanda Development Gateway
REMA	:	Rwanda Environment Management Authority
RURA	:	Rwanda Utility and Regulation Authority
TDS	:	Total Dissolved Solids
UTEXRWA	:	Usine de Textile du Rwanda
UNESCO	:	United Nations Educational, Scientific and Cultural Organization
WHO	:	World Health Organization

CHAPTER ONE

INTRODUCTION

Background

Water is present in many areas and can be found on both the surface of the soil and under the surface. Water is vital for the life and survival of humans, animals and all forms of vegetation on the Earth. However, part of the water usable for our needs only account for 1% of the total water present on the planet Earth (UNESCO, 2005). This limited capital, renewable but fragile resource is not only rare but also polluted. This pollution is primarily due to the human activities and changes in technologies. There are two main sources water pollution, that is to say, point source pollution and non-point source pollution. In the developed countries, water pollution is 80% caused by waste water and 75% is from industrial waste water discharges on the ground surface. Thus, the river waters constitute both contaminants of domestic and industrial waste water discharges (UNESCO, 2005).

Wastewater is any water that has been adversely affected in quality by anthropogenic influence. It comprises of the liquid waste discharged by domestic residences, commercial activities, industry, and/or agricultural activities. It encompasses a wide range of potential contaminants and concentrations. Waste water also refers to the municipal discharges and contains a broad spectrum of contaminants resulting from the mixing of wastewaters from different sources and background.

Wastewater from industries, institutions, households, joining the water supply system undergo physical and chemical changes that affect its quality and make it inappropriate for human use, as well as harmful to the environment. This is the same for wastewater in Nyabugogo stream in Kigali city.

Wastewater discharges are most commonly controlled through effluent standards. In industrial effluents, water is polluted by acids, alkalis, detergents, soaps, amines, heavy metals which are released from chemical industries. Food processing wastewater has a high content of organic matter and subsequently a high biological oxygen demand (BOD). Pollutants which may present a hazard if released into waterways and underground aquifers include toxic pollutants, carcinogenic compounds, suspended solids and other substances that can be revealed by BOD and chemical oxygen demand (COD) (Yang,1996).

Provision of safe and adequate drinking water and inadequate sanitation facilities constitutes one of major causes of death and disability as a result of water borne diseases, which is often on epidemic scale among the poor in developing countries (Orewole et al., 2006). However, water of adequate quality and quantity is essential for production and contributes directly to poverty reduction and socio-economic development in many sectors. It is a transparent fact that, much of the water demand cannot be met by present supply in most developing countries and both water quality and quantity are inadequate to support health living standards for the growing urban masses that do not have access to piped water and sewer services. Therefore, diseases, malnutrition disorders, socio-economic problems and poor sanitation and health conditions are largely blamed on lack of adequate and clean water supply in most families in developing countries. Despite its importance, water is the most poorly managed resource in the world (Fakayode, 2005).

Water pollution has disastrous consequences on the population and the environment in general. Lack of clean drinking water and equipment for keeping water clean can kill more children in the world and adults than the wars or HIV/AIDS. World Health Organization (WHO) considers approximately 14,000 deaths including 6,000 children per day related to the absence of clean drinking water. However, people try to reduce or remove pollution by chemical reactions or biological in power stations of cleansing or stations of purification which allow the water treatment (WHO, 2009).

Problem statement

Nyabugogo stream drains through Kigali City and almost the whole population of the city relies on the water from this stream for domestic use, agricultural production, industrial production and power generation. Many industries, car parks, garages, restaurants, markets and washing bays are located along Nyabugogo stream. Due to man's activities, a lot of wastes both liquid and solid are reaching this stream untreated. Also, more sewage and wastewater discharges are reportedly reaching this stream (UNESCO, 2005). In this research, the focus was put on identification of the water contaminants that come from wastewaters generated by various human activities in Kigali City to Nyabugogo stream. This can help to provide adequate information in dealing with the inspection and monitoring of pollution levels in Kigali city and Rwanda as a whole.

General objectives

The general objective of this work was to assess wastewater quality of the Nyabugogo stream and to evaluate the quality of the water at different points along the stream where people obtain their water for use.

Specific objectives

- To assess the physio-chemical characteristics of stream water
- To assess the chemical concentrations characteristics of wastewater

Scope of the study

The study was done in four different sites along Nyabugogo stream in Kigali city. Nyabugogo stream wonders through Kigali city in zig-zag pattern and passes through Nyabugogo wetland in the North to the the South-west of Kigali city. The sites were strategically selected to cover the areas of Nyabugogo stream that traverses the city including locations within Nyabugogo wetland. These sites included: The upstream Gasovu (USG1) at the entrance of Nyabugogo stream into Nyabugogo wetland, Gisozi bridge (GB2) in the middle of the wetland, Nyabugogo bridge (NB3) site at the end point of the wetland while the downstream site at Kiruhura (DSK4) was located at a distance of 500 meters after the Nyabugogo wetland, but along Nyabugogo stream, southwest of Kigali city **(Fig. 2)**.

Significance of the study

The results of this study can help to provide more recent information and understanding regarding water contaminants that are carried along wastewaters reaching Nyabugogo stream. This can help to provide adequate information to government agencies and decision makers in dealing with the inspection and monitoring of pollution levels.

The Kigali city authorities can use the results of the study to easily monitor and evaluate the extent of municipal and industrial discharges into the Nyabugogo stream, and can be helped to establish possible pollution reduction or control measures on Nyabugogo stream.

Definition of key concepts

pH: is a measure of the acidity or basicity of an aqueous solution. Pure water is neutral, with a pH close to 7.0 at 25 °C (77 °F). Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are basic or alkaline.

Wastewater: is any water that has been adversely affected in quality by anthropogenic influence. Wastewater also refers to the municipal discharges and contains a broad spectrum of contaminants resulting from the mixing of wastewaters from different sources and background.

Water pollution: is the contamination of water bodies (e.g. lakes, rivers, oceans, aquifers and groundwater). It occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds.

Water contaminants: are chemical or mixed substances that spoil the purity of water and can make it poisonous.

Water purification: is the process of removing undesirable chemicals, biological contaminants, suspended solids and gases from contaminated water.

CHAPTER TWO

REVIEW OF THE RELATED LITERATURE

Introduction

This chapter deals with the review of the literature relating to the research which is centered in chemical parameters, physicochemical parameters and bacteriological parameters.

The introduction of discharges in Nyabugogo stream cause accumulation of organic matter, inorganic metal and non-metal substances, such as nitrogenous compounds, phosphates, sulfates and other forms of pollutants that may exist in weak concentrations (heavy metals, pesticides and pathogenic substances), which lead to a deteriorating water quality in the stream. These are as a result of effluents (domestic, industrial and agricultural), the run-off into the stream, enriched in undesirable elements, agricultural chemicals, surfaces and/or to a lesser extent with fallen down atmospheric acid rain.

Concepts, opinions, ideas

Nature of impurities and degree of contamination of wastewater

Wastewater contains dangerous substances which cause pollution and contamination of the receiving water bodies (Shaw and Schrudam, 2000).

The average daily amount of waste in the sewage produced by individual, industry is customarily expressed by a related Biochemical Oxygen Demand (BOD) (Yang, 1996).

These effluents have generally been reported to have an adverse effect on water bodies such as lakes, rivers, oceans and groundwater (Abel, 1996). Pollutants in water include a wide spectrum of chemicals, pathogens and physical chemistry or sensory changes. Alterations of water's physical chemistry include acidity, conductivity, temperature an eutrophication (Abel, 1996; Nascimento et al., 2000; Sabae, 2004).

The change of water chemistry is the main associated environmental impact of discharging food processing's effluent on an open water body.

If inadequately treated wastewater were to be discharged to a stream or river, an eutrophic condition would develop within the aquatic environment due to the discharge of biodegradable, oxygen consuming compounds. If this condition were sustained for a sufficient amount of time, the ecological balance of the receiving stream, river or lake (i.e. aquatic microflora, plants and animals) would be upset.

Continual depletion of the oxygen in these water systems would also result in the development of obnoxious odors and unsightly scenes (Carawan 1979).

Wastewater from food processing with its high Biological Oxygen Demand (BOD) rapidly deplete available oxygen supply when discharged into water bodies endangering fish and other aquatic life and also creates septic conditions, generating foul-smelling hydrogen sulfide, which in turn can precipitate iron and any dissolved salts, turning the water black and highly toxic for aquatic life.

State of water quality from Nyabugogo stream in Kigali City

Rwanda is a small landlocked country with an area of 26,338 km^2 (RDG, 2007). It is the most densely populated country in Africa with an estimated 310 inhabitants per km^2. According to the national census, the total population was 8,162,175 in 2002 and annual population growth approximately 3.1% (MINITERE, 2004). Rwanda has abundant water resources. However, the distribution of potable water is still inadequate taking into consideration demand and accessibility. The average rainfall in Rwanda is 1200 mm per year which is highly favourable. However, the rate of access to safe drinking water in the entire country is approximately 54% and does not exceed 44% in rural areas (MINITERE, 2004). The lack of access to potable water has various negative effects on the population such as the time spent fetching water and also water borne diseases.

According to the annual report 2005 by EWSA, only 34% of the water need in urban areas has been covered. Specifically in Kigali City, the water servicing rate was 45%. This means that in 2005, 55% of the population was not provided with treated water.

Kigali City has grown very fast since the 1994 genocide in Rwanda. Kigali City is a young city which was established in 1907 and has 3 districts: Gasabo, Kicukiro and Nyarugenge. The total area under the control of Kigali City Council is 731 km^2, with a total population of 871,098 inhabitants (Kigali City Council - bureau of statistics,2006). Due to this growth in population, sanitation issues are becoming complex due to poor planning in the past. To this end, water resources are affected because of the unsafe disposal of untreated wastewater and a lack of sustainable sanitation infrastructure.

Despite the fact that women collect daily waste from households and commercial areas, many people and industries are still dumping their waste in open water channels. Dustbins have been put in place all over the city. However, the behaviour of the inhabitants is still a determining factor and it is clear that the attitudes and habits of many people in Kigali City contribute to water resource pollution. Behaviour change programmes are vital to change the undesirable activities of the inhabit-ants. Hence, the protection of public health should be based on behaviour change education together with the provision of environmental tools.

Untreated wastewater from such slums is discharged directly into water bodies or wetlands, which are thereby contaminated with multiple pollutants. Hence, Kigali City needs special planning and a sanitation code to cope with the complexity of sanitation and resulting water pollution.

The Nyabugogo stream draining Kigali City is receiving and draining off wastewater as well as solid wastes from Kigali City households and commercial areas. This stream has other tributaries such as the Mpazi River, where solid wastes from public markets and public car parks are dumped. This kind of water pollution in Kigali City is significantly linked to behavioural aspects of its inhabitants.

Plate 1: Discharge of wastewater and disposal of solid waste into river water bodies

Characteristics of wastewater

Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. Table 1 shows the levels of the major constituents of strong, medium and weak domestic wastewaters.

Table 1: Major constituents of typical domestic wastewater

Constituents	Concentration(mg/L)		
	strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids (TDS)	850	500	250
Suspended solids	350	200	100
Nitrogen (N)	85	40	20
Phosphorus (P)	20	10	6
Chloride	100	50	30
Alkalinity ($CaCO_3$)	200	100	50
Grease	150	100	50
BOD_5	300	200	100

Source: UN Department of Technical Cooperation for Development (1985)

Wastewater is a term applied to any type of water that has been utilized in some capacity that negatively impacts the quality of the water. Common examples of wastewater include water that is discharged from households, office and retail buildings, and manufacturing plants. Wastewater may also refer to any water that is utilized in an agricultural facility and is no longer considered fit for human consumption.

The most common example of wastewater is liquid sewage. Discharged from homes and factories alike, sewage usually contains a mixture of human waste, food remnants, water used in washing machines, and any other items that may have found their way into the sewage system. Many municipalities operate wastewater treatment plants that help to purify the sewage and recycle the water for other uses, such as watering lawns. The plant may employ many different devices to recycle the wastewater, including filters and chemical treatments.

Wastewater can also refer to groundwater that is contaminated due to a leaking septic tank or agents such as insecticide, petroleum products, blood, or cleaning liquids. Often, contaminated water can also be run through the municipal filtration system and be prepared for use once again. However, the nature of the contaminants may require additional measures before the water is suitable for use once more.

Table 2: Contaminants, sources and impacts of wastewater

Contaminants	**Sources**	**Impact**
Heavy metals	Industrial waste	Are toxic, may be carcinogenic
Dissolved inorganic solids	Domestic and/or industrial waste	Interfere with effluent reuse
Nutrients	Domestic and industrial waste	Eutrophication
Unmanageable organics	Industrial waste	Taste and odour problems (carcinogenic or toxic)
Pathogens	Domestic wastes	Communicable disease
Biodegradable organics	Domestic and industrial waste	O_2 depletion in receiving water bodies
Suspended solids	Domestic, industrial and erosion	Anaerobic condition in aquatic environment

Source: UN Department of Technical Cooperation for Development (1985)

Wastewater is characterized in terms of its physical characteristics and chemical characteristics. The impurities of wastewater may be settleable, suspended or dissolved substances organic or inorganic, toxic or non toxic in nature (B.H.R Group limited, 1995).

Table 3: Parameters used in the evaluation of water quality

PARAMETERS	**SYMBOL**	**UNIT**
Chemical		
Acidity or Basicity	pH	
Calcium	Ca^{2+}	mg/L
Potassium	K^{+}	mg/L
Chloride	Cl^{-}	mg/L
Sulphate	SO_4^{2-}	mg/L
Trace metal		mg/L
Physical		
Electrical conductivity	ECw	µs/cm
Temperature	T^{o}	^{o}C
Hardness		mg/L_{caco3}
Total Dissolved Solids	TDS	mg/L
Turbidity		NTU
Organic matters	OM	Mg

Physical characteristics of wastewater

Temperature

Temperature is a way to measure the warmth or coolness of an object, medium, body, or system. Temperature also plays an important role in determining the rate and extent to which chemical reactions occur. Temperature also controls the type and quantity of thermal radiation emitted from wastewater or other surface.

The temperature of wastewater is generally higher than that of the natural water. Temperature is an important parameter because its effect on chemical reactions and reactions rates, aquatic life and sustainability of water for beneficial uses. (Sawyer et al 2003)

Turbidity

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye. The measurement of turbidity is a key test of water quality. It is a measure of the degree to which the wastewater loses its transparency due to the presence of suspended particulates. Turbidity is measured in NTU: Nephelometric Turbidity Units. The instrument used for measuring it is called turbidimeter.

Turbidity is practical physical characteristic of water and is an expression of the optical property that causes light to be scattered or absorbed by particles and molecules rather than transmitted in straight lines through a water sample. It is caused by suspended matters or impurities that interfere with the clarity of water. Simply stated, turbidity is the measure of relative clarity of liquid. The standard method for determination of turbidity is based on the Jackson turbidimeter (Sandar, 1996).

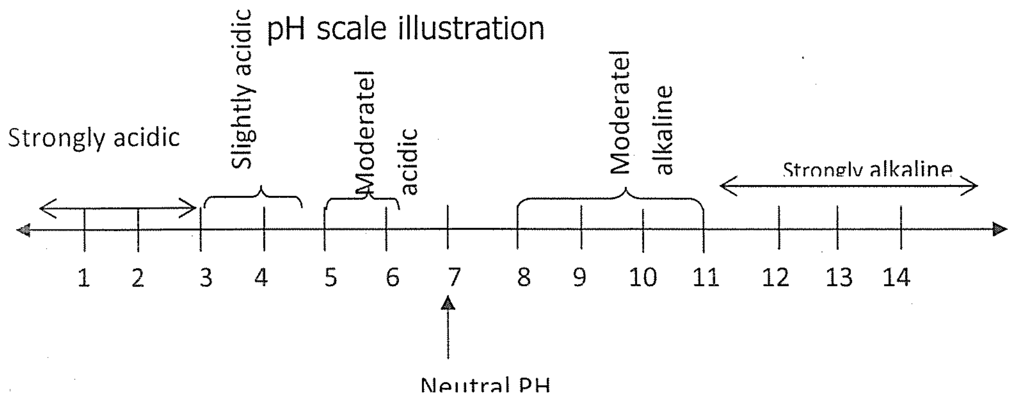
In water bodies such as lakes, rivers and reservoirs, high turbidity levels can reduce the amount of light reaching lower depths, which can inhibit growth of submerged aquatic plants and consequently affect species which are dependent on them, such as fish and shellfish. High turbidity levels can also affect the ability of fish gills to absorb dissolved oxygen.

Consequences of high turbidity to Environment and life is that the suspended particles absorb heat from the sunlight, making turbidity water become warmer, and so reducing the concentration of oxygen in the water, some organisms also can't survive in warmer water. The suspended particles scatter or absorb the light, thus decreasing the photosynthesis activity of plants and algae.

Water pH

The pH scale is based on logarithm and runs from 0.0 to 14.0, with 7.0 being neutral. Readings less than 7.0 indicate acidic solutions, while higher readings indicate alkaline or basic solutions. Some extreme substances can score lower than 0 or greater than 14, but most fall within the scale. (Frederick J. Kohlmann).

pH scale illustration



Total dissolved solids

Total Dissolved Solids (TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid or liquid waste in: molecular, ionized or micro-granular (colloidal sol) suspended form.

Generally principal application of TDS is in the study of water for streams, rivers and lakes. Although TDS is generally considered not as a primary pollutant, it is rather used as an indication of wastewater characteristics (Norby,2000). Total dissolved solids are differentiated from total suspended solids (TSS), in that the latter cannot pass through a sieve of two micrometers and yet are indefinitely suspended in solution. Some TDS constituents are calcium, chlorides, magnesium and sulphate.

Electrical conductivity of water

Conductivity is a measure of the ability of water to pass an electrical current. This ability depends on the presence of ions on their total concentration mobility and valence. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 degrees Celsius (25°C).

Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through.

Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate.

Water colour

Pure water has a slight blue color that becomes a deeper blue as the thickness of the observed sample increases. The blue tint of water is an intrinsic property and is caused by selective absorption and scattering of white light. Impurities dissolved or suspended in water may give water different colored appearances.

Chemical characteristics of wastewater

Nitrates (NO_3^-)

They are present in the ground at the natural state, like residues of the life of the plants, the animals and people. But they come mainly from agriculture (artificial fertilizers and animal manure for example liquid manures and manures) and from the domestic and industrial wastes.

The nitrates present in water have multiple origins:

- Not purified waste water.
- Effluents coming from the worn water purification and
- Wastes liquidate cattle sheds.

The nitrates are toxic when they are with excessive concentrations in the drink water.

Indeed, the nitrates which are the oxidized shapes of nitrogen once transformed into nitrites by the organization of infant or babies can cause the transformation of haemoglobin into methaemoglobinae (causing methaemoglobinaemia) thus involving a bad transfer of oxygen towards the cells. In the most serious cases, they can result in death.

For the older individuals, the nitrates are in addition suspected to take part in the appearance of cancers of the digestive system.

Chlorides and Sulphates (Cl^- and SO_4^{2-})

The chlorides are nonmetal chemical compounds resulting mainly from the chemical and agro-alimentary industries. The content chlorides generally increase with the degree of mineralization of water. Pollution brings to surface water considerable quantities of chlorides.

The human excretions in particular the urine, which is rich in chlorides, are responsible for a contribution of approximately 7g of ions Cl^- by anybody because the human organism eliminates totality from chlorides in the whole of its food. The chemical industry as well as dyeings rather frequently uses sulphuric acid in great quantity for the exchanging resins of ions. As well as chlorides, the sulphated salts rejected in great quantity can have a harmful action on the ecosystems. Strong sulphate concentrations cause gastro-intestinal disorders and can give an unpleasant taste to water.

Manganese (Mn^{2+})

The wastewater generated from the manganese electrolysis primarily come from three sources, which are filter press washing, electrode plate cleaning and the cleaning of the workshop floors. The wastewater generated from the above sources contains a great deal of suspended solids, soluble manganese, non ionic ammonia and also a small quantity of chromium. The common method for Mn-containing wastewater treatment is to use soluble alkaline as treatment agent. The manganese in the wastewater reacts with hydroxyl and forms insoluble manganese hydroxide to precipitate.

Manganese is also occasionally present, seasonally, in surface waters when anaerobic decay processes in sediments is occurring (Ontario, 2006).

Iron (Fe^{2+})

Iron is a major constituent of the earth's crust. It occurs naturally in groundwater and surface waters. Drinking waters containing iron are not known to cause any harmful effects in humans. Iron does interfere with laundering operations, imparts objectionable stains to plumbing fixtures, causes difficulties in distribution systems by supporting growths of iron bacteria and imparts a taste to water and products manufactured using water containing iron which is detectable at very low concentrations. For these reasons the U.S. Public Health Service Drinking Water Standard recommended limit for iron in public water supplies is 0.3 mg/L.

In groundwater and anaerobic surface waters, within the pH range of natural waters, iron is present in the reduced state, ferrous, Fe^{2+}, in its soluble forms. When such waters are exposed to air so that oxygen can enter or an oxidizing agent such as chlorine is introduced, the ferrous iron is converted into the oxidized form of iron, ferric, Fe^{3+}. These waters become turbid and highly unacceptable from the aesthetic point of view due to the oxidation of iron and the formation of colloidal precipitates.

Nickel (Ni^{2+})

Most nickel on Earth is inaccessible because it is locked away in the planet's iron-nickel molten core, which is 10 % nickel. The total amount of nickel dissolved in the sea has been calculated to be around 8 billion tones. Organic matter has a strong ability to absorb the metal which is why coal and oil contain considerable amounts

Nickel is released into the air by power plants and trash incinerators. It will than settle to the ground or fall down after reactions with raindrops. It usually takes a long time for nickel to be removed from air. Nickel can also end up in surface water when it is a part of wastewater streams.

Calcium (Ca^{2+})

Calcium occurs in water naturally. Seawater contains approximately 400 ppm calcium. One of the main reasons for the abundance of calcium in water is its natural occurrence in the earth's crust. Rivers generally contain 1-2 ppm calcium, but in lime areas rivers may contains calcium concentrations as high as 100ppm. Examples of calcium concentrations in water organisms: seaweed luctuca 800-6500 ppm (moist mass), oysters approximately 1500ppm (dry mass).

In a watery solution calcium is mainly present as $Ca^{2+}_{(aq)}$, but it may also occur as $CaOH^{+}_{(aq)}$ or $Ca(OH)_{2(aq)}$, or as $CaSO_4$ in seawater. Calcium is an important determinant of water harness, and it also functions as a pH stabilizer, because of its buffering qualities. Calcium also gives water a better taste.

Industrial wastewater discharge practices causing pollution.

Two industries operating in Gasabo and another in Nyarugenge districts in Kigali City called "Usine Textiles du Rwanda" (UTEXRWA) and SULFO RWANDA respectively were selected.

SULFO RWANDA is a manufacturing and trading company which produces assorted types of detergents (solids and liquids), cosmetics, confectionaries, mineral water and cartons. The company also trades batteries (including battery acids), tires, gasses, fridges, cooking ranges, etc and runs a car maintenance garage. SULFO RWANDA is situated within the area of Kigali City centre. The land covered by the industry is not traversed by a river or stream. It is however well drained as it is on a slope facing Nyabugogo valley, above Kigali Central Prison (KCP) and a poor neighborhood of Muhima. The slope conveniently drains surface water resultin from domestic and municipal wastewater towards the valley.

Two types of wastewater are produced in the industry; and these are chemical waste and human waste. Liquid chemical waste results from cleaning production vessels, chemical containers and a small amount from spillages. SULFO RWANDA does not have a liquid chemicals waste treatment plant, besides that strong acids, alkali and organic compounds are the main raw material for production of detergents and cosmetics. Liquid chemical waste produced is discharged into two filtration pits (soak), one for detergents and the other for cosmetics plants. The information obtained during field trips revealed that, before construction and use of this ground filtration pit, there were cases of complaints from residents in Muhima Sector on the unpleasant wastewater believed to have been flowing from the industry through public drains..

Human wastewater produced in the company comes from a canteen and toilets. The type of toilets used are flush toilets (water closet) connected to septic tanks with soak away pit for liquid waste, and the solid part is emptied when it is full by septic tanks emptying trucks and transported to Nyanza open dump site.

The second industry called UTEXRWA is a textile manufacturing company which produces more than fifty (50) textile products, ranging from cotton, polyester, viscous and mixed brands. The company is located in the neighbourhood called Gaculiro, Gasabo district about 5 km from the city centre. Like the majority of industries in Kigali, the land covered by the company is in the wetland with swamps and streams which pour into Nyabugogo river, besides that textile manufacturing use very strong chemicals as raw material in dyeing and other production processes.

There are two types of wastewater produced in the company. These are the effluent from production lines including spillages; and human waste produced in the workers kitchen, canteen and toilets. The effluent from production line contains dyes and strong alkali, including sodium hydroxide (caustic). For liquid chemical waste, UTEXRWA has effluent treatment plant. This plant treats the waste in four steps which involves dosing of hydrochloric acid, aluminium sulfate and cow dung, in the dose which depend on the initial concentrations. By the end of treatment, the effluent is usually have passed through raw effluent tank, clariflocculation tank, surface aeration tank and secondary clarifier tank. All this processes are intended to neutralize strong alkali effluent from production line to the pH of 7-9 before it is discharged into the environment. However, it was found that the treatment plant produces very high pH end-product of up to 12. Physical observation of final effluent also showed a dark brown colour with suspended solids, and this indicates that the effluent have high turbidity. The end-product is discharged in streams which pour into Nyabugogo River.

Requirement standards

Wastewater recovered from industrial source and returned to the natural environment is subject to some requirements. In general if water is to be discharged into hydrosphere, it should not contain a dangerous level of toxic chemicals and it should not supply excessive quantities of readily oxidazable compounds and it should not contain source nutrients which would support microbial growth .The treatment protocols depend on what contaminants have been introduced during the industrial processes. In most cases, the wastewater can not be discharged into natural water body such as rivers, lakes or ocean without any treatment. In the last days industrial effluents are under strict regulation to limit or eliminate discharge of known contaminant to public system.

Table 4: Requirement Standards for discharge wastewaters from industries into aquatic environment by EPA (Environmental Protection Agency) and REMA

Parameters	Standard levels(mg/L)	
	EPA	REMA
Ph	6-9	6-9
Total dissolved solid	≤2100	≤2000
Electrical conductivity*	≤1200	≤1200
Dissolved oxygen	4.5-8	6.0
Biological oxygen demand	≤5.0	5.0
Chemical oxygen demand	≤200	250
Sodium (Na^+)	6.3	6
Potassium (K^+)	2.3	2.0
Calcium (Ca^{2+})	15	15
Magnesium (Mg^{2+})	4.1	5
Chloride (Cl^-)	7.8	6.0
Bicarbonate (HCO^{3-})	58.4	60
Sulphate (SO_4^{2-})	11.2	13
Hardness	0-80	0-80
Nitrate (NO_3^-)	10	10
Zinc (Zn)	5.0	5.0
Iron (Fe)	3.5	3.5
Nickel (Ni)	2.0	2.0
Copper (Cu)	3.0	3.0

*:µs/cm

CHAPTER THREE

MATERIALS AND METHODS

Research design

The research design was done experimentally to assess the wastewater quality in Nyabugogo stream and some variables such as chemical, physicochemical and bacteriological parameters were looked at to achieve the relationship between the set standard quality and the obtained values in the experimental laboratory tests.

Study area and sampling sites.

The Nyabugogo stream is located in Kigali City on 1°55′59″ south latitude and 30°2′50″ east longitude. It is originating from Gaculiro hill exactly in Gasovu sector where its upstream is located. The upstream and the downstream are running alongside the Nyabugogo wetland. Some meters after the upstream the area is characterized by heavy industrial and establishments. The downstream is characterized by commercial institutions and garages. Between the up and down stream, there is Nyabugogo wetlands (**Table 5.**)

In this work, samples was collected on 4(four) different places or sites namely Upstream Gasovu (USG1), Gisozi bridge (GB2), Nyabugogo bridge (NB3) and downstream-Kiruhura (DSK4).

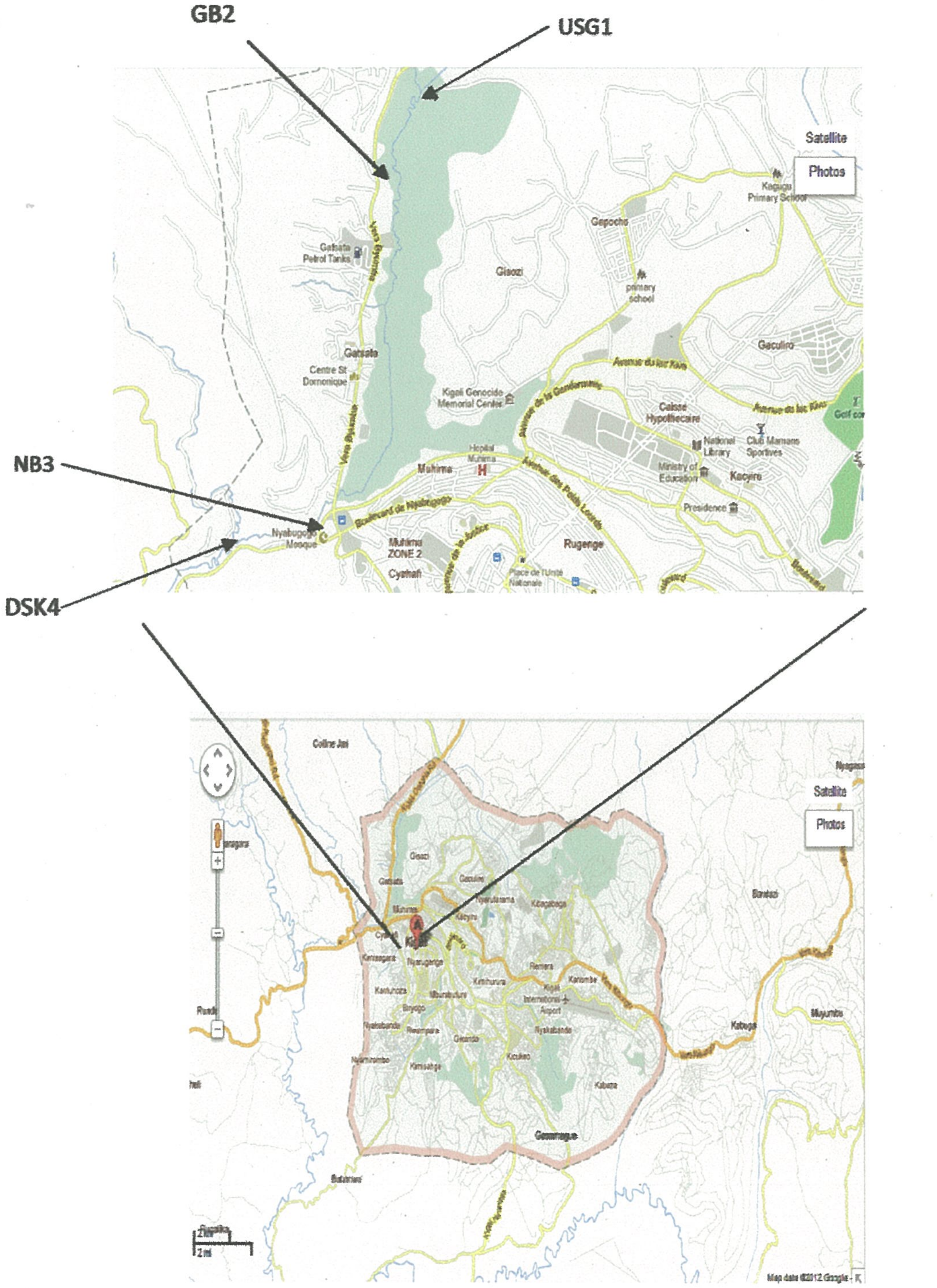


Fig 2. MAP OF KIGALI CITY SHOWING SAMPLE SITE ALONG NYABUGOGO STREAM

Table 5: Description of activities/establishments of the study area

Location	Code	GPS Coordinates		Activity/establishment
Upstream		Northing	Easting	
Gasovu primary school	USG1	2454180	0195019	Residential, industry, carpentry works, school
Midstream				
Gisozi bridge	GB2	2454012	0195001	Commercial, residential, petrol station, vehicle traffic, school
Nyabugogo bridge	NB3	2453511	0194504	Commercial, horticulture, garages, industries, slum, market
Downstream				
Kiruhura	DSK4	2453460	0194407	Commercial, residential, petrol station, garages, market, car traffic

Sample selection

The study used samples of water from the upstream Gasovu (USG1), Gisozi bridge (GB2), Nyabugogo bridge (NB3) and downstream Kiruhura (DSK4). These sites were chosen at strategic points as at the entrance of Nyabugogo stream through Nyabugogo wetland and 500 meters after the stream leave the wetland, so as to have significant samples that could contain a wide range of materials from industries and municipal activities into the stream. From these sites, very important concentrations of both dissolved and non dissolved waste contaminants in Nyabugogo stream were obtained and these were used to assess the water polluting activities in Kigali City. Water from the four sites along Nyabugogo stream was taken to EWSA laboratory for both qualitative and quantitative analysis.

Sampling procedure

Water samples were collected from the four sites using plastic containers of 500mL which were properly corked. The samples were placed in a dark box to avoid external light from reaching the water, and cause some life processes to change the characteristics of the water. The well packed samples were then taken to the EWSA laboratory for experimental analysis. At the same time, pH, temperature,Turbidity, total dissolved solids, conductivity of the water were measured directly on site using conductivimeter and for analyzing the concentration of Mn, Cu, Fe, K, Ca, Zn, Ni, Cl and $SO4^{2-}$ water samples were taken to the EWSA laboratory.

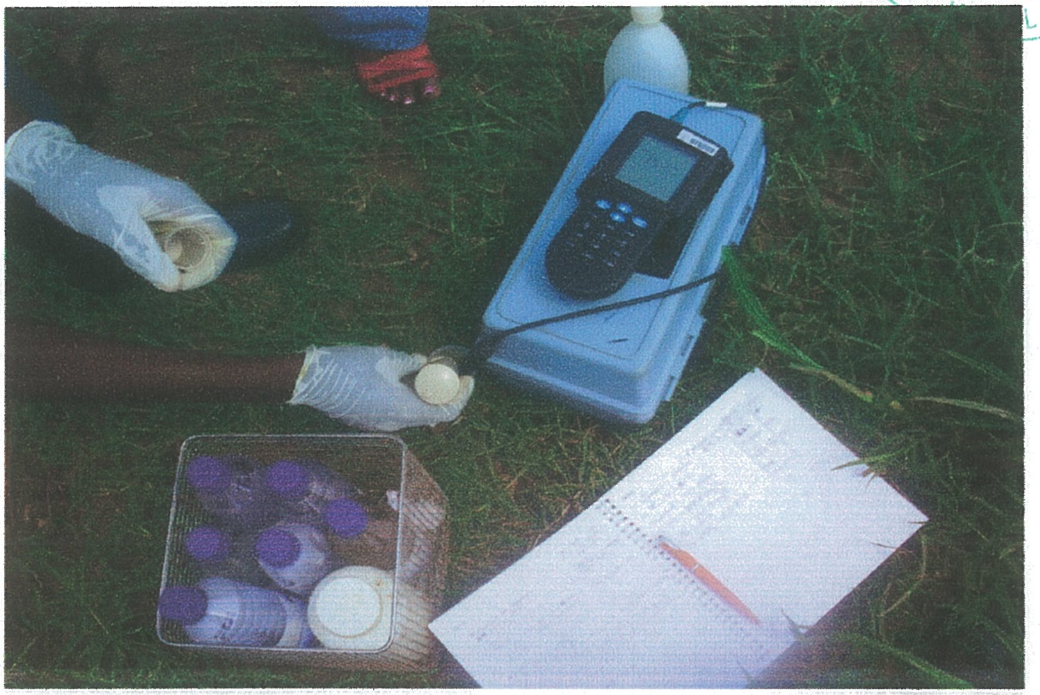


Plate 2: Recording of T°, TDS, pH, Conductivity and Turbidity using Conductivimeter.

Equipments

Physicochemical characteristics

A combination of water testing kits and meters that use chemicals or electronics were used to perform the water quality tests. The tests conducted included pH, turbidity, electrical conductivity, temperature and total dissolved solids. To measure the pH, a meter model pHTestr2 waterproof was used. To measure the temperature and the turbidity, a turbidimeter was used. The turbidity of the water is measured by the Turbidimeter model 2100P. A Conductivity/TDS Meter was used to determine the total dissolved solids and conductivity of the water. The Spectrophotometer 500 model was used to determine the chemical composition (Mn, Cu, Fe, K, Ca, Zn, Ni, Cl and $SO4^{2-}$ of the wastewater samples. Volumetric measurement were done using bottles of 500ml, pipettes of 25 mL and beakers of 250 mL capacity were utilized to graduate the water quantity.

In addition to the materials used at the laboratory (test-tubes, burettes, etc.), other types of materials were used for analyzing some variables in the water samples. Bottles were filled with samples of wastewater, their temperature measured using thermometer of capacity of 0-110°C; conductivity, total dissolved solids (TDS), pH and turbidity were measured using conductivimeter. Hardness in water was determined later in the laboratory using titration technique using soap solution.

Chemical characteristics

All chemical elements were determined using the same procedure but the rate of reaction and products formation was determined differently using the following procedure below for determining the presence of manganese, copper, iron, potassium, calcium, zinc, nickel, chlorides and sulfates.

10mL of deionized water were poured into a square sample cell. One packet of reagent powder is added to another square sample cell and swirled it to mix. Pipet 1.0mL of specific sln into each sample cell and swirl it to mix again. A color appears if the chemical element is present. Within 5 minutes after the timer expires, wipe the blank and insert it into the cell holder with the fill line facing the user. Press zero of the spectrophotometer 500 and then wipe the prepared sample and insert it into the cell holder with the fill line facing the user.

The apparatus that was used for analyzing samples included the spectrophotometer 500 and test tubes graduated at 10ml which were rinsed before use with distilled water.

To determine manganese in the sample wastewater, 10ml of deionized water were put into a square sample cell. And then the contents of one Ascorbic Acid powder pillow were added to each cell. The mixture is shaken and inverted to dissolve the powder. After 12 drops of alkaline-cyanide reagent solution were added to each cell and swirled gently to mix. After some minutes, 12 drops of PAN indicator solution 0.1% were added to each sample. Again the mixture swirled gently. The end point was expected by observing an orange colour appearance if manganese was present.

The procedure was repeated to analyze the other elements and different reagents were used for each element such as ferrover iron reagent powder for iron, nitraver 5 nitrate reagent powder for nitrate, phthalate-phosphate reagent powder and EDTA 0.02N for nickel, as shown in Table 6.

Plate 3: Chemical and Physio-chemical characteristics analysis in the laboratory

Table 6: Showing a summary of the procedures for tests of wastewater characteristics.

Variable/Element	Procedure
Mn^{2+}	10ml of wastewater, ascorbic acid powder,12 drops of alkaline-cyanide reagent solution,12 drops of PAN indicator solution 0.1%.
Fe^{2+}	10ml of water sample, ferrover iron AccuVac Ampul
Ca^{2+}	50ml of wastewater sample, add muredixe, 2 drops of sodium hydroxide solution 5.0N, EDTA 0.02N.
Ni^{2+}	10ml,Reactifs(phthalate-phosphate powder), EDTA 0.02N, 0.5ml of 0.3% PAN indicator
NO_3^-	10ml of water sample, nitraver 5 nitrate reagent powder.
Zn^{2+}	20ml of sample, Zincover5 reagent powder pillow, cyclohexanone.

Statistical analysis

Statistical analysis was conducted using Stata 8.0 version software. Pearson correlation coefficient was computed to establish the relationship between metal concentration and physico-chemical characteristics.

CHAPTER FOUR

THE PHYSIO-CHEMICAL CHARACTERISTICS OF STREAM WATER

Abstract

This study was carried out to assess the physio-chemical characteristics of Nyabugogo stream water. Water samples at selected sites USG1, GB2, NB3 and DSK4 were analyzed for physical quality of water. Conductivimeter was used to determine the pH, TDS, Conductivity, Turbidity and hardness while temperature was determined by pHTestr2 model. Results indicated that hardness was directly correlated with the high concentration of calcium come from households and industry. Water was poor physio-chemical contaminated referring the acceptable limit standard set by EPA and REMA and this renders the water inadequate for direct human consumption.

Methods

Samples were collected from four (4) different sites using 250ml bottles for physicochemical characteristics analysis of water quality characteristics. Water samples were collected at the same time for pH, T°, TDS, Conductivity (EC), Turbidity and Hardness. Conductivimeter and pHTestr2 water proof were used to determine these characteristics.

Water quality was determined by comparing the physical and chemical characteristics of a water sample obtained from Nyabugogo stream alongside using water quality guidelines or standards set by RURA/EPA. Drinking water quality guidelines and standards are designed to enable the provision of clean and safe water for human consumption, thereby protecting human health.

Results and discussion

Assessment of physio-chemical parameters of wastewater

Table 7: Physio-chemical characteristics of wastewater during dry season (sample 1)

CODE	pH	T°(C)	TDS(mg/l)	Conduc(μs/cm)	Turb(NTU)	Hardn
USG1	7.7	21.7	176.8	338	15.8	114
GB2	7.4	21.7	286	555	14.6	162
NB3	7.8	22.4	148.3	294	92.3	90
DSK4	7.7	22.8	146.4	294	97.5	92
REMA	6-9	≥3	≤2100	≤1200	30	80
EPA	6-9	≥3	≤2000	≤1200	30	80

T°: temperature, TDS: total dissolved solids, Cond: conductivity, Turb:turbidity, Hardn: hardness(mg/L_{CaCO3}).

The pH at all sites ranged from 7.4 to 7.8, affecting a neutral to slightly alkali pH and is within acceptable range of potable water. Temperature ranged from 21.7 to 22.8°C. Total Dissolved Solids of wastewater ranged from 176.8mg/L at USG1 to 286mg/L at GB2 and this is attributed to the low dumping quantity of solids remaining in the industries located at this area. The turbidity is significantly greater at the downstream 97.5NTU than at the upstream14.6NTU because of the high concentration of suspended particles at the downstream which are as the result of increased waste disposal into the downstream and other activities of laundry, cars washing bays, wastewater from restaurants and hotels among others.

Table 8: Physio-chemical parameter of wastewater during the wet season (sample 2)

CODE	pH	T°(°C)	TDS(mg/L)	Conduct(µs/cm)	Turb(NTU)	Hardn
USG1	8.3	21.7	146.5	286	76.8	160
GB2	7.3	21	213	410	71.5	160
NB3	8.8	20.6	97.4	188.1	90.2	100
DSK4	8.5	20.6	97.6	186.1	84.8	100
EPA	6-9	≥3	≤2100	≤1200	30	80
REMA	6-9	≥3	≤2000	≤1200	30	80

T°: temperature, TDS: total dissolved solids, Cond: conductivity, Turb: turbidity, Hardn: hardness.

The value of pH at GB2 7.3 during the wet season is the lowest of all the sites because of low concentration of ions H^+ . The temperature at this sample 20.6 °C is low than of the previous one because of the period of this sampling was in rainy season. The highest value of TDS is 213mg/l located at GB2 due to the great amount of remaining solids dump at this area of the stream. In turbidity, the average value in wet season is high 80.8 comparing to dry season 55.1 because of the sampling was done in rainy season and a great amount of rainfall was directed conducted to the stream. The range is above the threshold value of 30 recommended by both EPA and REMA.

pH measurements

The pH of liquid effluents is considered to be an extremely important parameter as it effects physical, chemical and biological environment. Strongly acidic and alkaline pH causes corrosion of sewers and plumbing materials (Manahan, 1993).

Wastewater samples from dry season taken from USG1 show that pH is ranged from 7.7 to 8.3 in wet season and 7.3 to 8.8 which the range is within acceptable value of aquatic water of pH 6.4-9.0 set by EPA and RURA and this effluent might not have a dramatic effect or influence on aquatic life.

At GB2, pH is 7.4 in dry season and 7.3 in wet season which are the smallest among the sites measured.

At NB3 meaning wastewater shows the result that is 7.8 in dry season and 8.8 in wet season which exhibit a slight alkaline pH and have little effect on most water organisms because it has with a pH range from 6 and 9 of standards set by EPA. The reason for the alkaline range may be due to mixing up of the alkaline chemicals, soap and detergents etc. from industrial, commercial (abattoir) and residential activities.

According to EPA and RURA, all discharged effluent must be in tolerance range extending from 6.0 to 9.0. Readings less than 6.0 and greater than 9.0 have a dramatic affect or influence on aquatic life.

Wastewater temperature

During present study the temperature range was between 21.7-22.8°C at sample 1 and 20.6-21.7°C at sample 2. The lowest value of temperature is found at USG1 and GB2 (21.7°C) and the highest value is at DSK4 (22.8) at the sample 1 and this is due of the season (dry season) the water was sampling. At sample 2, the lowest value was 20.6°C at NB3 and DSK4 and the highest value was 21.7°C. This sampling was measured in rainy season.

High temperature favors the breakdown of organic carbon by micro-organisms which produce organic acids therefore production of such acid lowers the pH (Manahan, 1993).

Total Dissolved Solids

The total dissolved solids (TDS) ranged between 146.4mg/l and 286mg/l at site 1(during the dry season), the second sampling (during the wet season) results ranged between 97.4-213mg/l. The results in the Table 7 and 8 showed variation of TDS within different sampling location. The TDS was lower in samples of waste water at DSK4 with 146.4 mg/l and higher at GB2 with 286mg/l during the first sampling and during the second sampling the lowest value was 97.4mg/l at NB3 and the highest value was 213mg/l.

Note that Total Dissolved Solids (TDS) is mainly consisted of some amounts of organic matter and inorganic salts like calcium, chlorides, sulfates, magnesium and potassium. Thus the high value of total dissolved solids means high quantity of inorganic and organic matters affects the conductivity of the water. At the second site (GB2), there is a high amount of the total suspended solids which is mainly due to the discharge of industrial and domestic waste. And according to analysis done, results from both sampling location were within the minimum allowable limit of EPA and RURA standards (≤2000mg/l).

Electrical conductivity

The electrical conductivity results in sample 1 were in range of 294-555µs/cm and in sample 2 were 186.1-410 µs/cm. The high values were found at GB2 both in sample 1 and sample 2 with 555µs/cm and 410µs/cm. This is due to the high concentration of dissolved ions in water come directly from the industry which is located before the point of sampling and according to the national and international standards of Rwanda and EPA the wastewater effluent must be ≤ 1200µs/cm. Thus these values obtained from those sites are below the maximum permissible limits.

Turbidity

Turbidity results in sample 1 and sample 2 were in range of 14.6-97.5 NTU and 71.5-90.2 NTU respectively. Referring to the Table 6 and 7, all values are high which are above of the RURA and international limits standards set by EPA except at USG1 and GB2 in sample 1 which their values are 15.8 and 14.6 NTU respectively. These last results fall in the range of standards given by EPA and RURA (≤30 NTU).

Turbidity of the water has a big influence of visual information on the water and translates the presence of the suspended particles in water. Thus the high value of turbidity influences the colour to be high.

Hardness

Total hardness in water is mainly represented the concentration of calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}). The ions responsible for hardness are mainly bicarbonates, chlorides, nitrates and silicates.

Referring to the Table 7 and 8 the lowest values of hardness are found at NB3 in sample 1 with 90 mg/L_{CaCO3} and at NB3 and DSK4 in sample 2 with 100 mg/L_{CaCO3}.

According to the international limit standards (0-80mg/l) these results showed that the water was very hard due to high concentration of calcium.

Table 9: Difference in mean and standard deviation (SD) of physico-chemical characteristics from dry and wet season samples

Sites	pH	Temp	TDS	Conduct	Turbid	Hardn
USG1	8± 0.42	21.7± 0.00	161.65± 21.42	312 ±36.77	46.3 ±43.13	137 ±32.52
GB2	7.35 ±0.07	21.35 ±0.49	249.5 ±51.61	482.5 ±102.53	43.05 ±40.23	161 ±1.41
NB3	8.3 ±0.70	21.5± 1.27	122.85 ±35.99	241.05 ±74.89	91.25 ±1.48	95 ±7.07
DSK4	8.1 ±0.56	21.7± 1.55	122 ±34.50	240.05 ±76.30	91.15 ±8.99	96± 5.65

Sites: USG1:Upstream Gasovu1; GB2:Gisozi Bridge2; NB3:Nyabugogo Bridge3; DSK4:Downstream Kiruhura4

Conclusion

Wastewater from different industrial and households' establishments that flow into Nyabugogo stream have not adverse effect on human health and the environment. Physico-chemical characteristics are within acceptable limits of disposal and therefore minimal effect on the ecosystem except the hardness which is high due to the high concentrations of calcium.

CHAPTER FIVE

CHEMICAL CONCENTRATION CHARACTERISTICS OF WASTEWATER

Abstract

The objective of this study was to assess the chemical concentration characteristics of wastewater in Nyabugogo stream. Water samples were selected at four (4) sites included USG1, GB2, NB3 and DSK4 along the stream. Titration was employed to determine the concentration of heavy metal and spectrophotometer apparatus were used to arrive to the results. The findings showed that water was contaminated by the high concentration of potassium, calcium, chloride and sulphates due to wastewater dumping directly from households, garages and industry. According to the results water was contaminated and inadequate for consumption and for agriculture.

Methods

Water samples were collected from four (4) different sites using plastics bottles of 500ml, pipettes for analysis of water quality characteristics. To minimize the potential for biodegradation between sampling and analysis, samples are stored in cooler box between sampling and analysis.

The analyses were done in the EWSA laboratory using the spectrophotometer 500 and reagents to determine the chemical concentration of elements. Chemical characteristics were analyzed differently using various wavelength and precise reagents; Mn (Ascorbic Acid Powder and Alkaline-Cyanide), Fe (Ferrover Iron

AccuVac), NO_3^- (Nitraver 5 nitrate), Ni (Phthalate-phosphate, EDTA 0.02N), Zn (Zincover 5), Cl^- (Mercuric Thocyanate solution).

Assessment of chemical characteristics of wastewater

Table 10: Difference in mean and standard deviation of chemical characteristics of wastewater in mg/L

Sites	Mn	Cu	Fe	K	Ca	Zn	Ni	Cl^-	$SO4^{2-}$
USG1	0.15±0.1	0.03±0.0	0.17±0.1	7.6±3.6	54±36.7	0.04±0.0	0.01±0.0	20.7±0.8	30.5±17.6
GB2	0.58±0.0	0.07±0.0	0.36±0.3	7.4±0.0	70±42.4	0.06±0.0	0.01±0.0	76.85±18.1	39±8.4
NB3	0.19±0.0	0.25±0.3	1.06±0.1	6.35±2.3	30±14.1	0.30±0.2	0.11±0.1	78.55±7.8	5.5±2.1
DSK4	0.16±0.0	0.01±0.0	0.81±0.3	4.6±0.5	30±14.1	0.14±0.0	0.02±0.0	78.45±4.9	4.5±2.1
*EPA	4.1	3.0	3.5	2.3	1.5	5.0	2.0	7.8	11.3
**REMA	5.0	3.0	3.5	2.0	1.5	5.0	2.5	6.0	13.0

*Environment Protection Agency,(2009) maximum permissible limits of wastewater into aquatic ecosystem

**Rwanda Environmental Management Authority,(2009) maximum permissible limits of wastewater into aquatic ecosystem

Results and discussion

After doing the statistical analyses of the present study, the 4 sites USG1, GB2, NB3 and DSK4 investigated were found contaminated with chemical elements such as Potassium, Calcium and Chloride which their concentration were high while USG1 and GB2 were contaminated with sulphate.

Wastewater can be used for irrigation but it has been generally acknowledged that the greatest hazard associated with the recycling of wastewaters is (i) the chemical component discharged from sewage and industries that contribute to oxygen demand and lead to a destabilized aquatic ecosystem and (ii) the potential presence of microbial pathogens, that constitutes a risk for the transfer of infections to humans or animals if they are exposed to pathogens in the wastewater.

Manganese

The lowest average concentration obtained was 0.15±0.1mg/L at USG1 and the highest concentration was 0.58±0.0mg/L at GB2. According these results with the allowable limits of wastewater disposal 4.1mg/l by EPA and 5mg/l by REMA, the results are below of the allowable limits which have no effects on the ecosystem.

Iron

The lowest average concentration for iron was 0.17±0.1mg/L at USG1 while the highest average concentration was 1.06±0.1mg/L at NB3. The reason of high concentration of iron at this site is the discharge of wastewater from many garages and industries that are located at this point. But according to the acceptable limits of wastewater disposal 3.5mg/l by REMA these concentrations have no effects in the water.

Copper

The lowest average concentration of copper in the wastewater was 0.01±0.0mg/L at DSK4 and the highest average concentration was 0.25±0.3 mg/L atNB3. Compared to the EPA/REMA acceptable limits (3mg/L) these values are below the limit and there is no negative impact on the ecosystem.

Calcium

During the present study the lowest average concentration of calcium in the wastewater was 30±14.1mg/l, located at two different points which are NB3 and DSK4 and the highest average concentration is 70±42.4 mg/L at GB2. Comparing these values with the allowable limits of wastewater disposal of 15mg/l, they seem to be above the acceptable limits and therefore there are effects on the ecosystem.

Calcium is largely responsible for water hardness that why at these points where the concentration of calcium is the high the hardness is also significant.

Zinc

The level of zinc is below the detection limit upstream 0.04±0.0mg/l of Nyabugogo stream and starts to increase especially after the Kabuye sugar refinery factory where the highest peak of zinc level 0.30±0.2mg/l all along the Nyabugogo stream is located. During present study the results of analysis of wastewater sample find out the lowest average concentration of zinc value was 0.04±0.0 mg/L at USG1 and the highest value was 0.30±0.2 mg/L at NB3 which are below the EPA/REMA standards of 5.0mg/L. Then there is no negative impact on the ecosystem.

Potassium

The lowest value concentration of potassium in the wastewater was 4.6±0.5mg/L at DSK4 and the highest value was 7.6±3.6mg/L at USG1. Compared these values with the allowable limits of wastewater disposal by the EPA and REMA standards, 2.3mg/l and 2.0mg/l respectively, they seem to be above of the standard limits and thus they have effects on the ecosystem.

Chlorides

Chloride is contributed in effluents of domestic origin through food processing. Human and animal excreta contain high quantities of chlorides. During the present study the lowest value concentration of chlorides in the wastewater was 20.7±0.8mg/L at USG1 while the highest value concentration was 78.55±7.8mg/L. Comparing these values with the allowable limits of wastewater disposal of 7.8mg/l and 6.0mg/l by EPA and REMA respectively, they seem to be above the acceptable limits and therefore there are effects on the ecosystem.

Sulphate

Sulphate is present in all kinds of natural waters and in rain water but its concentration increases in industrial and domestic wastes. Sulphate in wastewater is injurious to the sewerage system as it tends to undergo oxidation and reduction changes due to the presence and absence of oxygen. During the present study sulphate concentration value was low 4.5±2.1mg/l at DSK4 and was high 39±8.4mg/l at GB2. Comparing these results with the acceptable limits of wastewater disposal 11.2mg/l and 13mg/l by EPA and REMA respectively, USG1 30.5±17.6mg/l and GB2 39±8.4mg/l are more affected.

The sulphate profile shows that sulphates are in high concentration at GB2, means around UTEXRWA textile industry as this may be a potential source of pollution.

Nickel

The range of nickel concentration 0.01±0.0mg/l to 0.11±0.1mg/l is below the allowable limit standards of aquatic water of 2mg/l of EPA and REMA and therefore comparing with the limit standards there is no effects on the ecosystem.

Pearson correlation coefficients (r) were assessed as an indicator to show the dependence of metals among them (**Table 11**). The correlation was significantly viewed for some elements, either in sample 1(dry season) or sample 2(wet season): Mn/Cu (r=0.94); Mn/K (r=0.87); K/Ca (r=0.96); Fe/Ni (r=0.98) and others. This means that these elements have the identical chemical source. Also, a strong correlation was observed between Conductivity and Hardness, Manganese, Cupper, Potassium, Calcium and Sulphates. Note that the Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge).

Hardness is significant correlated with Calcium and Magnesium that shows a high concentration of calcium and magnesium ions in water. Magnesium and Potassium concentrations tend not to be heavily influenced by metabolic activities of aquatic organisms, whereas calcium can exhibit marked seasonal and spatial dynamics as a

Table 11: Pearson correlation coefficient (r) matrix for chemical and physico-chemical parameters in Nyabugogo river (n=15)

	pH	T	TDS	Conduc	Turb	Hardn	Mn	Cu	Fe	K	Ca	Zn	Ni	Cl	SO4
pH	1														
T	0.5653	1													
TDS	-0.967	-0.706	1												
Conduc	0.9715	-0.673	**0.999**	1											
Turb	**0.6626**	**0.9667**	-0.743	-0.712	1										
Hardn	0.9599	-0.766	**0.992**	**0.9864**	0.8147	1									
Mn	0.8434	-0.315	**0.861**	**0.8819**	-0.311	**0.7929**	1								
Cu	-0.962	-0.551	**0.978**	**0.9861**	-0.585	**0.9458**	**0.9459**	1							
Fe	0.2972	**0.8081**	-0.344	-0.302	**0.8728**	**-0.4546**	0.1802	-0.141	1						
K	-0.927	-0.721	**0.991**	**0.9895**	0.7236	**0.9755**	**0.8796**	**0.9727**	-0.2995	1					
Ca	0.9366	-0.816	**0.98**	**0.9705**	-0.86	**0.9965**	**0.7452**	**0.9169**	-0.5215	**0.9647**	1				
Zn	**0.9867**	**0.6349**	0.949	0.9481	**0.7492**	0.9628	-0.748	0.9142	0.4396	0.8985	0.9504	1			
Ni	0.1238	**0.737**	-0.179	-0.135	**0.7854**	-0.2956	0.3423	0.0306	**0.9843**	-0.141	-0.3696	0.274	1		
Cl	-0.277	0.4646	0.223	0.2663	**0.4846**	0.1057	**0.6802**	0.4226	**0.8341**	0.2499	0.0261	-0.1237	**0.9179**	1	
SO4	-0.688	-0.959	**0.761**	**0.731**	0.9993	**0.8313**	0.3336	**0.6076**	0.864	**0.7385**	**0.874**	-0.7731	0.7714	-0.462	1

Correlation is significant at P=0.05 (2tailed) result of biological activity. Similarly, chloride concentrations are not heavily influenced by biological activity, whereas sulphate and inorganic carbon (carbonate and bicarbonate) concentrations can be driven by production and respiration cycles of the aquatic biota (Wetzel, 2001).

The physico-chemical associations' pH/Turb; Temp/Turb; TDS/Conduc; TDS/Hardness and Conduc/Hardn were significantly correlated with each other while the others are not.

Conclusion

Wastewater from UTEXRWA industry, Muhima Hospital and households establishments that flow into Nyabugogo stream have not adverse effect on human health and the environment. Most of the sites analyzed have their chemical characteristics below the allowable limit standards except for potassium, calcium and chloride which have high concentration due to direct dump of wastewater into Nyabugogo stream.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

Introduction

This chapter presents the conclusions and recommendations prepared from the present study. The main part of the conclusion is founded on the results got from the analysis and the recommendations are based on the feasible ways for improving the good way to sustain the river.

Conclusion

Based on the findings of this study, it is concluded that the water in the Nyabugogo stream system is contaminated along the stream as far as physical parameters are concerned. The chemical parameters such as Potassium, Calcium and Chlorides monitored showed consistently high levels of contaminants at USG1, GB2, NB3 and DSK4, warrant urgent attention to arrest further deterioration of water quality in the Nyabugogo stream.

The main causes of the contaminants of the stream are the solid and liquid wastes discharging to the stream coming directly from the UTEXRWA industry, Kigali City Prison, Muhima Hospital and households. These wastes affect directly the composition of the water and change its natural state and cause the deterioration of the soil and swamp around and even the ecosystem.

Recommendations

The following recommendations are enumerated based on the results founded on the present study.

The future of water quality at local, regional, and global scales depends on investments of individuals, communities, and governments at all political levels to ensure that water resources are protected and managed in a sustainable manner. This includes not only technological solutions to water quality problems, but changes in human behavior through education and capacity of building to better preserve aquatic resources.

It would be better to reduce the discharge of wastes from the industries in order to render a good stability of the geological nature of the soils.

The domestic sewage is still playing a role in the deterioration of the river and the impact would be buffered by the extensive Nyabugogo swamp. The government has to sensitize the population which lives near the river to protect it, to do not discharge directly the cosmetic product in the river.

The government through its water agency has to ensure effective protection of environment by enforcing wastes disposal and by-products treatment regulations.

It is duty of the relevant civic agency to treat wastewater before dumping into the river. It would not only help to minimize the pollution in water bodies but it would also help to safe the aquatic life from land based pollution.

The industrial areas of Kigali city, which are the main cause of degradation of the ecosystem in the river, be checked strictly in terms of effluents they discharge. The government should enforce the various acts and rules and their strict implementation be ensured. Monitoring of effluents quality from individual industry at the point of origin needs to be conducted. Each industry is ensured to have treatment plant for disposal of wastes and effluents or wastes should be recycled.

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APPENDICES

EWSA

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Kigali, ... 2011

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Mr. **Bonane BAHATI**
C/O Kampala International University
Tel: 078 856 2843

Copy:
-Water Department

RE: Your request

Dear Sir,

We acknowledge receipt of your letter requesting to conduct research in EWSA Company;

In this regard, we are glad to inform you that you can be hosted in EWSA, Water Department.

Regards.

RUDAKUBANA Chryso
Director of Human Resource