

**WASTEWATER MANAGEMENT IN COTTON WET PROCESSING IN THIKA
CLOTH MILLS IN KIAMBU COUNTY, KENYA**

By

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DECLARATION

This thesis report is my original work and has not been presented for degree in any other university or any other award.

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DEDICATION

I dedicate this work to my family; dear husband Shadrack and lovely children, Meshack Mercy, Melvin and Ryan.

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DEFINITION OF TERMS

Aliquot

It is a known fraction of a whole or part of a sample for chemical analysis.

Bioaccumulation

It is the tendency of a substance to be absorbed from an environmental medium such as water and soil or prey item into the tissues of an organism, where it may accumulate

Effluent

Refers to water or liquid or other fluid of industrial origin treated or untreated and discharged directly or indirectly into the aquatic environment.

Heavy metal

Refers to any metallic element that has a relatively high density and is toxic or poisonous at low concentrations.

In-situ

It means in the field.

Optimization

Improving the technical and financial performance of a system. It entails reduction of operating overheads and enhancement of revenue streams.

Pollutant

Refers to any substance which may directly or indirectly alter the quality of any element of the receiving environment; is hazardous or potentially hazardous to human health or the environment.

Pollution

Any direct or indirect alteration of the physical, chemical, or biological properties of any part of the environment by discharging, emitting, or depositing wastewater so as to effect any beneficial use adversely.

Process wastewater

Refers to the wastewater streams discharged from the factory wet processes.

References

Refers to the act of referring or a short note recognizing a source of information or of a quoted passage. American Psychological Association (APA) style of referencing is used throughout this document.

Sustainable development

Refers to development that meets the needs of the present generation, without compromising the ability of future generations to meet their needs, by maintaining the carrying capacity of the supporting ecosystems.

Wastewater

Includes any matter prescribed to be waste and any liquid matter which is discharged in the environment in such volume, composition or manner likely to cause an alteration of the environment.

WWTP effluent

Refers to the pretreated wastewater discharged from Thika Cloth Mills wastewater treatment plant into the municipal sewer.

Wet processing

Refers to water and chemical intensive fabric manufacturing processing which include: sizing, bleaching, desizing, printing, mercerizing, dyeing, and finishing.

LIST OF ACRONYMS AND ABBREVIATIONS

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EMCA	Environmental Management and Coordination Act
GOK	Government of Kenya
KIRDI	Kenya Industrial Research and Development Institute
mS	micro Siemens
NEMA	National Environment Management Authority
Nm	Nanometer
NTU	Nephelometric Turbidity Unit
PVA	Polyvinyl Alcohol
SPSS	Statistical Package for The Social Sciences
TCM	Thika Cloth Mills
TDS	Total Dissolved Solids
THIWASCO	Thika Water and Sewerage Company
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation
WHO	World Health Organisation
WWTP	Waste Water Treatment Plant.

ABSTRACT

Wastewaters generated from textile industry are usually variable in composition, difficult to biodegrade and have been classified as potentially harmful to the environment. Research on the physico-chemical characteristics and concentration levels of the potentially hazardous substances in these wastewaters is apparently lacking. This study evaluated the physico-chemical characteristics of polluting substances in raw wastewater from cotton wet processing and pretreated wastewater in Thika cloth mills, in comparison with National Environment Management Authority (NEMA) discharge limits to the sewer. The key pollution indicator parameters were; colour, dissolved oxygen, temperature, turbidity, pH, conductivity, biochemical oxygen demand, total suspended solids, chemical oxygen demand, total dissolved solids, nitrates, phosphates, phenols, sulphides, chromium, manganese, aluminium, cadmium, lead, Zinc and copper. Two sampling techniques namely purposive and professional judgment were used in this study. Samples were collected at two weeks intervals for a period of three months, between May and August 2013. Field measurements were taken for each of the 33 samples collected from wet processes namely; scouring, desizing, bleaching, washing, mercerizing, dyeing, printing, finishing and municipal sewer. Analysis of the 22 indicator parameters was carried out at Kenya Industrial Research and Development Institute analytical laboratory using APHA standard methods of testing. Descriptive analysis of the data for means and standard deviations was done with the aid of Statistical Package of Social Sciences and Excel. Results, showed that, the untreated wastewater discharged from the cotton wet processes streams was characterised by alkaline pH (9.992), high; temperature (43.406°C), COD (5231.83mg/l), BOD (2160.13), TSS (2979.7 mg/l), TDS 24339.78mg/l, colour (1219.71 hazens) and sulphides (81.233mg/l) against Nema standards at pH(6-9), temperature(20°C-35°C), COD(1000mg/l), BOD(500mg/l), TSS (250mg/l), TDS (2000mg/l), colour (<40 hazens) and sulphides (2mg/l). Other parameters including zinc, lead, nitrates, phenols, phosphates, chromium, cadmium and copper were within the Nema standards. The study hypotheses were tested using the Mann-Whitney U test for two independent groups. There was a significant difference in concentration of polluting substances in the dyeing wastewater as compared to Nema standards where Mann-Whitney U value Z (-0.226) was less than α (0.05). Pre-treated wastewater exhibited TSS (423.5 mg/l), TDS (3842mg/l), color (200 hazens) and sulphides (19mg/l) in excess of Nema limits, while other parameters were within the discharge limits. When compared to the untreated wastewater under Mann-Whitney U test, the pretreated wastewater exhibited a low concentration of polluting substance whereby its mean rank (16.21) was lower than (22.79) for untreated wastewaters. This was an indication of the effectiveness of the pretreatment process. Similarly, the null hypothesis that there was no difference in concentration levels of the polluting substances in pretreated wastewater compared to Nema standard was rejected where Mann-Whitney U value Z (-0.829) was less than α (0.05) and the mean ranks (15.30) for pretreated and (17.88) for Nema standards. This was an indication of suitability of the pretreated wastewater for discharge to the sewer. However, there is need for advanced research, to determine the volumes and the toxicity levels of the textile effluent. Other effluent streams discharging to the sewer need to be studied to determine their potential to pollute the municipal water resources.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Industrial effluents consist of undesirable by-products of economic development and technological advancement (odjegba and Bamgbose, 2012). Their impact of human health and the environmental can be great when and if improperly disposed off. The world's ever increasing population and progressive adoption of an industrial based economy has led to an increased anthropogenic impact on the biosphere (Jadeja, 2013). Panayotou (2003), in fact wonders if the world will be able to sustain economic growth indefinitely without running into resource constraints or despoiling the environment beyond repair.

According to Chikogu *et al.* (2012), water pollution is a worldwide problem and its potential to influence the health of human populations and the environment is great. This environmental problem is related not only to its waste through misuse, but also to the release of industrial and domestic effluents. Chequer *et al.* (2013), Desai and Kore (2011) further alluded that industrial effluents are a main source of direct and often continuous input of pollutants into aquatic ecosystems with long-term implications on ecosystem functioning not only in India, but also globally. Pollution of ground and surface waters is largely linked to the industrial production of manufactured goods, wasting liquids and solid matter. Industrial processes are characterized by the use of inputs inform of raw materials, water and energy, that undergo transformation giving rise to products, byproducts and waste. While the wastes produced at all stages of the various types of human activity, vary according to the consumption practices and production methods both in terms of composition and volume, the main concerns are on the impact these can have on human health and the environment (Chequer *et al.*, 2013).

Textile industry is notably one of the most important and rapidly developing industrial sectors with a high importance in terms of its environmental impact (Banu and Murugesen, 2013). In textile production units, opportunities exist for the release into the ecosystem of potentially hazardous compounds at various stages of operation. Actually, the wastewater from this industry have been classified as the most polluting of all the

industrial sectors, considering the volume generated as well as the effluent composition (Chequer *et al*, 2013). The wet production processes comprising of pre-treatment, dyeing, printing and finishing, not only consume large amounts of energy and water, but they also produce substantial waste products. Waste water generated by these processes have high concentration of detergents, oil, suspended and dissolved solids, dispersants, leveling agents, toxic and non-biodegradable matter, colour and fluctuating temperatures (Babu *et al*,2007). This is as a result of diversity in composition of chemical reagents used, ranging from inorganic compounds to polymers and organic products. The untreated effluent in millions of litres, which may also be difficult to treat in conventional wastewater treatment plant, discharges in the forms of wastewater into public drains that eventually empty into rivers. This alters the pH, increases the biochemical and chemical oxygen demand and releases intense colouration into water bodies thereby affecting their suitability for use.

Cognizant of the importance of industrial development for economic freedom and poverty eradication, failure to effectively manage industrial effluents is likely to cause adverse environmental effect and constrained water resources (Maude, 2008). Emerging environmental legislations and increasing awareness of environmental wellness on the other hand, compels sectors of industry and commerce to enhance environmental compliance and resource efficiency (Alanya *et al.*, 2010). Therefore, as Eckenfelder *et al.* (2009) observed one of the ways of attaining and maintaining industrial-environmental compliance is regular point source environmental monitoring and audit, suitably designed to provide accurate and up-to date information that can quantify environmental impact.

In view of the above, Muruges and Selvadass (2012), argued that an essential, though often difficult step in pollution prevention is to accurately and realistically assess the current status of an industry and it's potential for improvement. This assessment is necessary in order to target specific waste streams that will optimize pollution reduction.

It follows therefore, that the first and most effective step in pollution prevention in textile operations is a thorough audit and characterization of the wastewater (EWA, 2005). Comparing the information from such audit with benchmark data ultimately allows for realistic goal setting. It is the responsibility of every textile industrialist to routinely

monitor the quality of the effluent discharged to ensure that it is in compliance with the national regulations. This study therefore combined an analysis of the characteristics of wastewater from textile wet processes with a discussion on wastewater management strategies.

The study area is formerly an industrial town hosting some of the heavy industries like tannery, textile, footwear, food processing (macadamia nuts and Bidco), motor vehicle assembly chemical (Kel) and cigarette manufacture and over a hundred light industries. Onjala (2002) recorded that, most of these industries have old and inefficient wastewater treatment plants and a number of them discharge their wastewater into a nearby river or streams while others discharge into the municipal sewer.

The study site is a textile processing factory located on the factory street in Thika town. It is a composite textile factory, processing about 650,000 metres of fabric every month in different blends, colours and prints. It comprises of spinning, weaving, and wet processing. The factory has a functional wastewater treatment plant and discharges effluent to Thika municipal sewer.

It emerged that Thika water and Sewerage Company was experiencing discharge of pollutants to the sewer, presumably from textile, paper mills and metal box industries. However, it emerged that characteristic of the waste loads from these factories and their effect on the environment has not been scientifically documented. To bridge this information gap therefore, this study undertook a point source analysis of the wet processing wastewater and the pretreated effluent discharged from Thika Cloth Mills with particular emphasis on their characteristics.

1.2 Problem Statement

Wastewater from textile wet processing is a complex mixture of polluting substances which ranges from chlorine-based pesticides to heavy metals associated with dyes and other auxiliaries (Zaharia and Seteu, 2009). This is partly due to inefficiencies in processes, resulting in large amounts of the pollutants being directly lost to the wastewater and partly due to the nature and amounts of chemicals used which ultimately find their way into the environment (Parvathi *et al.*, 2013). Such discharges unless

meeting the standard guidelines, could either become a hazard to persons, property and the environment, and/or interfere with the operation of municipal infrastructure.

Thika water and Sewerage Company raised concern over the quality of wastewater generated from various industries among them TCM, metal box and paper industry. According to THIWASCO, discharge of this wastewater to the municipal sewer has resulted to enormous infrastructural damage, thereby exposing the environment to severe degradation and consequently increasing the waste load.

Although it was alleged that the discharge of contaminated wastewater was from a textile factory, this could not be easily determined for two reasons; i) There were no records available for reference at that moment to show the nature and concentration of pollutants in the effluent; ii) Wastewaters were a combination of streams from different industries. Further, identifying and tracking the source of pollutants for effective monitoring had proved difficult and expensive. Relevant information both from primary and secondary sources, critical for effective management of the wastewater discharge was apparently inadequate. It is in this premise therefore, that this research was undertaken, in order to provide the necessary information on the characteristics of raw wet process wastewater, and pretreated effluent generated from TCM, with the ultimate aim of enhancing sustainable environmental management.

1.3 Research Questions

In view of the problem stated above, this study seeks to answer the following questions:

1. What are the “physico-chemical” characteristics of the wet process/untreated wastewater?
2. Does the concentration of pH, temperature, COD, BOD, TSS, TDS, colour, phosphates, nitrates, copper, phenols sulphides, chromium, cadmium, lead and zinc in the pre-treated wastewater, vary significantly with NEMA standards?
3. How effective are the wastewater management strategies in Thika Cloth Mills?

1.4 Objectives

The broad objective of this research was to identify the source and determine characteristics of pollutants in untreated and pretreated wastewater from cotton wet processing in Thika Cloth Mills, for process optimization and pollution prevention.

The Specific objectives were:

1. To evaluate the “physico-chemical” characteristics of the wet process/untreated wastewaters in comparison to Nema standards.
2. To compare the concentration levels of pH, Temperature, COD, BOD, TSS, TDS, colour, phosphates, nitrates, copper, phenols sulphides, chromium, cadmium, lead and Zinc in the pre-treated wastewater, with NEMA standards.
3. To evaluate the effectiveness of the wastewater management strategies in Thika Cloth Mills.

1.5 Research Hypotheses

Based on a review of the objectives and research questions stated above, this study was guided by two major hypotheses:

1. Dyeing process wastewater had high concentration of polluting substances compared to Nema standards.
2. There is a significant difference between the concentration levels of pH, temperature, COD, BOD, TSS, TDS, colour, phosphates, nitrates, copper, phenols sulphides, chromium, cadmium, lead and zinc in the pre-treated wastewater compared to NEMA discharge limits.

1.6 Justification

There has been increasing global concern over the public health impacts attributed to water pollution, in particular, the global burden of disease for the last three decades. The World Health Organization estimates that about a quarter of the diseases facing mankind today occur due to prolonged exposure to water pollution (WHO, 2004). In this regard

therefore, there is need to reduce on a large scale the amount of waste and pollution generated by human activity (Kano and Achi, 2011).

Cognizant of this fact, the government of Kenya through the constitution and the Kenya vision 2030 development blue print keenly promotes the need for a clean and safe environment as a basic human right (GoK, 2007). The Kenya Environmental Management and Co-ordination legislation on water quality regulations provides that, every owner or operator of an industrial undertaking issued with a license to discharge effluent into any existing sewerage systems, comply with the standards set out in the Fifth Schedule to these regulations. At the same time the operator is required to carry out effluent discharge quality and quantity monitoring and submit quarterly reports to NEMA (GoK, 2006). The findings of this study are therefore fundamental to the various stakeholders involved in environmental management in Kenya as follows:

1. Thika Cloth Mills management for self-evaluation. The outcomes of this study could form a basis of identifying areas of environmental performance improvement, operational cost reduction and rectification of operational and maintenance problems in the industry. Characterisation data for to be treated wastewater is necessary for development of process design and informs on selection of treatment process.
2. Nema, the principal agency in Kenya charged with the responsibility of coordinating, monitoring and supervision of all activities in the field of the environment could use the findings of this study for implementation of effluent discharge guidelines and for monitoring.
3. Overall, the findings of this study will provide vital information necessary for further scientific research, thereby contributing to the existing knowledge in the field of environmental management.

1.7 Conceptual Framework

The conceptual model describes the expected source and nature of contaminants and their possible environmental effect. It identifies the relevant transport pathways and defines potential exposure pathways. The nature of pollutants in cotton wet processing effluent (dependent variables) is a factor of the inputs (independent variables) inform of chemicals, water and steam. The toxicity level and pollution loads are however largely influenced by the amount and type of chemicals, nature of the process, state of the equipment, skills level and housekeeping practices herby referred to as the intervening variables. Raw wastewater from various process streams is variable in temperature, TSS, TDS, DO, BOD, turbidity, conductivity, nitrate phosphate pH, phenols and heavy metals. Above the normal water regulation limits, such parameters could be the cause of severe damage to the environment and imbalanced ecosystem. An attempt to lower these parameters to acceptable limits has an implication on the costs of production, operation, treatment and overall efficiency of the treatment plant. Interrelation between various variables is as shown in Figure 1.1 below.

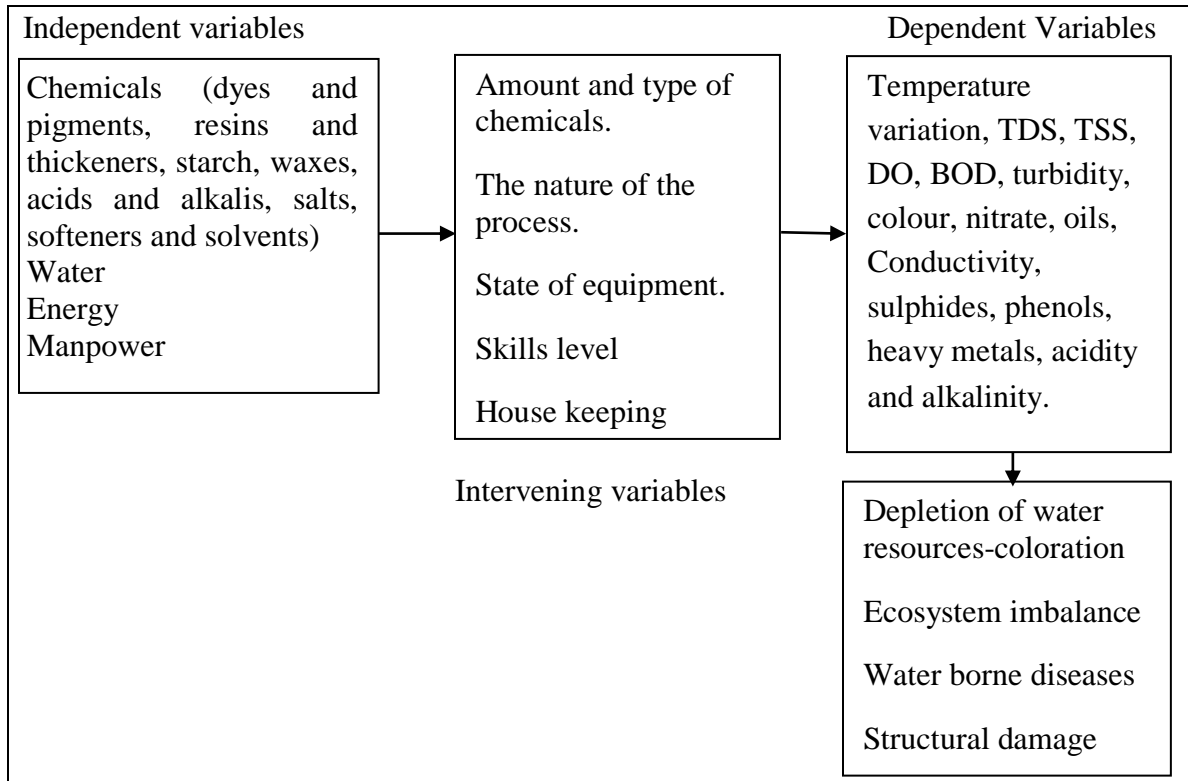


Figure 1. 1: Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Textile Manufacturing

Textile industry is one of the largest in the world with a high capacity for employment creation. According to Omolo (2006), the industry can be divided into four broad categories, namely cotton growing and ginning, yarn and thread production (spinning), fabric manufacture (weaving) and apparel manufacture (garment making). Desai and Kore (2011), Prasad and Rao (2011), observed that textile industries are large industrial consumers of water as well as producers of high load of polluted wastewaters. With the increased demand for textile products, the textile industry and its wastewaters have been increasing proportionally, making it one of the main sources of severe pollution problems worldwide. This industry comprises a diverse and fragmented group of establishments that produce and/or process textile-related products (fiber, yarn, and fabric) for further processing into apparel, home furnishings, and industrial goods (Zaharia and Seteu, 2009). The establishments receive and prepare fibers; transform fibers into yarn or thread through spinning, convert the yarn into fabric or related products by weaving or knitting; and dye, print and finish these materials at various stages of production.

The textile manufacturing in Kenya operates at small scale owing to low demand for new textile products, cheap imports, high production costs, stiff competition from other manufactures and low technological development. However, regardless of its low magnitude, its importance in terms of environmental impact cannot be overemphasized. This is because it is resource intensive and characterized by high effluent discharge and inefficient waste treatment technologies. (Omolo, 2006). With the ever increasing demand on green textiles by the world market and the current focus on sustainable development, future survival of this industry is therefore indefinable. It follows therefore that, while there are numerous pollution minimization opportunities, a paradigm shift from the current resource intensive and polluting production systems, to resource optimization and cleaner production strategies is imperative.

2.2 Textile Wet Processing

Textile industry represents a range of industries with operations and processes as diverse as its products (Jaishree and Khan, 2014). The operations in this industry consist of a number of processes both dry and wet, some of which are highly water intensive.

The wet processing comprises of various operations which are either continuous or batch processes. These processes are essentially based on water, chemicals/dyes and energy input in form of steam and electricity. According to Barclay and Buckley (2000), a typical water requirement for cotton processing is about 100 to 150 m³ of water per 1000kg of fabric produced. The effluent characteristics vary largely between processes and materials, while water usage and effluent generation entirely depends on the equipment and raw material, and varies greatly between processes (Bisschops and Spanjes, 2008). Although the wastewaters from these wet processes contain substantial pollution loads, it is almost impossible to describe a typical textile effluent because of its diversity despite the importance. Muruges and Selvadass (2012) argued that a thorough audit and characterization of wastewater streams from the various wet processes is an essential step in realizing pollution reduction. This therefore calls for an understanding of the flow of cotton through the various wet processes and the nature of chemicals and other inputs.

Figure 2.1 below illustrates cotton material path through a wet processing section.

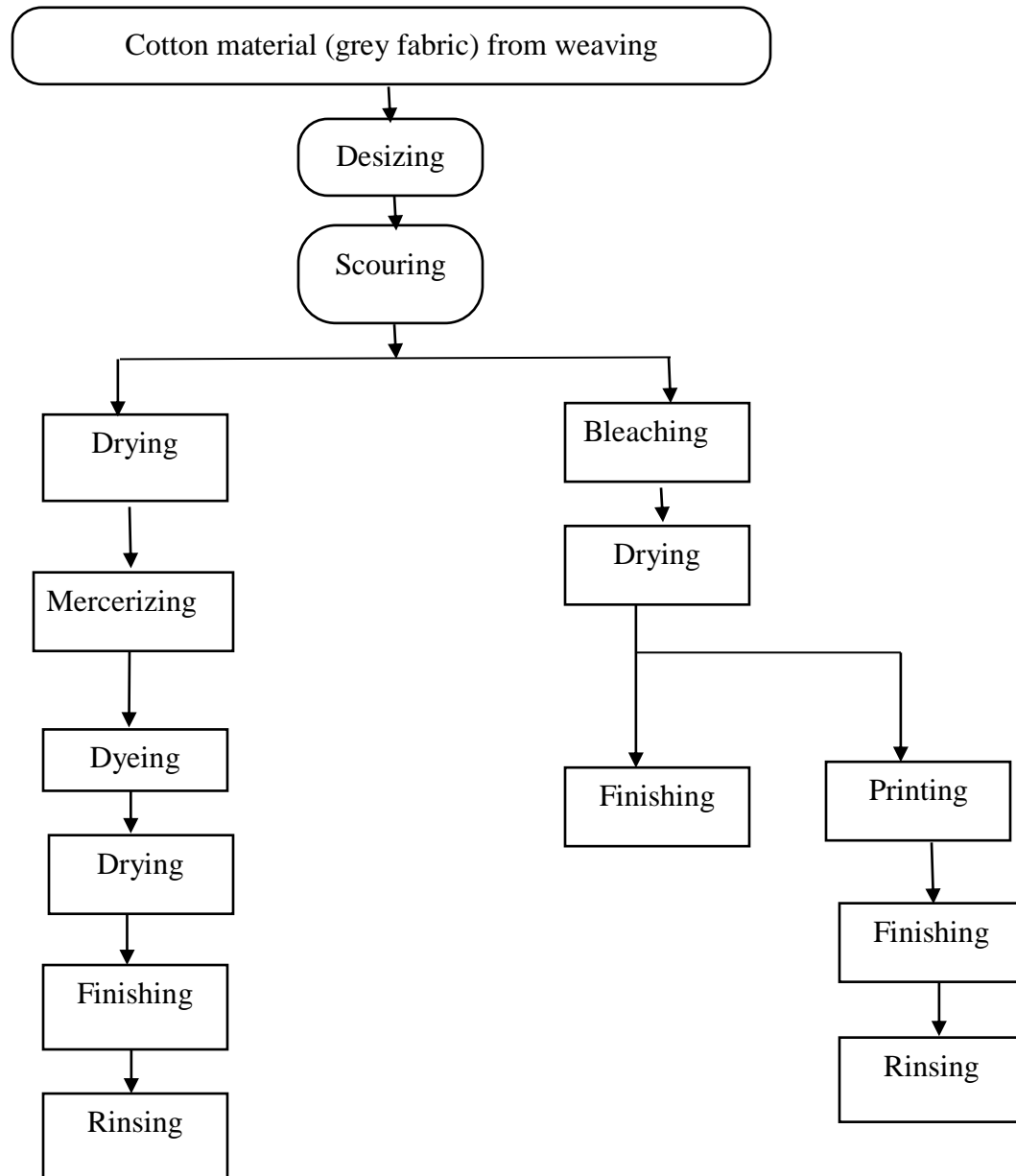


Figure 2. 1: Cotton material path through the wet processing section (*Author*)

Sizing although not necessarily a wet process, is the first preparation step, in which chemicals (sizing agents) are applied to the yarn before the production of a woven fabric. This is done in order to provide strength and enhance smoothness to the warp yarns and therefore minimize breakage during weaving (Yusuff and Sonibare, 2004). The grey sized fabric from weaving sequentially undergoes pretreatment prior to dyeing and printing through: desizing, scouring, bleaching and mercerizing (Zaharia and Seteu, 2009). Desizing is the process of removing residue size on cotton fabric in order to

facilitate dye uptake and enhance shade uniformity as well as to reduce the amount of dyes used and time spent in the dyeing process. The process involves chemical boiling at 90 °C for about six hours. Chemicals used in desizing include: oxidizing agents such as hydrogen peroxide, solvent, alkali usually caustic soda and a wetting agent. While wastewater characteristics vary according to the sizes and the agents used for desizing, sizes generally have a high BOD. Achwal (1990), observed that waste stream of the desizing operation can contribute up to 50 % of the total pollution load of a mill's wastewater. Water with high BOD indicates the presence of decomposing organic matter and subsequent high bacterial counts that degrade its quality and potential uses.

Scouring, is the process of removing impurities such as natural and added oils, grease, fats, waxes, water soluble sizes, minerals and plant matter. As Bisschops and Spanjes (2008) reports, scouring process is performed in an alkaline solution usually caustic soda at high temperature in the range of 80 °C to 100 °C and upon saponification. Soaps and detergents added during scouring may also precipitate with calcium, magnesium and iron (III+) if present.

Based on customer's specifications, three main types of cotton fabrics may be produced in the processing section namely: dyed, printed or bleached white fabrics. After scouring, the fabric follows three distinct paths depending on whether it is to be dyed, printed or bleached. A dyeing fabric is dried in a pad steam drying unit soon after scouring. Thereafter it is treated with a strong caustic soda preferably cold sodium hydroxide at 30% concentration under high tension in a process called mercerizing. This is done in order to improve strength, dye affinity, light fastness, absorption, lustre, smoothness and general appearance (Bisschops and Spanjes, 2008). Sufficient washing in acid is required after this step to remove any traces of caustic soda while excessive caustic is pumped back to a recovery plant. Cotton fabric is dyed in a continuous pad dyeing machine

Dyeing is the aqueous application of color to the textile substrates, mainly using synthetic organic dyes and frequently at elevated temperatures of 102 °C-105 °C and pressure, and at pH of 9.5-11 (Walter *et al.*, 2005). During dyeing, dyes and various chemical aids such as surfactants, acids, alkali/bases, among others are applied to the textile material to get a

uniform depth of color, with the color fastness properties suitable for the end use of the fabric (Chequer *et al.*, 2013). As described by Walter *et al.*, (2005), dyes are compounds that can be dissolved in solvents, usually water. Up to 40% of the dyestuff may be hydrolysed by water rendering it inert, thus leading to the presence of reacted or inert dye in wastewater streams, that is difficult to isolate. According to (Bisschops and Spanjes, 2008), direct, vat, disperse/reactive and sulphur dyes are the most common types of dyes. Azo dyes, a type of direct dyes made from a nitrogen compound, are the most important class of dyes and pigments. These dyes have been reported to give off a range of carcinogenic particles and have been banned in the European Union (Blackburn, 2006). Their effluent has been found to contain 5 % to 20% of residual dyestuff, plus salt and dye fixing agents (Oecotextiles, 2009).

Vat dyes are used for colouring cellulosic fibre such as cotton and need a powerful reducing agent, such as alkali, to make them soluble. These dyes are expensive and complicated to use and their effluent contains substantial amount of residual dyestuffs, reducing agents, oxidizing agents, detergents and salts. Sulphur dyes on the other hand, contains sodium sulphide, which poses hazard to human health, damages sewerage infrastructure, leads to high pH and causes unpleasant odours. Reactive dyes like other environmentally damaging dyes are made from synthetic petrochemicals. Bisschops and Spanjes (2008) reported that, the effluent from dyeing process can still contain high concentrations of salt, alkali, detergent and about 20 % to 50 % of residue dye, even when the unfixed dye is reclaimed. Although dyes may constitute a small portion of the total volume of waste discharged in textile processing, colour removal from effluent can be a major problem because of several factors as listed below.

1. The presence of a small fraction of dyes in water is highly visible due to their high tinctorial value. This affects the aesthetic merit of streams and other water resources
2. Most dyes due to their complex aromatic structure are resistant to light, biological activity, ozone and other degradative environments and have carcinogenic action
3. Synthetic dyes are non-biodegradable with long-term effects on the environment and are not readily removed by typical waste treatment processes.

4. Dyes have also been known to interfere with certain municipal wastewater treatment operations such as ultra violet disinfection.
5. The alkaline reducing systems based on Na_2S in some dyeing recipe cause discharges of sulphur containing effluent which give foul smell and contaminate water resources

The picture below shows a typical red coloured wastewater stream from a dyeing process.



Figure 2. 2: Red coloured dyeing wastewater. Source:(*Oecotextiles*,2009)

Accessed on 8th January 2014. Website: <https://oecotextiles.wordpress.com/2009/09/>

Various studies including those by Zaharia *et al.* (2011); Desai and Kore (2011) and Chequer *et al.* (2013) among others, have reported that dyeing contributes to most of the metals and almost all the salts and colour present in textile wastewater. This is because most of the metals and salts are not biodegradable in conventional or aerobic treatment processes. As a result, some of them may be instantly adsorbed by the sludge at wastewater biological treatment plant. Conventional synthetic dyes on the other hand present health risks to those working with them as well as the clothe wearers. Further, the environmental issues associated with residual dye content or residual colour in pretreated textile wastewater are always a concern for each textile operator that directly discharges in sewage treatment works, in terms of compliance to the requirements placed on effluent

discharge (Zaharia *et al.*, 2011). Due to their low exhaustion rate usually estimated at 80%, high concentrations of these dyes in water bodies inhibit the oxygenation capacity of the receiving water, and cut off sunlight. This therefore upsets biological activity in aquatic life as well as the photosynthesis process of aquatic plants (Zaharia and Seteu, 2009). Ultimately, with the current global discharge estimated at 40,000 to 50,000 tonnes and more than 200,000 tonnes of salt into water bodies, textile dyes thus pose even a greater environmental hazard now and in future (Chequer *et al.*, 2013). In this context and considering the importance of coloured products in present day societies, it is necessary to optimize the colouring process with the objective of reducing environmental impact of the dye house wastewater.

A fabric made for printing on the other hand is bleached and dried prior to printing in order to remove unwanted natural colouring matter. The bleaching process as earlier described is done in hot steam at high temperature, usually 100°C using sodium hypochlorite, hydrogen peroxide, sodium chlorite as well as optical brighteners and other auxiliaries. According to Chequer *et al.*, (2013), hydrogen peroxide is an irritant to the skin and mucous membranes and is dangerous to the eyes. If swallowed, the sudden evolution of oxygen could cause internal injury. The wastewater generated from this process is usually high in solids content and residue chemicals. The bleached fabric is then dried using hot steam after which it is printed to desired prints.

Printing has been defined as a type of localized dyeing or dyeing confined to a certain portion of the fabric that constitutes the design (Parvathi *et al.*, 2013, and Babu *et al.*, 2007). The printing paste consists of water, thickeners, catalyst, binders, dyes, urea, and various other chemicals such as surfactants and solvents. The wastewater from the printing unit is often coloured owing to residual and spilled dyes. Disposal of the residue paste with other wastewater streams has been found to considerably increase COD, nitrogen, dye loads and colour.

The printed fabric is taken through the finishing process based on either the customer specification or intended application. The finishing process aims at modifying the properties of the cotton fabric or yarn, thus affecting care, comfort, durability or human

safety (Chequer *et al.*, 2013). As Irina and Butnaru (2008) reported, the main purpose of finishing is the improvement of the serviceability, and adaptation of the products to meet the ever-changing demands of fashion and function. Although formaldehyde-based cross-linking agents are widely used to give desired properties in this process, previous studies have recorded that formaldehyde resin is a known carcinogen. Other natural polymeric substances, such as natural oils and waxes, widely used for water-proofing, may lead to water colouration when discharged in wastewater. This may result in an imbalance in the ecosystem and increase in treatment costs.

The rinsing process, which follows immediately after finishing, often involves use of hot water to remove any dye residues and finishing chemicals in the fabric. Depending on the method used, Bisschops and Spanjes (2008), and Irina and Butnaru (2008), recorded that rinsing can make up to 50% of the total water usage in textile wet processing. It follows therefore that, optimization of these processes is likely to save significant amounts of resources and, in turn, reduce the ultimate pollution load to be treated. And as Christie (2007) further asserts, careful auditing and implementation of controls can achieve wastewater reduction of up to 70 %.

2.3. Wastewater Characterisation

While physico-chemical characterization of textile treated effluents has been widely studied, the characterization of the process wastewater is one of the areas that have been rarely studied, particularly in Kenya. Considering that wet textile processing involves a wide range of inputs in form of chemicals, machine and processes, to produce the desired shape and properties of the final product whether yarn or fabric, its potential for environmental pollution is equally high. The rapid changes in the customer's demands, tastes and preferences, resulting in increased use of wide variety of chemicals and other auxiliaries and discharge of large volumes of wastewater is likely to exacerbate this problem further. Resultant wastewater streams are hazardous, usually variable in composition and difficult to biodegrade. Because of the large number of processes, many of which are batch operations, wastewaters of many types go down the drains oftently untreated and at irregular intervals. Whether the substances or impurities in the wastewaters will cause serious pollution, depends upon their composition and

concentration levels. Furthermore, if not properly treated, this wastewater is capable of causing problems in the receiving aquifers such as, oxygen depletion resulting in deaths of aquatic organisms, adverse effect on human health, and adverse effect on clarity and colour. Wastewater discharges may also contain toxic substances such as heavy metals, which may affect the use of the receiving water for domestic purposes or aquatic life.

In some cases, it is required that these wastes are segregated and either treated separately or added to the main flow over a lengthy period of time for dilution (Christie, 2007). Examples of such wastes are those from cotton desizing and scouring, cotton sulphur dyeing, and unused dye liquors and printing pastes. And as Babu and Parande (2007) reported, unless meeting the requirements set out by the national and international guidelines, discharges could become a hazard to persons, property or the environment or interfere with the operation of municipal infrastructure. It is therefore essential to obtain information on the composition of such discharges over a considerable length of time. It is also important to examine individual processes that give rise to highly polluting wastes because these could cause shock loads on a treatment plant and lead to erratic treatment. Various studies have been done and reported on general characteristics of the process wastewater streams based mainly on the most prevalent pollution indicators. The possible pollutant and the nature of effluents released from each step of the wet process are listed in Table 2.1 below.

Additional information on specific parameters is however required, in order to understand fully the environmental implication of each process and for effective mitigation action. A comprehensive review of the various characterization parameters considered in characterizing wastewater from the textile mill under study is therefore given in the section that follows. These includes BOD, COD, TSS, TDS, colour, turbidity, conductivity, temperature, pH, dissolved oxygen, sulphides, nitrates, sulphate, phosphates and selected heavy metals.

Table 2. 1: Sources and characteristics of textile wastewaters

Process	Composition	Nature
Sizing	Starch, waxes, carboxymethyl cellulose, polyvinyl alcohol.	Left over sizing liquid high in BOD, COD and suspended solids.
Desizing	Starch, glucose, carboxymethyl cellulose, polyvinyl alcohol, fats and waxes.	High in BOD, COD, suspended solids, dissolved solids.
Scouring	Caustic soda, waxes, grease, soda ash, sodium silicate, fibres, surfactants, sodium phosphate	Dark coloured, high pH, high COD, dissolved solids
Bleaching	Hypochlorite, chlorine, caustic soda, hydrogen peroxide, acids, surfactants, sodium silicate, sodium phosphate	Alkaline, suspended solids
Mercerizing	Caustic soda	Alkaline, low COD, high dissolved solids
Dyeing	Dyes, mordants, reducing agents, acetic acid, soap	Strongly coloured, high COD, dissolved solids, low suspended solids, heavy metals
printing	Pastes, starch, gums, oil, mordants, acids, soaps	Highly-coloured, high COD, oily appearance, suspended solids.
Finishing	Resins, Formaldehyde, PVA, Waxes, Hydrocarbon	Slightly alkaline, low BOD

Adapted from: *Yusuff, R.O., and Sonibare, J.A. (2005). Page 215.*

Website: https://www.academia.edu/912996/Characterization_of_textile_industries_effluents_in_Kaduna_Nigeria_and_pollution_implications.

(Maximum allowable limits shown in appendix 2).

2.3.1 Biochemical oxygen demand in a textile effluent

Biochemical oxygen demand has been defined as a measure of the concentration of organic matter present in any water (Varsha *et al.*, 2013). Measure of BOD is an empirical test to determine the relative oxygen requirements of wastewaters, polluted waters and effluents. BOD results from the respiratory processes of microorganism and its measurement concerns the determination of the degradation of organic substances by

microorganisms. The greater the decomposable matter present, the greater the oxygen demand and the greater the BOD values. In sizing and desizing, where cloth is treated with starch, gum and enzymes, effluents have exhibited BOD levels exceeding the recommended limits. According to Varma and Sharma (2011), high BOD levels may deplete dissolved oxygen from water resources, cause death of aerobic organisms as well as increase anaerobic properties of water. This indicates that there could be low oxygen available for living organisms in the wastewater, hence the need for consistent analysis of this parameter, to ensure compliance with international standards.

2.3.2 Chemical oxygen demand in a textile effluent

Chemical oxygen demand (COD) measures the oxygen equivalent of a portion of organic matter in a sample that can be oxidized by a strong oxidizing agent. It is used to measure the oxygen equivalent to organic material in the wastewater that can be oxidized chemically using dichromate in an acid solution. According to Varsha *et al.* (2013), high COD levels imply toxic conditions and the presence of biologically resistant organic substances. When evaluating the best strategy for the management of wastewater, oxygen demand is one of the important parameter to consider. This is because organic compounds are generally unstable and may be oxidized biologically and chemically to a stable inert end product. An indication of organic oxygen demand content of wastewater can be obtained by measuring the amount of oxygen required for its stabilization either as BOD or COD. The BOD: COD ratio is an important factor in evaluating the extent of organic pollution since it reveals the treatability of waste water. If this ratio is above 0.5, the waste water is considered to be highly biodegradable. When the ratio is less than 0.3, the waste water is deemed to undergo a chemical treatment before the routine biological treatment. Azbar (2003, as cited in Jadeja, 2013), reported that textile wastewaters exhibit low BOD: COD ratios of less than 0.1, thus indicating the non-biodegradable nature of dyes. Although their high molecular weight chromophores contribute little to BOD in textile dye effluent, these compounds are however major contributors to effluent COD and color toxicity due to their inability to pass through the cell membranes.

2.3.3 Colour in a textile effluent

Colour in wastewater is classified into two, namely: true and apparent color. Apparent color is the total color due to both turbidity and the color of the wastewater. It includes not only colour due to substances in solution, but also that due to suspended matter. True color is the colour after filtration of the wastewater. It is colour from which turbidity has been removed. Colour may result from the presence of natural metallic ions such as iron and manganese from dyes, industrial wastes inform of colloidal or suspended material among others. According to Zaharia and Suteu (2012); Al-Kdasi *et al.* (2005), residual colour is mainly due to insoluble dyes, pigments and other coloured compounds with a low biodegradability. It has been estimated that losses of colourants to the environment can reach up to 10 %–50 % during the dyeing (Chequer *et al.*, 2013). Coloured industrial wastewater therefore requires colour removal before discharge into watercourses since they affect their aesthetic value. The colour of water is expressed in terms of hazen units, which is defined as the colour produced by 1 mg/l of platinum in the form of chloroplatinic acid.

2.3.4 Turbidity in a textile effluent

Turbidity is an expression of the optical property that causes light to be scattered and absorbed, rather than transmitted in straight lines through a sample (Morrison *et al.*, 2001). Turbidity in water is caused by suspended matter such as, finely divided organic and inorganic matter, soluble coloured organic compounds, plankton and other microscopic organisms. (Mohabansi *et al.*, 2011). To a greater extent, turbidity of a textile wastewater may be as a result of colour and suspended substances. It has been reported that turbidity affects aquatic systems by limiting the transmission of light into the system, makes water aesthetically undesirable and may even stain food. Apart from harboring micro-organisms, turbidity may also clog or scour pipes and machinery thereby affecting industrial process.

2.3.5 Conductivity in a textile effluent

Conductivity has been defined as a measure of the ability of an aqueous solution to carry an electric current (Mohabansi *et al.*, 2011). This ability depends on the presence of ions, their total concentration, mobility and valence as well as on the temperature of

measurement. Conductivity measurements are important for designing instrumentation, for corrosion control and are used as a measure of total dissolved substances. As Morrison *et al.*, (2001) remarked, conductivity of the receiving water is a function of the concentration of soluble ionic salt and other inorganic materials such as alkalis, chlorides, sulphides and carbonate compounds present in the wastewater. In textile processing, salts are mainly used to improve the exhaustion of direct and reactive dye baths and can be formed as by-product in other processes such as neutralization. According to (Kemker, 2013), a sudden increase or decrease in conductivity in a body of water can indicate pollution. Sewage leak will also increase conductivity due to the additional chloride, phosphate and nitrate ions. An oil spill or addition of other organic compounds would decrease conductivity as these elements do not break down into ions.

2.3.6 Temperature in a textile effluent

Temperature of the wastewater at the point of discharge is equally a very important ecological factor, and an environmental variable that limits the distribution of life. Temperature greatly influences vital activities like metabolism, behavior, reproduction and development of microorganisms (Jadeja, 2013). At high temperatures, the rate of dissolution of atmospheric oxygen in water is usually low and this affects the sustainability of the aquatic habitats due to reduction in the level of dissolved oxygen. High temperatures can increase the solubility and thus toxicity of certain compounds including heavy metals such as cadmium, zinc and lead as well as ammonia (Kemker, 2013).

In addition to its own effects, temperature influences several other parameters and can alter the physical and chemical properties of water. Figure 2.3 shows interrelation of some of the parameters that are influenced by either the rise or drop in temperature. Some reactions may be speeded up by the discharge of wastewater into the stream, thereby lowering the solubility of oxygen and subsequently amplifying odour. Kemker (2013), has further reported an indirect relationship between temperature and dissolved oxygen whereby, the solubility of oxygen and other gases decreases as temperature increases. Textile mills generally have their effluent temperature between 35.7 °C-40 °C.

2.3.7 pH in a textile effluent

pH is a measure of how acidic or basic a solution is. It measures the concentration of hydrogen ions in water. At a given temperature the intensity of the acidic or alkalinity character of a solution is indicated by pH or hydrogen ion activity. Measurement of pH is one of the most important tests in water analysis. This is because every phase of wastewater treatment such as, acid-base neutralization, precipitation, and coagulation and corrosion control is pH dependent. Wastewaters with extreme concentration of hydrogen ions are difficult to treat by any biological means simply because the concentration range suitable for the existence of most microorganisms is generally pH 5-9 (Jadeja, 2013).

The textile wastewater pH varies widely, whereby extremities such as 2 or 12 are common. Extreme variations of pH affect the survival of aquatic organisms living within it. In addition, extreme pH levels increase the solubility of essential elements and compounds such as Al, Fe, Cu, and Mn, thus making toxic chemicals more mobile and increasing the risk of absorption by aquatic life (Jaishree and Khan, 2014). Kemker (2013) reported that pH levels outside of the recommended standard can damage and corrode pipes and other systems, thus increasing further heavy metal toxicity. Another effect of the pH that is related to textile wastewater is the variation of colour intensity with pH.

Acids and alkalis used in various wet processes contribute widely to change in pH. For instance, large quantities of alkali are used in bleaching, desizing, scouring and mercerizing. Discharge of wastewater containing detergents and soap-based products can cause a water source to become too basic. While acids contribute to corrosiveness and influence chemical reaction rates, chemical speciation and biological processes, alkalinity on the other hand is significant in control of wastewater treatment processes, largely due to its acid-neutralizing ability.

2.3.8 Dissolved Oxygen in a textile effluent

Dissolved oxygen has been defined as a measure of free, non-compound oxygen present in water or other liquids. According to Kemker (2013), DO is considered an important parameter in assessing water quality because of its influence on the organisms living

within a water body. A dissolved oxygen level that is too high or too low may cause harm to aquatic life and affect water quality. Aquatic animals are most vulnerable to lowered DO levels in the early morning on hot summer days when stream flows are low and water temperatures high (APHA, 1999). DO levels fluctuate seasonally and over a 24-hour period. They vary with water temperature and altitude. Cold water holds more oxygen than warm water and water holds less oxygen at higher altitudes. Thermal discharges, such as water used to cool machinery in a manufacturing plant or a power plant, raise the temperature of water and lower its oxygen content.

2.3.9 Total Suspended Solids in a textile effluent

Suspended solids refer to residue or non-filterable matter in wastewater. In a textile mill, suspended substances may result from undissolved solid particles removed from cloth. Sometimes chemicals used also get precipitated due to change in pH which increases the suspended particles. Solids analyses are important in the control of biological and physical wastewater treatment processes, for assessing compliance with effluent limitations (APHA, 1999). The solids present in water, besides effecting the growth of the plants directly, also affect the soil structure, permeability and aeration thus affecting plant growth (Varsha *et al.*, 2013).

2.3.10 Total Dissolved Solids in a textile effluent

TDS is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granular suspended form. When and if the roots of a plant are placed in water with a high salt concentration, the water from the plant moves into the salt water causing the plant to wilt. Therefore irrigation with high TDS water could result in decrease in optimal crop production (Varma and Sharma, 2011).

2.3.11 Sulphides in a textile effluent

The presence of sulphides in a textile wastewater is associated with use of Sulphur related process chemicals and sulphur dyes (Hussain *et al.*, 2004). Sulphur has a characteristic smell of rotten egg, which can be detected at levels as low as 0.05 mg/L and may therefore cause disagreeable tastes and odours. Real human impacts from hydrogen

sulphide are however not likely until air levels reach at least 0.2 mg/l, at which vulnerable groups such as some asthmatics, may respond with some minor irritative changes in their bronchial capacity. Respiratory, neurological, and ocular effects are the most sensitive end-points in humans following inhalation exposure (WHO, 2003).

2.3.12 Nitrates in a textile effluent

Presence of nitrate in textile effluent may be associated with the impurities present in the chemicals used in various processes including dyeing. Various dyes and their additives have nitrate ion as a functional group (Hussain *et al.*, 2004). Printing pastes contain urea, another compound that can be present in large quantities. Nitrate levels exceeding recommended limits are frequently encountered in textile wastewater as a result of ammonium nitrogen. Such levels may contribute to eutrophication effects, particularly in freshwater (Varsha *et al.*, 2013).

2.3.13 Phosphates in a textile effluent

The prevailing forms of phosphorus in natural waters and wastewaters, are orthophosphates, condensed phosphates, and organically bound phosphates. Dye bath streams containing phosphate buffers are the main source of phosphorus in a textile effluent (Hussain *et al.*, 2004) Phosphates are used in different steps in textile wet processing. For instance in buffers, scouring, water conditioners, surfactants, and flame-retardant finishes.

2.3.14 Sulphates in a textile effluent

High levels of sulphur compounds can be present in textile effluent depending on the nature of chemicals used. For example, where sodium sulphate is used as an auxiliary in reactive dyeing, sulphate levels in the dye bath can be as high as 20 g-42 g (Bisschops and Spanjers, 2008). Sodium sulphide and sodium hydrosulphite are commonly used as reducing agents when dyeing with sulphur or vat dyes. According to Santhi and Moses (2008), the use of these agents contributes to the formation of products such as sulphite, sulphate, thiosulphate and toxic sulphur. Another source of sulphur compounds is from the use of sulphuric acid in pH control.

2.3.15 Heavy Metals in a textile effluent

According to (APHA, 1999), textile effluents contain trace metals like Cr, As, Cu and Zn, which are capable of harming the environment. When the rate of uptake of such metals by organisms is more than the excretion phase, increasing concentration may lead to bioaccumulation in fauna and flora. Joshi and Santani (2012) reported that, since heavy metals are non- biodegradable, they accumulate in primary organs in the body and over time begin to fester, leading to various symptoms of diseases

Metals may enter the wastewater streams through: incoming water supply system; electrolyte; oxidizing and reducing agents; acid and alkali; dyes and pigments; herbicides and pesticides; finishes; and maintenance chemicals. The main sources of heavy metal pollutants in textile wet processing are dyeing, printing and finishing processes. This is because heavy metals are often used in these processes as oxidizing agents, dye stripping agents, in sulphur dyeing, as metal complex dyes, fastness improvers, and finishers (Zeiner *et al.*, 2009).

As Zeiner et.al (2009) further states, most synthetic dyes contain cadmium, chromium, copper, zinc, or other metal atoms. Some metals present in cotton may contribute to problems in yarn manufacturing, bleaching, dyeing, and in the processing quality. Manganese and ferrous for instance are readily air-oxidized and form compounds causing yellowing. Deepali et al (2009) asserted that, since most of the heavy metals are non-degradable into non-toxic end-products, their concentrations must therefore be reduced to acceptable levels before discharging into the environment. Some of the heavy metals commonly found in a textile effluent including lead, chromium, iron, copper, manganese, aluminium and cadmium have been reviewed.

2.3.15.1 Lead

Major contributor of lead in a textile effluent is the chemical impurities (Hussain *et al.*, 2004). Lead can also be found in natural fibers, such as cotton, flax and hemp, which can absorb it from the environment. Lead is used in the textile industry in a number of ways and under a variety of names as shown below.

Substance	Use
Lead acetate	dyeing
Lead chloride	preparation of lead salts
Lead molybdate	pigments used in dyestuffs
Lead nitrate	mordant and oxidizer in dyeing

Source: (*Oecotextiles, 2009*).

Acute lead poisoning in humans may cause severe dysfunction in the kidneys, reproductive system, liver, the brain, nervous system as well as delay in physical and mental development in children. Lead has adverse health effects on shellfish at very small concentrations, and particularly disturbs the body functions of phytoplankton and can influence ecosystem balances to a great extent (*Oecotextiles, 2009*). Lead can end up in water and soils through corrosion of leaded pipelines in a water transporting system and through corrosion of leaded paints. It is therefore important to maintain the levels of this metal to acceptable limits in order to avert the dangers of its accumulation and associated health consequences.

2.3.15.2 Copper

Impurities in chemicals or use of copper complex dyes may introduce substantial amount of copper in a textile effluent (*Hussain et al., 2004*). Copper salts are also used in water supply systems to control biological growths in reservoirs and distribution pipes and to catalyze the oxidation of manganese. Corrosion of copper-containing alloys in pipe fittings may introduce considerable amounts of copper into the water (*APHA, 1999*). Copper is toxic to aquatic plants at concentrations below one mg/l, while concentrations near this level can be toxic to some fishes (*Sharif et al., 2009*). Above the allowable limits, copper may have adverse effect on human health, leading to fatigue, insomnia, osteoporosis, heart disease, cancer, migraine headaches and seizures.

2.3.15.3 Chromium

Chromium based dyes and impurities in chemicals present in various processes are the main sources of chromium in textile effluent (*Hussain et al., 2004*). While Chromium is essential for plant and animal metabolism it can cause allergic reactions in human skins,

damage the lungs and may cause asthma attacks. When accumulated in high levels, say concentration reaches 0.1 mg/g of body weight, chromium becomes lethal and can cause lung cancer. Chromium VI has been reported to be more toxic for bacteria, plants and animals (Deepali et al., 2009).

2.3.15.4 Iron

Iron concentration in textile effluent results from chemical impurities or use of iron complexed dyes (Hussain *et al.*, 2004). High concentration of iron may contribute to stringent taste, decolouration, turbidity, deposits and growth of iron bacteria in pipes thus affecting the acceptability of water for domestic use (Rastogi and Poonam, 2012).

2.3.15.5 Aluminium

Soluble, colloidal and insoluble aluminium may appear in treated water or wastewater as a residual from coagulation with aluminium-containing material (APHA, 1999). According to Hydro and Artbox (2012), high intake of aluminium may be a health risk for patients with renal failure.

2.3.15.6 Cadmium

Use of dyes and other finishes contributes significantly to presence of cadmium in a textile effluent. Long term exposure to lower levels of cadmium in air, food or water leads to a build-up of cadmium in kidneys and possible renal diseases. Other potential long term effects are lung damage and fragile bones (Rastogi and Poonam, 2012). Cadmium is extremely toxic to humans because of its inhibition of various enzyme systems. It is also associated with testicular damage and male sterility.

2.3.15.7 Manganese

Manganese results from impurities present in chemicals used in various processes (Hussain *et al.*, 2004). If inhaled, manganese can enter the brain in two ways, namely: by olfactory nasal airway, that provide a direct path to the brain tissue, and by lung uptake, that could provide a source of continuing exposure.

2.4 Wastewater Management

While there are many possible in-plant changes, process modifications, and water-saving measures through which industrial wastewater loads can be significantly reduced, the basic principle underlying effective wastewater management is a strict limit on the

discharge of hazardous liquids to sewers. Beirut (2010) asserts that, a cornerstone of good wastewater management is the segregation in the form of capture, separation and storage of different waste streams to allow material recovery, recycling and re-use.

Approaches for reducing discharges to the environment take two general forms: a) Source reduction, which basically involves reducing the loading of constituents delivered to the wastewater treatment system, and b) installing additional treatment system capacity or components. Various studies have made recommendations on possible interventions in pollution control ranging from, cleaner production techniques to various ways of treating the wastewater before discharge. Notably, Beirut (2010), in his study on cleaner production in Lebanon, explored cleaner production options with specific emphasis. Process optimization and raw material substitution such as eco-friendly dyes and enzymatic desizing where the enzymes are catalysts, has been tried and reported to be most economical and safe. Three enzymes namely bacterial, malt and pancreatic have been used (UNEP, 1996). Sarayu and Sandhya (2011) carried out a study on the potential of facultative microorganisms for bio-treatment of textile wastewater. Technology change on the other hand improves operating efficiencies. Muruges and Selvadass (2012) pointed out that, application of known technologies, based on documented studies often produces great benefits. Internal recycling and re-use on the other hand conserves resources and lowers the waste loads.

Among the options worth considering in ensuring resource optimization as pollution abatement measure is the 3R's approach namely Reduce, Recycle and Re-use. Firstly, efficient utilization and reducing amounts of resource/inputs, such as water, chemicals and energy within the entire production process, secondly, ensuring that process losses are kept at minimum; thirdly, maximum recovery of resources, and lastly, re-use/recycling of the recovered resources are key. For effective implementation of the 3Rs, it is important that the wastewater streams are, (i) analysed by source, (ii) characterised by the most prevalent parameters (iii) treated (iv) evaluated for toxicity and (v) recycled. The end of pipe treatment at the WWTP is only for the heavily contaminated streams while highly toxic streams are treated and alternatively disposed

ensuring minimal harm to the environment. Figure 2.3 is an illustration of a textile process effluent management path.

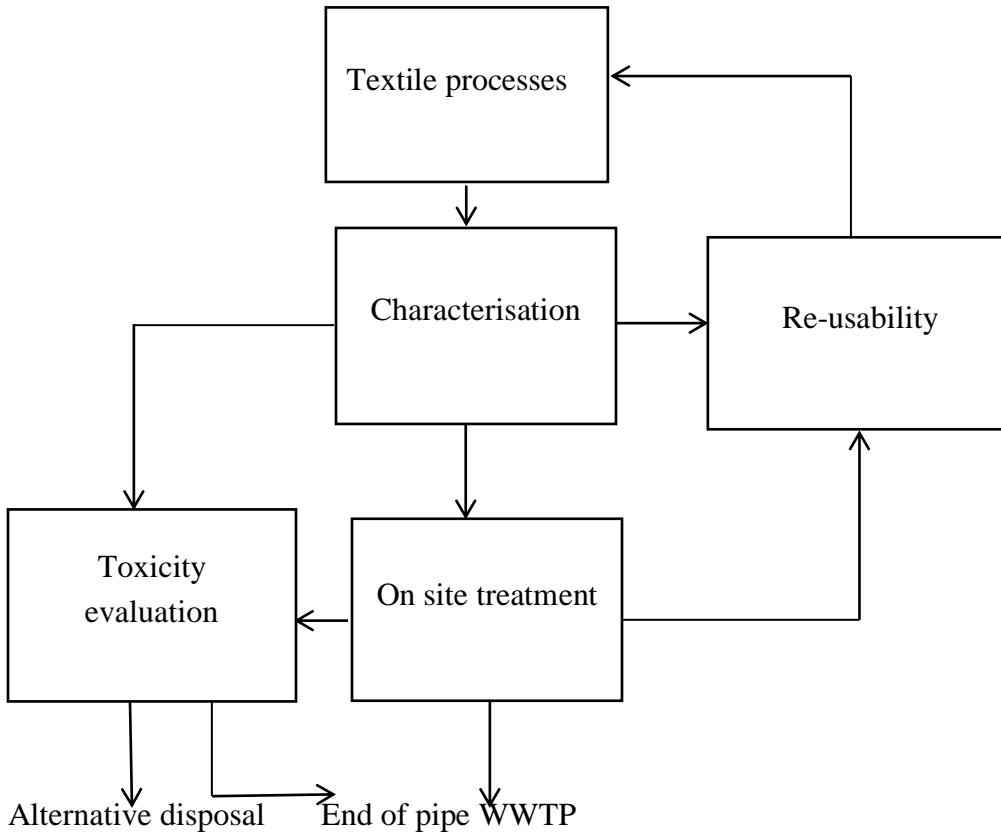


Figure 2. 3: Effluent management path. Source: *EWA (2005). Page 16*

Website: <http://www.ewa-online.eu/>

As Chougule and Sonaje (2012) found out, effluents released from washing processes are clear and pure. Their relatively small chemical content picked up from the earlier process may not adversely affect other process for which they are reused. For example, the rinses after bleaching can be collected and used for rinsing after scouring without detriment to the latter process, while desizing effluent can be reused after the recovery of size. Wastewater from mercerizer may be re-used in scouring, resulting in less water and chemical consumption, and hence lower cost of operation. Further, less contaminated effluent could be collected, treated and reused in some of the operations. Reuse of exhausted dye bath is also possible with certain class of dyes. For instance, vat dyes may be recovered from spent dye liquors, for reuse. And lastly, new product design, resulting

to reduced use of hazardous substances, reduced waste disposal, reduced energy consumption and more efficient production processes. On the contrary, while wastewater treatment has been seen as a possible option to pollution control, traditional technologies which include various combinations of biological, physical and chemical techniques, require high capital investment and operating costs. Zaharia and Seteu (2009) further observed that, conventional bio-treatment methods are not effective for most of the synthetic dyestuffs due to their complex polyaromatic structure and recalcitrant nature.

According to Joshi *et al.*, (2003), colour pollution can be most efficiently controlled by good source reduction practices, administrative and engineering control. Arslan *et al* (2002 as cited in Al-kdasi *et al.*, 2005), documented that high colour removal of simulated reactive dye bath effluent was achieved at a neutral pH, while decolouration time reduced by 32% at alkaline pH. Further, a right first time production technique minimizes waste and makes significant contribution to reduce colour loads in the effluent. Improving the exhaustion levels of the various dyes in the dye bath has been shown to improve shade reproducibility as well minimising spills. Chequer *et al* (2013) therefore, emphasized on the need to optimise the coloring process with the objective of reducing the environmental impact. Sapci and Ustun (2003), reported high efficiency in the use of pumice as an adsorbent to remove colour and COD due to its high adsorption, while, waste pumice can be re-used as adsorbent for organic matters in dyeing wastewater. Natural polymers derived from renewable plant sources, such as locust bean gum, guar gum and cassia gum have also been reported to be highly effective at cleaning effluent whilst being much kinder to the environment.

Zaharia and Seteu, (2009); Babu and Parande (2007); and Al-kdasi *et al* (2005), have recommended biodegradation, coagulation/flocculation, adsorption on activated carbon, ozone treatment, electrochemical processes, reverse osmosis, and ultrafiltration or microfiltration as best alternative methods for large scale ecologically friendly treatment processes. Figure 2.5 is a schematic diagram of an electrochemical treatment and recovery of chemicals from a textile effluent. Ultimately, the responsibility for proper wastewater management rests with the generator and should be considered part of the cost of doing business.

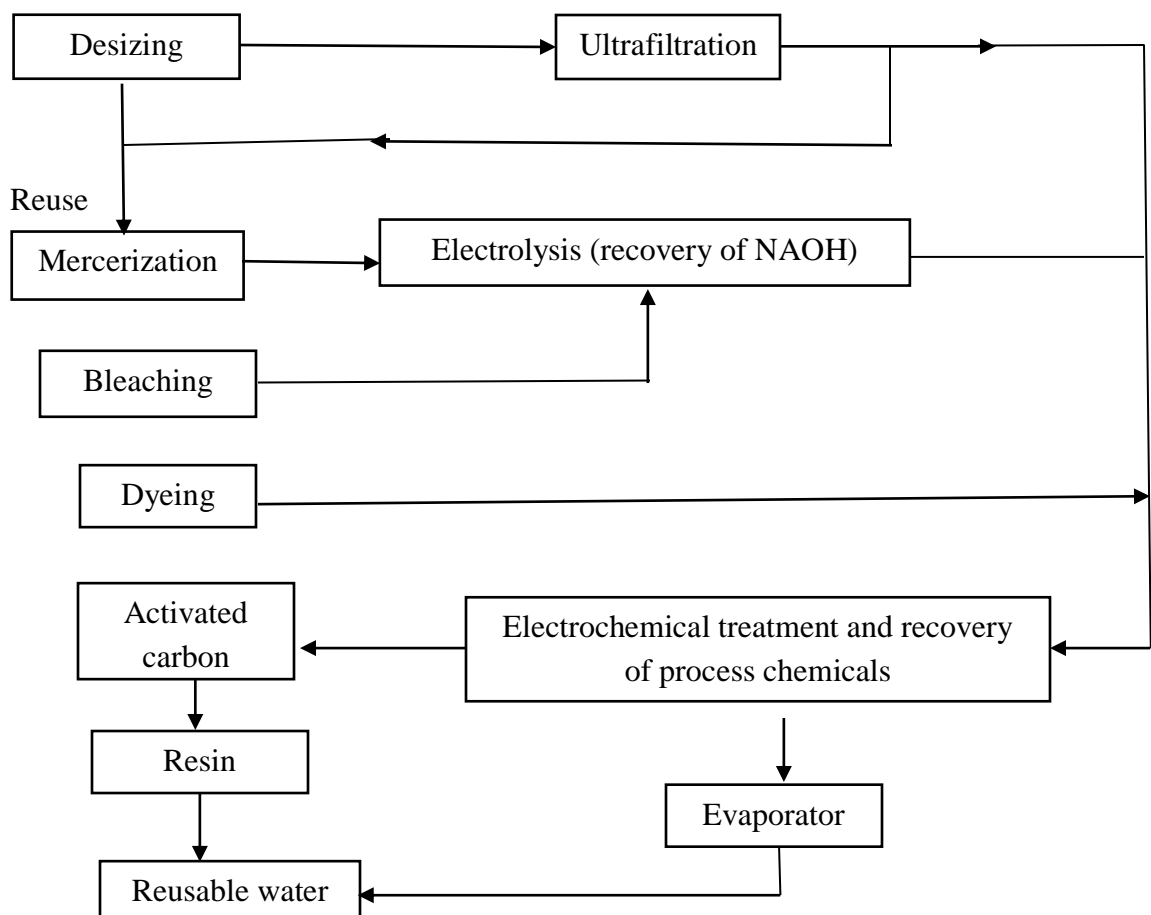


Figure 2. 4: Electrochemical treatment and recovery of chemicals from textile effluent

Source: Babu and Parande (2007). Page 148: Website: <http://journal.cotton.org>.

Various studies have explored broadly on general characteristics of the textile wastewaters based on the most prevalent pollutants. Globally, characteristics of textile effluent and their effect on environment and human health has been documented albeit scantily. In Kenya however, studies have focused mainly on the trade and policy issues with very little information on environmental and health impact of textile processing. This thesis therefore addresses an important knowledge gap on the characteristics of the textile wet processing effluent and their effect on the environment. The study further highlights key mitigation measures and recommendations for environmental protection.

CHAPTER THREE: METHODOLOGY

3.1 Study Design

A descriptive research methodology was used for this study. Data was collected through observations, field measurements and by laboratory testing of both the process wastewater streams and wastewater treatment plant effluent. The actual study was preceded by a reconnaissance visit to the study site and a walk through survey in order to collect background information on the processes and acquaint with the code of practice. Secondary data was obtained from published literature which includes and not limited to; theses and dissertations, journals, books, magazines and government publications,

3.1.1 Study Site

The study was carried out in Thika Cloth Mills, in Thika town, Kiambu County, Kenya. Thika is a market town in Kiambu County, Kenya, located about 40 km north of Nairobi on the Thika River. It is situated at 1°03'23" South latitude, 37° 05'10" East longitude and 1495 meters elevation above the sea level.

The study site is a textile factory located in the industrial area along factory road as shown in the study area map (Figure, 3.1). It is a composite factory, processing about 650,000 metres of fabric every month in different blends, colours and prints. The factory which opened its doors in 1958 employs about 650 skilled workers. Further, it supports 22,000 small-scale cotton farmers around the country and 54,000 jobs in the value chain. The mill operates under three main departments namely spinning, weaving, and wet processing. The wet processing unit comprises of; singeing, sizing, desizing, bleaching, mercerizing, dyeing, printing and finishing. The factory has a functional wastewater treatment plant and discharges substantial amount of pre-treated effluent into the municipal sewer.

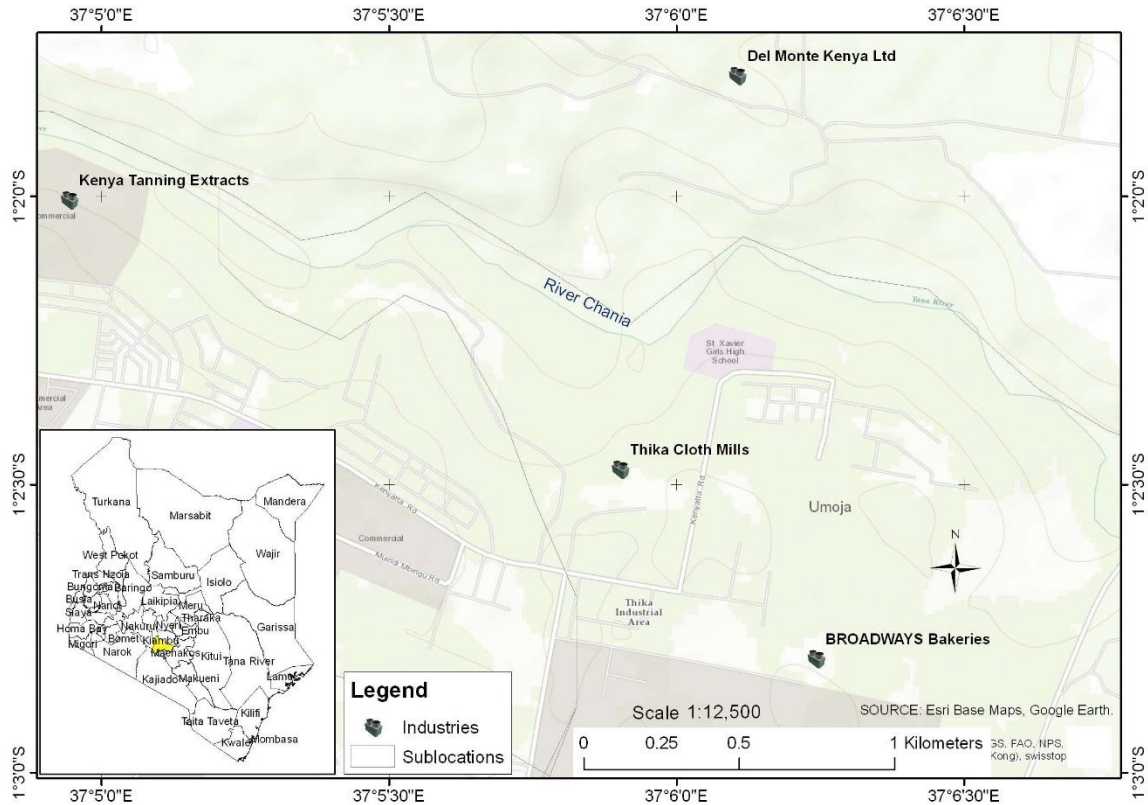


Figure 3. 1: Study area map. Source: (google maps, 2015). Website: www.googlemaps.com

3.2 Sampling Design/data collection protocol

Purposive sampling, a non-probability sampling technique was used for the purpose of this study, in accordance with Mugenda and Mugenda (2003). Unlike probability sampling methods, personal judgment is critical in choosing cases that help answer research questions or achieve research objectives. This technique was found appropriate because of low cost, time effectiveness and limited number of samples.

Sampling took place in the wet processing section of the factory. This section, comprising of ten wet processes was selected because of its high pollution potential, owing to the quantities and range of chemicals used, and volumes and nature of wastewater generated. According to Elango et al (2017), major pollutants released from the textile industries are from several of their wet processing operations like scouring, bleaching, mercerizing, dyeing, printing and finishing.

Sampling was done according to standard sampling principles and guidelines outlined in American Public Health Association (APHA, 1992).

3.2.1 Sampling Points and Frequency

Samples were obtained from ten wet processes namely: desizing, batch and continuous scouring, cold and hot wash, bleaching, mercerizing, dyeing, printing and finishing as well as the municipal sewer as described below. Three samples were collected from each of the processes in two weeks intervals between May and August 2013. Altogether, thirty three (33) samples were collected and used for analysis.

3.2.1.1 Desizing process

The main objective of de-sizing is removal of starch from fabric. For this purpose, the fabric was impregnated in the de-sizing bath containing chemicals at 90 °c for 6 hours. Caustic soda, a saponification agent, sodium hydroxide, a wetting agent and a surfactant for lowering the surface tension of water were used in this process. Three samples were collected from the desizing chamber at three intervals. Plate 3.1 presents the desizing chamber as captured on the 3rd of July 2013 at 3.25 p.m.



Plate 3. 1: Desizing unit

3.2.1.2 Scouring process

Scouring process took place in the scouring chamber at 80-100°C for three hours in order to remove fats and waxes. Samples were collected from two scouring operations namely batch for cotton polyester blends and continuous scouring for 100% cotton materials. Since the processes were not running continuously, sampling was done at, and only when the machines were operational. Three samples were collected from each operation at irregular intervals throughout the sampling period. The wastewater stream was

conspicuously brownish in colour, foamy and at boiling point. Plate 3.2 shows the scouring chamber as observed on the 31st May of 2013 at 3.30 p.m.

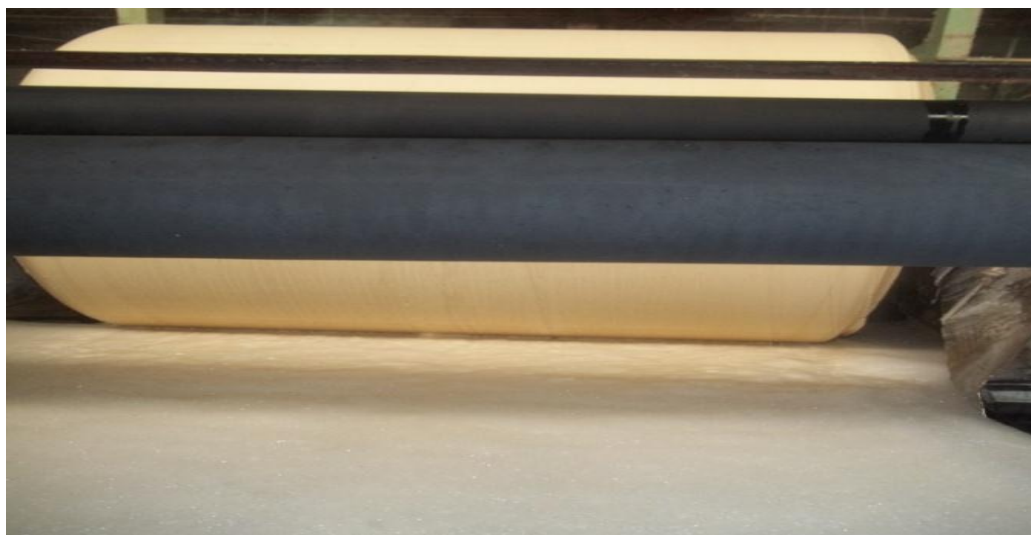


Plate 3.2: Scouring chamber

3.2.1.3 Hotwash process

Hot wash was done in hot water in order to remove residual scouring chemicals. Three samples were collected from this process at irregular intervals.

3.2.1.4 Cold wash process

This process was carried out with cold water in acetic acid, for rinsing the cotton material after scouring. A total of three samples were collected during the entire sampling period

3.2.1.5 Bleaching process

This process was done in order to acquire an optical white colour on a printing fabric using hydrogen peroxide. Waste water stream was brownish in colour. In one instance, sample volatilized during analysis of BOD. Volatilization was largely associated with discharge of highly concentrated raw chemicals particularly hydrogen peroxide and other additives, following a mechanical breakdown.

3.2.1.6 Mercerizing process

This process involved treatment of cotton fabric caustic soda in order to impart lustre and improve affinity for dyes and other finishes. Samples were collected from the

mercerizing unit at two points namely: during the first wash and at rinsing. As observed on this particular day, residual caustic was pumped back into a recovery plant after completion of the process. Plate 3.3 is a photograph of the mercerizing process as captured on the 5th of June 2013.



Plate 3. 3: Mercerizing unit

3.2.1.7 *Dyeing process*

Cotton dyeing was done in the continuous pad steam dyeing unit using VAT dyes and dyeing auxiliaries such as sodium hydrosulphite and sodium hydroxide. The process was carried out under hot steam at 105^oc. to facilitate dye fixation. Collection of samples in this process was oftently interrupted by numerous machines down time in a number of sampling trips. Three samples were collected at various intervals.

3.2.1.8 *Printing process*

Printing took place in a rotary screen printing unit, using pigments, binders and fixers at a pH of 8.3 and curing at 150^oc. Wastewater from this process was intensely coloured, foamy and turbid. Residual chemicals and spills were washed down the drain during rinsing. Sampling was done at the point where the wastewater collected after printing and washing off. Plate 3.4 shows printing work in progress captured on the 24th July 2013 at 11 a.m.



Plate 3. 4: Printing unit

Plate 3.5 shows intensely coloured wash offs resulting from of spills and residual dyes from the printing unit. This photograph was taken on the 24th of July 2013 at 11.05 a.m.



Plate 3. 5: Blue coloured wastewater with residual chemicals

3.2.1.9 Finishing process

The finishing unit consisted of several chambers where the finishing solution was highly diluted before discharge. Samples from this process were collected at the draining point.

3.2.1.10 Municipal Sewer

Contaminated wastewater streams from the factory processes collected in the treatment plant where the effluent was biologically treated through aeration and filtration before

discharging to the municipal sewer. The effluent was then discharged from the wastewater treatment plant through the municipal pipeline to the sewer, from where samples were collected.



Plate 3. 6: Effluent flow through the municipal sewer. 7th August 2013 at 10 a.m.



Plate 3. 7: Sewer sampling point. 7th August 2013 at 10 a.m.

3.2.2 Sampling Procedure

Sampling was carried out from the various wet processes listed above at different intervals during process operation, while samples from the WWTP were collected at the discharge point to the municipal sewer. Areas of excessive turbulence were avoided because of potential loss of volatile constituents and of potential presence of toxic vapours. For safety considerations, protective clothing including dust coats, safety boots and gloves were used when handling the samples.

All sample specimens were collected in two litres plastic cans which were rinsed twice with the wastewater sample before filling. The sample carrying cans were tightly sealed to prevent unauthorized tampering prior to analysis. Sample identification gummed paper labels indicating the sample code, date and time of sampling was affixed to the sample cans at the time of sampling in order to prevent sample misidentification. Samples were carried in a cooler box in order to ensure that they did not deteriorate or become contaminated during transportation to the laboratory. Reference codes were assigned to each of the sample specimen for identification preceding analysis. Coding was based on the process from which the sample was collected, month of sampling and sample number. At the laboratory, the samples were preserved in a refrigerator at 4 °C prior to testing (plate 3.8).



Plate 3. 8: Labeled and sealed samples



Plate 3. 9: Refrigerated samples

Sample integrity during delivery to the laboratory was maintained by use of a chain of custody record. The chain of custody record contained information about: sample number, date of sample receipt, sample type, signatures of persons involved in the chain of possession, dates of possession and parameters to be tested. The samples were taken to the laboratory by the sample custodian, after assigning to each sample, a laboratory number, logged them in the laboratory log book and stored them in a refrigerator preceding analysis. The laboratory head thereafter handed over the samples to the section head who in turn assigned them to the technologists for analysis.

3.3 Data Collection, Analysis and Presentation

3.3.1 Data Collection

Data collection was preceded over by a reconnaissance visit to the study site soon after acquiring a research permit from the then National Council for Science and Technology Data was obtained mainly through field measurements and laboratory analysis. One on one discussion with section heads also formed an integral part of data collection.

3.3.2 Analytical Parameters and Procedures

Sample analysis was done both insitu and in the laboratory and in accordance to procedures outlined in the Standard Method for the Examination of Water and Waste water (APHA, 1998). The specimens were analysed for temperature, DO, turbidity, conductivity, pH, BOD, COD, TSS, TDS, nitrates, phosphates, phenols, sulphides and heavy metals (chromium, cadmium, lead, Zinc and copper) as discussed here below. Laboratory testing was carried out at the Laboratory Services Center at Kenya Industrial Research and Development Institute. Two basic techniques namely; Gravimetric and Volumetric techniques were used for analysis. The gravimetric technique was used to analyse the concentration levels of total dissolved solids and suspended solids, while the volumetric technique was used to determine the concentration of BOD and COD. Calibration of the equipment was done according to procedures provided in (APHA 1999).

3.3.2.1 pH analysis in the wastewater samples

pH was measured in-situ using a portable pH meter with a temperature measuring device. Model: Mrc.Scientific Instruments PH-207.Q64029.RS232. The meter was calibrated using buffer solutions. The electrode was removed from the storage solution, rinsed with distilled water and dried with a soft tissue prior to taking the readings. The sample was gently stirred to homogeneity to establish equilibrium between electrodes and sample as well as minimize carbon dioxide entrainment. It was thereafter allowed to stabilize and pH values recorded.

3.3.2.2 Turbidity analysis in the wastewater samples

Turbidity was measured in-situ using a turbidimeter model 2100p-HACH. The turbidimeter consisted of a nephelometer with a light source for illuminating the sample and a detector with a read out device to indicate intensity of light scattered. The cuvette was rinsed with the wastewater and sample put into the meter to read the turbidity. Dilutions were made where the readings were above or outside the meter reading and the results calculated as Turbidity reading X dilution factor.

3.3.2.3 Conductivity analysis in the wastewater samples

Conductivity was measured on site using a conductivity meter model CD-4303.Q572825. The meter was switched on and the electrode rinsed using distilled water. After pressing the meter reading button, rinsed electrode was dipped in the sample and the readings in micro Siemens (mS) were recorded.

3.3.2.4 Temperature analysis in the wastewater samples

Temperature was measured on site using a portable meter model: Mrc.Scientific Instruments -RS232. The measuring electrode was rinsed with distilled water and dipped into the sample where readings were taken in degrees centigrade.

3.3.2.5 Dissolved Oxygen analysis in the wastewater samples

DO was determined on-site using oxygen meter model MRC-RS.232.AC 79261. The measuring electrode was rinsed with distilled water, dipped into the sample and the reading recorded. Since dissolved Oxygen varies with temperature, the two parameters were measured simultaneously.

3.3.2.6 Colour analysis in the wastewater samples

The true color, which is the color of water from which turbidity has been removed, was determined in the lab using a lovibond model NESSLERISER 2150 apparatus (Plate 4.8) and samples compared against standard disc in the range of 10 hazen.





Plate 3.10: Lovibond colour measurement apparatus

A measure of 50 ml supernatant sample was taken into 50 ml nessler tubes, and placed into the right compartment of the lovibond apparatus. A similar amount of distilled water (blank) was placed into the left compartment and the color matched using the color disc. Dilution to a predetermined factor was made where the color was outside the highest range (90) hazen units and the results expressed in terms of color of the sample X the dilution factor.

3.3.2.7 Total Dissolved Solids analysis in the wastewater samples

TDS were measured in the laboratory as follows: A clean dish was heated in an oven to 180 °C for about one hour and then cooled to room temperature in a desiccator. About 50 ml of well mixed sample was filtered and the filtrate put in to the pre-weighed dish. The filtrate was evaporated to dryness and the evaporated sample dried for about one hour in an oven at 180 °C. The dish was cooled in a desiccator to room temperature and weighed. The cycle of drying, cooling, desiccating and weighing was repeated until a constant weight was obtained for every sample. TDS were then calculated as follows;

$$\text{Mg/L} = \frac{(A - B)100}{\text{Sample Volume}}$$

Where,

A= weight of dried sample + dish in mg

B = weight of dish in mg (APHA, 1999)

3.3.2.8 Total Suspended Solids analysis in the wastewater samples

A well-mixed sample was filtered through a weighed standard glass fibre filter and the residue retained on the filter dried in an oven to a constant weight at 105 °C. The increase in weight of the filter represents the total suspended solids. About 50 ml well mixed sample was filtered through a sintered glass crucible porosity number four and the residue was dried at 105°C for one hour, cooled in a desiccator and weighed. Drying and cooling was repeated until constant weight was obtained and TTS determined as follows:

$$\text{Mg/L} = \frac{(A - B)100}{\text{Sample Volume(ml)}}$$

Where,

A= weight of crucible + residue in mg

B = weight of empty crucible in mg (APHA, 1999)

3.3.2.9 Biochemical Oxygen Demand analysis in the wastewater samples

The basic principle involved the estimation of dissolved oxygen uptake of sample and blank initially and after incubation for 5 days at 20°C. This parameter was measured in the laboratory by the respirometric BOD_n determination method using the OxiTop® (Plate 3.11). This method uses carbon dioxide and measures change in pressure.



Plate 3.11: The Oxitop BOD measurement apparatus

Wastewater samples were preserved in the refrigerator at 4 °C and incubated within 24 hours of collection. Each sample was neutralized to a pH value within the recommended range of 6.6 to 7.2. Expected BOD value was estimated in order to select the correct range of measurement for a determination. On the basis of the estimated value, the required volume of sample was selected according to Table 3.1 below. Sample was diluted where estimated value lay outside the specified ranges of measurement.

Table 3. 1: Expected BOD values against the expected amount of sample

Expected BOD value [mg/L]	Amount of sample to be Used [ml]	Factor (*)
0-40	432	1
0-80	365	2
0-200	250	5
0-400	164	10
0-800	97	20
0-2000	43.5	50
0-4000	22.7	100

(*) The OxiTop Control measuring system need to take these factors into account.

Source: *BOD Primer WTW manual*.

Website: http://old.omnilab.de/hpb/export/2/BSB_E.PDF

The measuring range of the sample to be analyzed was estimated as shown in the table above. The predetermined sample solution was transferred into BOD bottles and a magnetic stirrer bar inserted into the bottle. Two sodium hydroxide pellets were placed in the rubber sleeve and the rubber sleeve suspended on bottle mouth. Oxi Top® measuring head was then tightly screwed and measurement started. The BOD bottles with the BOD head on, were placed in the incubator for five days at 20°C and results recorded thereafter.

3.3.2.10 Chemical Oxygen Demand analysis in the wastewater samples

COD was measured in a reflux apparatus with an electric motor. The sample was refluxed with known amount of potassium dichromate and silver sulphate catalyst in sulfuric acid. Part of the dichromate was reduced by the organic matter in the sample while the remainder was determined by titration with ferrous ammonium sulphate. The following reagents were used:

1. Sulfuric acid-silver sulfate solution –Solution made by dissolving 22 g silver sulfate (Ag_2SO_4) in a 4.1 kg bottle of concentrated sulphuric acid (H_2SO_4).
2. Potassium dichromate solution 0.25M ($\text{K}_2\text{Cr}_2\text{O}_7$) – this solution was made by dissolving 12.25g potassium dichromate previously dried at 103°C for 2 hours in distilled water and made up to 1 litre.
3. Ferroin indicator –About 1.485g of 1,10-phenanthroline monohydrate ($\text{C}_{12}\text{H}_8\text{N}_2\cdot\text{H}_2\text{O}$) together with 0.695g ferrous sulfate crystals ($\text{FeSO}_4\cdot 7\text{H}_2\text{O}$) were dissolved in sufficient distilled water and diluted to 100 ml.
4. Ferrous ammonium sulfate solution 0.25 M was made by placing 98.0 g ferrous ammonium sulfate ($\text{FeSO}_4(\text{NH}_4)_2\text{SO}_4\cdot 6\text{H}_2\text{O}$) in a 1000 ml volumetric flask and dissolving in 500 ml of distilled water. About 20 ml of concentrated H_2SO_4 was then added and the solution made up to one litre mark with distilled water.

A measure of 0.4 g mercuric sulfate crystals were placed in a refluxing flask and a few granules of anti-bumping agent added. Depending on the smell and physical characteristic of the sample, either 20 ml of sample was added or an aliquot diluted to 20 ml. About 10 ml standard potassium dichromate solution was added and the flask connected to the condenser. About 30 ml concentrated sulfuric acid containing silver sulfate was slowly added through the open end of the condenser, mixing thoroughly by swirling while adding the acid. The mixture was refluxed for 2 hours, cooled and 90 ml of distilled water added.

A blank consisting of 20 ml distilled water, and the reagents was refluxed in the same manner. Excess dichromate was titrated with standard ferrous ammonia sulfate using three drops of ferritin indicator. End point was recorded as the color changed from blue-green to reddish brown. Plate 3.12 shows reflux apparatus in use.



Plate 3.12: Reflux COD measurement apparatus

The COD level was computed as follows;

$$\text{Mg/l} = \frac{(A - B)M8000}{\text{MI Sample}}$$

Where,

A - ml ferrous ammonium sulfate used for the blank

B- ml ferrous ammonium sulfate used for the sample

MI-Molarity of the ferrous ammonium sulfate (APHA, 1999)

3.3.2.11 Nitrates analysis in the wastewater samples

Presence of nitrates was analysed using the spectrophotometric method in accordance with (APHA, 1998). The method specifies the determination of nitrate in water by spectrophotometric analysis with sodium salicylate using UV-CARY 50 CONC UV-Visible Spectrophotometer. Nitrate ions and sodium salicylate reacts in an alkaline media to form a yellow sodiumnitrosalicylate, which can be determined spectrophotometrically at 420 nm wavelength. The following reagents were used;

1. A measure of 0.5 g of AR grade sodium salicylate dissolved in distilled water and diluted to mark, in 100 ml mark volumetric flask.
2. Sulphuric acid AR grade (ρ 1.84 g/ ml).

3. Sodium hydroxide solution; made by dissolving 400 g AR sodium hydroxide pellets and 16g AR potassium sodium tartrate (Rochelle salt) in a plastic beaker with distilled water. The mixture was cooled, made up to one litre and the solution stored in a plastic container.
4. A nitrate stock solution 1000 ppm; made by dissolving 1.37 g AR sodium nitrate in distilled water, and made up to 1 litre. One ml of this solution contained one mg of NO_3^- nitrate standard solution 100 ppm was prepared by diluting nitrate stock solution with distilled water in the ratio 1:10. One ml of this solution contained 0.1 mg of nitrate.
5. A nitrate reference solution; made by diluting nitrate stock solution with distilled water in the ratio 1:100. One ml of this solution contained 0.01 mg of nitrate.

The analytical procedure involved first and foremost preparing calibration solutions from the standard solution in the range of 1.0, 3.0, 6.0, 9.0 and 12.0 mg/l in 50 ml one-mark volumetric flask, and transferring the solutions into 100 ml plastic beakers. This was followed by preparation of a blank containing 50 ml of distilled water in a similar manner. Sodium salicylate measuring 2 ml was added to the above mentioned solutions and evaporated to dryness in the oven at $100\text{ }^\circ\text{C} \pm 0.5\text{ }^\circ\text{C}$. The residue was cooled in a desiccator, two ml of sulphuric acid added and the solution allowed to stand for 10 minutes. About 15 ml of distilled water added, followed by 15 ml of sodium hydroxide solution, cooling constantly, and then transferring the solutions to 100 ml one-mark volumetric flask. The solution was made up to the mark with distilled water and the absorbance of the solutions measured using a calibrated spectrophotometer at 420 nm after taking the zero reading using a blank test solution.

The sample was prepared in a similar manner without adding the nitrate solution and its absorbance measured. The absorbance readings of the calibration standards against the concentration were plotted. Thereafter, the linear correlation coefficient of the graph (r) was determined to the linearity of the graph and the graph accepted only when the linearity value was within the range of 0.99 to 1.0. The appropriate nitrate content in the sample was read from the calibration curve and the concentration of nitrate in the sample was calculated as follows:

$$C \text{ mg/l} = \frac{(C_s - C_{bl})V * df}{V_s}$$

Where,

C is the concentration of the nitrate in mg/l, C_s is the concentration of the nitrate obtained from the calibration curve in mg/l. C_{bl} is the nitrate concentration of blank obtained from the calibration curve in mg/l. V_s is the volume of the sample taken for the test in ml. V is the volume to which the test portion was diluted and df is the dilution factor. The results were expressed in mg/l of Nitrate as NO_3^- . (APHA, 1999)

3.3.2.12 Sulphides analysis in the wastewater samples

In determination of presence of sulphide in the wastewater, zinc sulphide was precipitated by addition of the sample to a solution of zinc acetate. The precipitate was then separated and acidified in the presence of excess standard iodine solution. Hydrogen sulphide liberated was oxidized by the iodine, the amount of iodine consumed being determined by titration with sodium thiosulphate. About 10 ml zinc acetate solution was added to 100 ml of unfiltered sample taken in a conical flask to form a precipitate. The precipitate was allowed to settle, filtered on a filter paper and transferred into a 250 ml conical flask containing about 200 ml of distilled water. Ten ml of 25% sulphuric acid and 20 ml of N/8 Iodine solution were added. Iodine solution N/8 was prepared by dissolving 25 g potassium iodide (KI) in about 50 ml water in a glass stoppered 1litre volumetric flask. 15.9 g of iodine was then transferred into a flask, thoroughly shaken until all the iodine had dissolved then standardized against N/8 sodium thiosulphate using starch indicator. Iodine colour was maintained by adding more iodine. Excess iodine was titrated with N/8 sodium thiosulphate using starch indicator. Sulphide concentration was then determined as follows:

$$S^2 = \frac{2000VI \text{ mg/l}}{V2}$$

Where,

VI is the volume of N/8 Iodine in ml consumed

$V2$ is the volume of sample in ml.

S^2 is sulphide concentration in mg/l (APHA, 1999)

3.3.2.13 Phenols analysis in the wastewater samples

Determination of phenols was based on the fact that steam distillable phenolic compounds react with 4 – aminoantipyrine at $7.9_{\pm} 0.1$ pH in the presence of potassium ferricyanide to form a colored antipyridine dye. The resultant dye was kept in aqueous solution and the absorbance measured at 500nm.

The reagents used in determination of phenols were

1. Stock phenol solution: made by dissolving 0.1g of phenols in freshly boiled and cooled distilled water and diluted to 100 ml to make 1000 ppm phenol.
2. Intermediate phenol solution was made by diluting 1.00 ml stock phenol solution in freshly boiled and cooled distilled water to 100 ml to make 10 ppm phenol.
3. Standard phenol solution: made by diluting 50 ml intermediate phenol solution to 500 ml with freshly boiled and cooled distilled water to make 1ppm phenol.
4. Ammonium hydroxide (0.5N): made by diluting 35 ml fresh concentrated NH_4OH (ammonium hydroxide) to 1 liter with distilled water.
5. Phosphate buffer solution: this solution was formulated by dissolving 104.5g K_2HPO_4 (dipotassium hydrogen phosphate) and 72.3 g potassium dihydrogen phosphate (KH_2PO_4) in water and diluting to 1 liter while keeping the PH at 6.8.
6. 4- Aminoantipyrine solution: made by dissolving 2.0 g 4-aminoantipyrine in water and diluting to 100 ml.
7. Potassium ferricyanide solution: made by dissolving 8.0g $\text{K}_3\text{Fe}(\text{CN})_6$ in water and diluting to 100 ml filtered and stored in a brown glass bottle.

The procedure involved placing a portion containing not more than 0.5mg phenol diluted to 100 ml, in a 250 ml beaker. A 100 ml distilled water blank and a series of 100 ml phenol standard containing 0.1, 0.2, 0.3, 0.4, and 0.5ppm mg/l phenol was prepared. The samples, standards and blank were then treated with 2.5 ml, 0.5N NH_4OH solution and at pH $7.9_{\pm} 0.1$ with phosphate buffer. Measures of 1.0 ml 4-aminoantipyrine solution and 1.0 ml $\text{K}_3\text{Fe}(\text{CN})_6$ solutions were added and mixed thoroughly. After 15 minutes, the mixture was transferred to cells. Absorbance of sample and standards was recorded against the blank at 500 nm. Concentration of phenols was therefore determined as follows:

$$\text{Phenols} = \frac{A100}{B}$$

Where, A is the mg phenol in sample, from calibration curve.

B is ml of original sample (APHA, 1999)

3.3.2.14 Phosphates analysis in the wastewater samples

To determine the concentration of phosphates, 50 ml of the sample was taken in a beaker, digested with 1:1 hydrochloric acid and filtered in a 100 ml volumetric flask. After topping up to mark with distilled water, 10 ml of ammonium molybdate was placed in a 50 ml volumetric flask and 20 ml aliquot added and topped up to mark with distilled water. The absorbance of the sample was measured against the blank at a wavelength of 430 nm and a dilution factor of 3.0661 used for calculation of phosphate concentration.

Mg/l P = ppm * dilution factor (3.0661). Where, ppm is parts per million

3.3.2.15 Metals analysis in the wastewater samples

All the metals namely: copper, aluminium, manganese, iron, chromium, lead and zinc were determined by an atomic absorption spectrometry model AA-6300 SHIMADZO (Shimadzu.1996). In this method, each sample was aspirated into a flame and atomized. A light beam was directed through the flame into a monochromator and onto a detector that measured the amount of light absorbed by the atomized element in the flame. The amount of energy at the characteristic wavelength absorbed in the flame was proportional to the concentration of the element in the sample over a limited concentration range.

3.3.3 Data Analysis and Presentation

Data was entered in appropriately designed data sheets prior to analysis and organized by coding and keying into a database in statistical package for social scientists (SPSS) and excel sheets. Data was subjected to both descriptive and inferential analysis using non-parametric statistics. Non-parametric tests are suitable for data that is skewed, of small sample size mainly less than 30, and with large number of outliers. Mann Whitney U test was used to compare concentration levels of two independent groups at significance level $p \leq 0.05$.

CHAPTER FOUR: RESULTS AND DISCUSSION

The results of the field measurements and laboratory analysis on the identified parameters are presented in following pages. Discussion on the findings is based on each of the three objectives and in comparison to NEMA standards. Although, international standards for effluent discharge from textile processes such as WHO, USEPA among others have been documented, individual countries have further adopted these standards to establish their own national standards. In Kenya, NEMA has been mandated to establish and implement such standards and guidelines as to ensure compliance with international requirements. The discussion in this section therefore, is largely based on the NEMA standards as outlined in schedule six of the Environmental Management and Coordination Act (EMCA) (GOK, 2006).

4.1. Physico-chemical Characterisation of the Wet Process/Untreated Wastewater.

This section presents findings on the physical and chemical characteristics of various wastewater streams analysed in-situ and at the laboratory in line with objective one of the study. Presented in Tables (4.1a and 4.1b) are the physical and chemical characteristics of the process wastewater streams. All the measurements are in mg/l except the pH and where otherwise specified.

Table 4. 1a: The mean values and standard deviations of the physical and chemical characteristics of process /untreated wastewater.

Process	Batch Scouring	Continuous scouring	Hot wash	Printing	Desizing	Bleaching
Physical parameters						
Turbidity	637.33	5.67	70.00	2610	378.0	69.50
Conductivity	3.13	5.57	2.05	3.11	13.88	17.51
TSS	8366	201.67	5102	1798	3145	14880
TDS	15190	3232	16163	7900	14655	10578
Colour	2396	106.67	1833	170.00	125.0	55.00
Chemical parameters						
pH	11.87	9.23	12.42	8.38	11.00	10.02
Temperature	65.90	28.74	74.26	27.47	40.30	26.70
DO	1.73	4.03	2.67	1.66	10.37	20.00
COD	23467	271.67	8733	245.83	5867	12600
BOD	43.33	3.83	10.00	43.50	0.00	0.00
Zinc	2.68	0.52	3.05	0.54	1.22	1.90
Lead	0.24	0.00	0.88	0.49	1.04	0.32
Phosphates	82.80	0.00	0.95	2.86	1.00	107.33
Chromium	0.00	0.00	0.00	0.06	0.07	0.02

Cadmium	0.25	1.04	0.60	0.25	0.27	0.00
Nitrates	1.33	0.38	8.00	0.53	2.80	2.05
Phenols	14.73	0.00	2.87	9.63	1.00	0.00
Iron	4.32	0.51	0.98	0.48	14.56	2.86
Aluminium	1.72	0.77	1.07	1.13	3.70	11.46
Manganese	0.79	0.21	0.33	0.23	0.78	0.76
Copper	0.00	0.00	0.04	0.03	0.02	4.00
Sulphides	36.67	6.67	41.33	50.00	22.67	0.00

Table 4.1b: The mean values and standard deviations of the physical and chemical characteristics of the process wastewater

Process	Cold wash	Mercerising	Finishing	Dyeing	Mean	NEMA value
Physical parameter						
Turbidity	19.50	8.27	0.00	35.33	408.414±1448.992	*
Conductivity	2.01	1.87	15.63	6.44	6.348±6.074	*
TSS	194.8	484.9	1945	1425	2979.7±5290.49	250
TDS	3035	9322	5211	18347	24339.78±65424.82	2000
Colour	210	49.17	8592	1563	1219.71±3303.83	<40
Chemical parameters						
pH	9.65	9.40	8.18	9.16	10.277±3.033	6-9
Temperature	30.85	51.35	26.40	38.71	43.406±20.29	20-35
DO	6.30	1.73	5.20	3.23	5.692±	*
COD	170	45.42	2500	3463	5231.83±7620.1	1000
BOD	7.00	8.83	27695	152.7	2160.13±10777.76	500
Zinc	1.38	1.16	1.54	0.83	1.435±1.542	5
Lead	0.85	0.43	0.09	1.49	0.583±.771	1
Phosphates	0.94	0.29	12.27	30.66	19.919±50.908	30
Chromium	0.09	0.00	0.00	0.10	0.039±0.07349	2
Cadmium	0.40	0.73	0.00	0.00	0.413±0.732	0.5
Nitrates	0.46	0.33	20.8	10.10	3.395±81.469	20
Phenols	0.00	0.05	25.8	7.38	5.291±9.526	10
Iron	0.80	1.10	8.45	17.40	4.852±10.113	*
Aluminium	0.16	0.56	1.37	3.92	2.207±3.600	*
Manganese	0.16	0.19	0.00	0.70	0.412±0.433	*
Copper	0.03	0.00	0.00	0.04	0.282±1.458	1
Sulphides	61.00	10.83	254	423.3	81.233±185.67	2

Note: Table 4.1b is a continuation of Table 4.1a on the mean values and standard deviations of the physical and chemical characteristics of process wastewater

Temperature was measured in °C, colour in hazen units, and conductivity in m/S and turbidity in NTU. *denotes non-existence of a NEMA standard for the concentration levels of the corresponding substances.

4.1.1 pH Concentration Level in the Wastewater Samples

pH was recorded in the field to avoid alteration of the sample characteristics and or contamination of the samples during transportation. The highest pH value was recorded in hot wash process at 12.42 and lowest in finishing process with at 8.18 and an overall mean of 10.277. NEMA limits provides that pH for effluent discharge to the sewer is between 6 and 9. Contrary to the values recorded above, textile effluent has been reported to vary widely in pH and values in the range of 2 to 12 are not uncommon (Jaishree and Khan 2014). The strong alkaline nature can be explained by the fact that caustic soda and other detergents which are alkaline in nature are used in large quantities as highlighted by Hussain et al, (2004). High alkalinity is an indication that the wastewaters have the capacity to neutralize acids. This therefore means that there was need to lower the pH to acceptable limit prior to discharge.

4.1.2 Temperature Concentration Level in the Wastewater Samples

Temperature was recorded in the field. According to EPA guidelines (EPA, 1998), it is important to measure temperature in situ, because a water sample will gradually reach the same temperature as the surrounding air. The highest temperature was recorded in hotwash at 74.267 °C and lowest in finishing at 26.4 °C and an average of 43.406 °C. Nema standard for temperature is between 20 and 35 °C. In cotton processing, hotwash takes place in hot liquor sometimes at boil. While the lowest value was within the national standards, the highest value was out of the range. It has been observed that high effluent temperature affects the dissolved oxygen of a water reservoir which in turn affects the aquatic environment of living organisms (Chougule and Sonaje 2012).

4.1.3 Turbidity Concentration Level in the Wastewater Samples

Highest value of turbidity was recorded in printing at 2610 NTU; lowest value was zero in finishing while average value was 408.414 NTU. High value of turbidity is associated with soluble coloured organic compounds as indicated by (Mohabansi, 2011). NEMA has does not provide a standard for levels of iron in textile wastewater for discharge to the sewer.

4.1.4 Conductivity Concentration Level in the Wastewater Samples

The measurement was done in the field soon after obtaining the water sample. Research has shown that conductivity changes with storage time and is also temperature-dependent (EPA, 1998). The highest conductivity value was recorded in bleaching at 17.51 mS, lowest value in mercerising at 1.87 mS while the average value was 6.348 mS. Although NEMA has not given any standard on conductivity limit for a textile wastewater, international standards recommends a limit of 3m/S (WHO 2004) . As (Varsha and Seema 2013) argued, the high value of conductivity may be as a result of high concentration of dissolved salts and ionic substances in process wastewater streams. This agrees with the findings of Manikanda et al (2015) who reported that conductivity increases with increase in total dissolved substances

4.1.5 DO Concentration Level in the Wastewater Samples

Dissolved oxygen was highest in desizing at 20.00 mg/l, lowest in printing at 1.66 mg/l and an average of 4.816 mg/l. Essentially, the levels of dissolved oxygen in a wastewater sample varies with temperature. It has been observed that a rise in thermal value of water lowers the level of dissolved oxygen significantly (Kemker, 2013). Nema has not provided a limit for levels of DO in textile wastewater for discharge to the sewer.

4.1.6 COD Concentration Level in the Wastewater Samples

COD value was highest in batch scouring at 23466 mg/l, higher than the NEMA limit of 1000 mg/l, while lowest value of 170 mg/l was recorded in coldwash and average of 5231.833 mg/l. The high value may have been contributed by fabric impurities removed during scouring (Ntuli et al, 2009). High COD levels imply toxic condition and the presence of biologically resistant organic substances (Varsha and Seema, 2013)

4.1.7 BOD Concentration Level in the Wastewater Samples

A high BOD of 27695 mg/l was recorded in finishing far above the NEMA range of 500 mg/l and average of 2160.135 mg/l. This value contradicts the findings by Yusuff and Sonibare (2005) who reported a low BOD in finishing wastewater. The lowest values were in desizing and bleaching at 0. In one instance, wastewater sample from bleaching crystallised breaking the BOD bottles. Babu and Parande (2007) have indicated that

finishing, printing and dyeing auxiliaries or organic substances are non-recyclable and contribute to high BOD/COD of the textile wastewater. Hussain et al (2004) also observed that starch, gum and enzymes used in sizing and desizing are responsible for high BOD in wastewater.

Concentration level of BOD (2160.135mg/l) was about two and half times that of COD (5231.833mg/l). The remarkable increase in COD levels compared with BOD, indicates significant levels of toxicants such as heavy metals in the wastewater as argued by (Chavan, 2001). Ultimately, high BOD value indicates the extent of biodegradable substances present in the wastewater. Tanwar and Mathur (2016), reported that the greater the decomposable matter, the greater the oxygen demand, thus greater BOD value.

4.1.8 TSS Concentration Level in the Wastewater Samples

The highest value of TSS was recorded in finishing at 14880 mg/l; lowest was 194.88 mg/l in cold wash and average of 3235.360 mg/l, against NEMA standard of 250 mg/l. Although the findings of this study recorded high average TSS values in the process wastewater streams, low value of this parameter has also reported in other studies. High TSS is associated with precipitation of salts and undissolved impurities (Hussain et al 2004). Further, chemicals precipitation due to change in pH may also increase the concentration of suspended particles. Al-kadasi et al., (2005), observed that suspended solids are a major pollutant in textile wastewater.

4.1.9 TDS Concentration Level in the Wastewater Samples

TDS Value was highest in batch scouring at 151907 mg/l and lowest in cold wash at 3035 mg/l. The average value was 24339.776 mg/l; while NEMA discharge limit is 2000 mg/l. Use of chemicals of high solubility are major contributors to the high TDS.

4.1.10 Colour Concentration Level in the Wastewater Samples

Colour value was highest in finishing at 8592 hazens. As Irina and Butnaru (2008) observed, intense colour may result from use of natural oils and waxes used in the finishing process. The Lowest value was recorded in mercerizing at 49.17 hazens. The calculated average value was 1219.710 hazens, while the NEMA limit value is less than

40 hazens. Generally, use of dyes and pigments in dyeing, printing and finishing may have contributed to the high average colour value as observed by (Zaharia and Suteu, 2012). This possibly explains why the colors of the effluents at the points of entry into the sewer varied on each day of sampling. It is therefore imperative that stringent measures are taken to ensure colour level is kept low in the above mentioned wet processes prior to discharging to the main drainage.

4.1.11 Zinc Concentration Level in the Wastewater Samples

The highest value of Zinc was recorded in hotwash and lowest in continuous scouring at 3.05 mg/l and 0.52 mg/l respectively and at an average of 1.435 mg/l. These values were well within the NEMA limit of 5.00 mg/l.

4.1.12 Lead Concentration Level in the Wastewater Samples

Lead value was highest in dyeing at 1.49 mg/l, lowest value in continuous scouring at 0.0 mg/l and average value of 0.583mg/l. While the highest value was higher than the NEMA limits of 1.00 mg/l, the average value indicates compliance with the standard. Research has shown that, high concentration of lead in dyeing wastewater may be as a result of lead compounds used as pigment (Deepali et al., 2009).

4.1.13 Nitrates Concentration Level in the Wastewater Samples

Nitrate value was highest in finishing at 20.8 mg/l and lowest in mercerizing at 0.33 mg/l. The average was 3.93 mg/l, well within the NEMA limits of 20 mg/l. Although high nitrate concentrations are frequently encountered in textile wastewater as a result of ammonium nitrogen this analysis recorded good results across the spectrum. Nitrates may also increase as a result of types of dyes which have nitrate ions as a functional group as observed by (Hussain et al 2004).

4.1.14 Phenols Concentration Level in the Wastewater Samples

Value of phenols was highest in finishing at 25.8 mg/l and lowest in continuous scouring, bleaching, coldwash and dyeing at 0. While the average value 5.290 mg/l was within the standard, the highest value was above NEMA limits of 10 mg/l.

4.1.15 Phosphates Concentration Level in the Wastewater Samples

Phosphates were highest in bleaching with 107.33 mg/l against the NEMA limits of 30 mg/l, and lowest in continuous scouring at zero. The average value of 19.919 mg/l was within the standard. Ntuli et., al (2009) indicated that phosphates exist as orthophosphates from detergents used mainly in the washing process.

4.1.16 Chromium Concentration Level in the Wastewater Samples

Chromium values were highest in dyeing and lowest in continuous and batch scouring, finishing and dyeing at 0.10 mg/l and 0 respectively. The average value was 0.039 mg/l and within the NEMA limit of 2 mg/l.

4.1.17 Cadmium Concentration Level in the Wastewater Samples

Cadmium was highest at 1.04 mg/l in continuous scouring and above the NEMA standard of 0.5 mg/l. Lowest in bleaching, finishing and dyeing at 0 and average of 0.354mg/l. Exposure to high levels of cadmium can lead to adverse health effect (Sharif et al., 2009).

4.1.18 Iron Concentration Level in the Wastewater Samples

Highest value of iron was recorded in dyeing at 17.40 mg/l, lowest in printing at 0.48 mg/l and average at 4.852 mg/l. A study by Babu and Parande (2007) recorded that dye bath in addition to high colouration, has a high concentration of iron based salts and organic matter thus considered heavily polluted. At high levels, taste and appearance of domestic water is affected. Promotes iron bacteria and water supply structures (Deepali et al., 2009). NEMA has not provided a limit for levels of iron in textile wastewater for discharge to the sewer.

4.1.19 Aluminium Concentration Level in the Wastewater Samples

Levels of aluminium were highest in bleaching and lowest in coldwash at 11.46 mg/l and 0.16 mg/l respectively. The average value was 2.207 mg/l. While NEMA does not provide a standard for this substance in textile wastewater, WHO recommends value of 0.1-0.2 mg/l for drinking water (WHO, 2004).

4.1.20 Copper Concentration Level in the Wastewater Samples

Copper levels were highest in bleaching at 4.00 mg/l against NEMA limits of 1mg/l and lowest in batch and continuous scouring, mercerizing and finishing, at 0. The average value was 0.282 mg/l. Copper is essential for mammalian nutrition. Conversely, exposure to high levels of copper can result in a number of adverse health effects (Deepali et al., 2009) and is toxic to aquatic plants (Sharif et al., 2009). In addition, it gives a stringent taste to domestic water and causes discolouration and corrosion of distribution pipes and fittings.

4.1.21 Manganese Concentration Level in the Wastewater Samples

Manganese values were highest in batch scouring at 0.79 mg/l; lowest in finishing at 0 and an average of 0.402 mg/l. Impurities in chemicals used in various processes contribute to high levels of manganese in wastewater (Hussain *et al.*, 2004). NEMA has not provided a limit for levels of manganese in textile wastewater for discharge to the sewer.

4.1.22 Sulphides Concentration Level in the Wastewater Samples

Highest values of sulphides were recorded in dyeing at 423.33 mg/l, lowest value in bleaching at 0 and average of 81.233 mg/l. Nema recommends a level of 2 mg/l as acceptable limit. The high sulphide levels can be attributed to use of sulphur dyes and sulphur based compounds in dyeing. Sulphides are known for bad odour from hydrogen sulphide gas and damage to the sewer pipes resulting from generation of sulphuric acid by bacteria (Ntuli et., al 2009).

Cognizant of the need for characterisation of textile process effluent streams, Prasad (2011) highlighted that, characterisation and continuous monitoring is important in developing strategies for treatment and water recycling. A descriptive summary of the characteristic of the untreated process wastewater is given in Table 4.2.

Table 4. 2: Descriptive summary of the characteristics of the process wastewater

Wet process	Effluent Characteristics
Desizing	High BOD, high TDS, high TSS, alkaline pH, high sulphides.
Scouring	High BOD, high TS, high alkalinity, high temperature
Bleaching	High BOD, high TS, alkaline wastewater
Mercerizing	High BOD, high TS, alkaline wastewater
Dyeing	Wasted dyes, high COD, TSS, TDS, alkaline, high levels of sulphides and colour
Printing	Wasted dyes/residual, high BOD, COD, solids, neutral to slightly alkaline
Finishing	Wasted dyes/residual, high BOD, COD, solids, neutral to alkaline, colour

Maximum allowable limits are shown in appendix 2.

To test hypothesis that dyeing wastewater had a high concentration of polluting substances compared with NEMA standards, the effluent was characterised and analysed using Mann-Whitney test. Characterisation and analysis were based on parameters whose Nema has provided discharge limits for textile wastewater. The results are illustrated in Tables 4.3 for characterisation and 4.4 for Mann-Whitney test. The results showed that, parameters above the allowable Nema limits included: COD, TSS, TDS, sulphides, colour, temperature and lead. The high levels of sulphides in dyeing process wastewater may be attributed to use of sulphur black dyes, and sodium hydrosulphite as a reducing agent in VAT dyeing. The colour of the wastewater was attributed to the presence of unused dyes, pigments and other coloured compounds (Zaharia and Suteu, 2012). These findings follow those of a similar study by Oke *et al* (2006), which found out that high coloration of textile industry effluent resulted from residue dyes.

Table 4. 3: Physico-Chemical Characteristics of the dyeing wastewater compared to NEMA standards

Parameters	Mean and Std deviations	NEMA Standards
Physical parameters		
TSS	1425.25±1989	250
TDS	18347±25226	2000
Colour	1563±1914	<40
Chemical parameters		
pH	9.163±3.82	6-9
Temperature	38.71±16.05	20-35
COD	3463±3812	1000
BOD	152.67±215.04	500
Zinc	0.83±0.32	5
Lead	1.49±2.07	1
Phosphates	30.66±28.11	30

Chromium	0.15±0.09	2
Cadmium	0.00±0.00	0.5
Nitrates	10.10±8.15	20
Phenols	7.38±8.48	10
Copper	0.04±0.06	1
Sulphides	423.33±492.23	2

Under Mann-whitney test of difference between two independent samples, the results presented in Table 4.4 indicate that there was a significant difference in the concentration levels of dyeing wastewater as compared to Nema Standards for Z (-0.226) is less than α (0.05). The null hypothesis was therefore rejected. Further, dyeing wastewater had the highest concentration levels of pollutants with a mean rank of 16.88 compared to Nema mean rank of 16.13.

Table 4. 4: Mean of ranks and test statistics for dyeing wastewater and Nema standards

Group	N	Mean rank	Sum of ranks	Mann-Whitney U Z
Dyeing wastewater	16	16.88	270	-0.226
Nema standards	16	16.13	258	

4.2 Comparison of Concentration Levels of the Pretreated Wastewater with Nema Standards

Concentration levels of TSS, TDS, colour, pH, and temperature, COD, BOD, zinc, lead, cadmium, chromium, phosphates, nitrates, phenols, copper and sulphides in pre-treated wastewater were compared with the NEMA standards in line with objective two and research question two of this study. The above parameters were selected from the hindsight that NEMA has provided discharge limits of textile wastewater, only for the above listed parameters as shown in table 4.6. The graph below shows how the concentration levels of the above parameters in the pretreated wastewater varied with Nema standards.

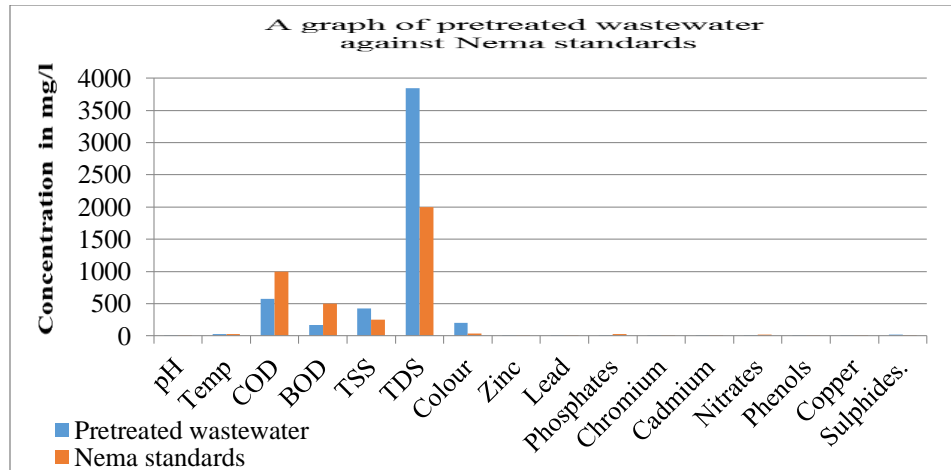


Figure 4. 1: A graph of pretreated wastewater against Nema standards

The difference in concentration levels of the two samples (pre-treated wastewater and Nema standards) was analysed using Mann-Whitney U test and the results are shown in Table 4.5.

Table 4. 5: Mean of ranks and test statistics for pretreated wastewater and Nema standards

Group number	N	Mean rank	Sum of ranks	Mann-Whitney U Z
Pretreated	16	15.30	242.00	-0.829
NEMA standard	16	17.88	286.00	

The null hypothesis that there is no difference in concentration levels of pre-treated wastewater samples compared to Nema standards was rejected where Mann Whitney U value Z (-0.829), is less than α (0.05). Nema samples a mean rank (17.88) hence high concentration of pollutants as compared to the pretreated sample with mean rank (15.30) as shown in Table 4.5. This further indicates the suitability of the pretreated wastewater for discharge to the sewer.

4.3 Wastewater Management Strategies

The main environmental concern on industrial operations is about the amount of waste water discharged and the chemical load it carries (Chougule and Sonaje 2012). Any management strategy should therefore aim at first reducing the amounts of water generated and secondly to lower the chemical load.

There were two approaches used in managing wastewater generated during production of textiles in the study area:

1. Recovery of caustic. It was noted that caustic soda from the mercerising process was recovered albeit in small scale. The recovered lot was then pumped back to the reservoir and reused after mixing with freshly mixed lot.

2. Pre-treatment at the wastewater treatment plant

The factory under study has an operational WWTP shown in Plate 4.1, where untreated wastewater from various processes combined into a single effluent stream before undergoing pretreatment. The pretreatment process involved taking the effluent streams through a series of biological and aeration stages. The effluent was first dosed with sulphuric acid to lower the pH, and then passed through alum to coagulate the dissolved substances before draining into wastewater lagoons. In the lagoons, the effluent was aerated continuously then pumped to sand tanks for filtration.



Plate 4. 1: Wastewater treatment plant (WWTP). Picture for noon 24th July 2013.

In light of the above, the effectiveness of the effluent pretreatment process was evaluated by comparing characteristics of the process (untreated) wastewater, the pre-treated wastewater and Nema standard in line with objective three of this study. Results are presented in Table 4.6.

Table 4. 6: Physico-chemical characteristics of untreated and pre-treated wastewater compared to Nema standards

Parameters	Concentration levels				
	NEMA Standards	Untreated wastewater		Pretreated wastewater	
		Max value	Mean value	Max value	Mean value
Physical parameters					
TSS	250	14880	2979.7±5290.49	638.75	423.25±227.16
TDS	2000	151907	24339.78±65424.82	3990.0	3842±239.809
Colour	< 40	8592	1219.71±3303.83	200.00	200±0.00
Chemical parameters					
pH	6-9	12.42	10.277±3.033	9.58	9.483±.167
Temperature	20-35	74.267	43.406±20.29	28.8	26.40±2.351
COD	1000	23466	5231.83±7620.1	720.0	573.3±161.658
BOD	500	27695	2160.13±10777.76	240.00	173.3±61.101
Zinc	5.0	3.05	1.435±1.542	2.428	1.114±1.154
Lead	1.0	1.49	0.583±.771	0.986	0.604±0.435
Phosphates	30	107.33	19.919±50.908	6.133	3.424±2.394
Chromium	2	0.10	0.039±0.07349	0.202	0.067±0.117
Cadmium	0.5	1.04	0.413±0.732	0.751	0.25±0.434
Nitrates	20	20.8	3.395±81.469	1.610	0.537±0.929
Phenols	10	25.8	5.291±9.526	3.400	2.1±1.836
Copper	1	4.0	0.282±1.458	0.490	0.016±0.283
Sulphides	2	423.33	81.233±185.67	29.00	19±10.536

The pretreated treatment effluent for discharge to the municipal sewer was found to be basic at 9.483 and slightly above the NEMA limits of 6-9 while temperature was within the NEMA limits at 26.4 °C. Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values were within the permissible limits and therefore of no consequential damage to the environment. Total Dissolved Solids (TDS) and Suspended Solids (SS) in the effluent were high at 3842 mg/l and 423.25 mg/l respectively thus exceeding the allowable limits of 2000 mg/l and 250 mg/l

High levels of TSS were attributed to their high concentration in bleaching at 14880 mg/l, while those of TDS could have been as a result of their high concentration in batch scouring at 151907mg/l. Since such high levels of TDS could cause severe damage to the ecosystem, it is important to significantly lower their concentration prior to discharge.

Colour concentration at 200 hazens was above the NEMA recommended limits of less than 40 hazens. This was as a result of high concentration of colour in finishing at 8592 hazens, hence likely to affect biological processes and aesthetic value. Sulphides at 19 mg/l were higher than the allowable limits as a result of their high concentration of

423.33 mg/l recorded in dyeing. This could lead to release of hydrogen sulphide gas to the atmosphere which is associated with foul smell.

Lead concentration was higher than the admissible limits in finishing at 3.88 mg/l against standard of 1.0 mg/l, but reduced to 0.604 mg/l after treatment. High concentrations of phosphates at 107.3 mg/l were recorded in bleaching but reduced to acceptable limits of 3.424 mg/l after treatment. Cadmium reduced to 0.251 mg/l after treatment from a high of 1.04 mg/l. Levels of nitrates were slightly above the NEMA limits in finishing at 20.8 mg/l vis-a-vis 20 mg/l, but significantly reduced to 0.537 mg/l in the treated effluent. Concentration of phenols though high in finishing at 25.8 mg/l against 10 mg/l NEMA standards, were well within acceptable limits at 2.10 mg/l after treatment.

Levels of copper were high in bleaching at 4.00 mg/l against the NEMA limits of 1.00 mg/l, but reduced significantly to acceptable limits of 0.016 mg/l after treatment. Concentration levels of zinc at 1.114 mg/l and chromium at 0.0672 mg/l against NEMA limits of 5.00 mg/l and 2.00 mg/l respectively, were well within the admissible limits after treatment. While the pre-treated wastewater was characterised by high levels of sulphides, intense colour, alkalinity and high levels of TDS, other parameters were well within the Nema limits for discharge to the sewer.

The significance of the differences in concentration between the untreated and pretreated wastewater was analysed by use of Mann-Whitney U test for two independent groups. Results are shown in Table 4.7.

Table 4. 7: Mean of ranks and test statistics for the untreated and pretreated wastewater

Group	N	Mean rank	Sum of ranks	Mann-Whitney U Z
Untreated	16	22.79	433.00	-1.825
Pretreated	16	16.21	308.00	

N denotes the number of parameters analysed.

Since Z (-1.825) was less than α (0.05) as shown in Table 4.7 , it therefore follows that there was a significant difference in concentration of the polluting substances contained in the untreated wastewater as compared to the pretreated wastewater samples. Similarly,

the untreated wastewater exhibited a higher mean rank of 22.79 (Table 4.7), an indication of high concentration of pollutants as compared to the pretreated wastewater with a mean rank of 16.21. Overall, considering the significant reduction in concentration of polluting substances in the pretreated wastewater, it can therefore be concluded that the pretreatment process was effective.

Key environmental issues associated with wet processing unit were identified during the study. Notably, the wastewater streams showed large variations in composition and concentration levels of the polluting substances between various processes and on different days. Mercerization washings for example, contained substantial amounts of caustic. Temperatures on the other hand fluctuated, with cold wash wastewaters merging with very hot dye liquors, sometimes at the boil. Wastewater streams from scouring, dyeing, printing and finishing were intensely coloured and were characterised by extreme fluctuations in many quality indicators such as COD, TSS, TDS, pH, and temperature. This intense color could have been the combined effect of pH, temperature and acidic conditions that do not allow the chromophore group of dye to degrade, and spillage of printing paste and finishing pigments. Other factors that could have contributed to the increase in waste load and subsequent environmental pollution were among them:

1. Batch processing. Where processing chemicals were put in a chamber and drained after completion and subsequent rinsing carried out in the same chamber.
2. Water leakage from pipes and spillage resulting to over-abstraction.
3. Steam leakage especially from the dyeing unit leading to energy loss.
4. Residual paste from feeding pipes at the printing unit.
5. Worn out machine parts thereby causing leakage of chemicals, water, and steam
6. Lack of wastewater recycling system
7. Poor housekeeping and worn out machines parts contributed to wastage of productions inputs including water, chemicals, fibres, and energy.

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This study was carried out in a textile factory in Thika town. The main objective of the study was to investigate the characteristics of the wastewater discharged by this factory into the municipal sewer. By so doing, the nature and concentration levels of the polluting substance in the wastewater were determined. The study aimed at bridging the wide information gap on the polluting potential of textile activities in Kenya.

The study was done by collecting wastewater samples from the wet processing operations namely: scouring, washing, desizing, printing, mercerising, dyeing and finishing and from the municipal sewer. Analysing the characteristics of various textile wet process wastewater streams and the municipal sewer effluent was carried out in the field and at KIRDI laboratory using APHA methods of analysis (APHA 1999). The concentration levels of analysed substances were then assessed for compliance by comparing with the NEMA national standards. The findings showed an indication of the effectiveness of the wastewater management strategies within the textile mill and further provided a basis for recommendations on continued improvement, and further research.

5.2 Conclusions

Based on the objectives and the findings of this study, it was concluded that:

1. The untreated wastewater discharged from the cotton wet processes streams was characterized by high: pH (10.277), temperature (43.406°C), COD (5231.833mg/l), BOD(2160.135mg/l), TSS(3235.36mg/l),TDS (24339.776mg/l), colour (1219.71 hazens) and sulphides (81.233mg/l) compared to NEMA standard for discharge to the sewer at pH(6-9), temperature (20°C -35°C), COD (1000mg/l), BOD(500mg/l) TSS (250mg/l),TDS (2000mg/l), colour (<40 hazens) and sulphides (2mg/l). Other parameters including zinc, lead, nitrates, phenols, phosphates, chromium, cadmium and copper were within the NEMA discharge limits (Tables 4.1a and 4.1b). The wastewater also exhibited large variations in concentration levels of the substances analysed between various processes. If discharged at this state, the wastewaters were capable of causing severe damage to the environment.

2. Wastewater from the dyeing process was characterised by extreme fluctuations in parameters such as COD, TSS, TDS, pH, colour, and temperature (Table 4.3). The variability may have been brought about by bath discharges, residue dyes and other coloured compounds. High concentration of sulphides may have resulted from use of sulphur black dyes and other sulphur based chemicals and sodium hydrosulphite as a reducing agent in VAT dyeing. However, there was a significant difference in the concentration levels of dyeing wastewater as compared to Nema standards for Z (-0.226) was less than α (0.05), when analysed using Mann-Whitney test for two independent groups (Table 4.4). Further, dyeing wastewater had the highest concentration levels of pollutants with a mean rank of 16.88 compared to Nema mean rank of 16.13.
3. The wastewater management strategy, which comprised of biological treatment at the WWTP, was largely effective. There was significant reduction in concentration levels of most of the substances contained in the process streams after treatment, as shown in Table 4.6. For instance; concentration levels of zinc, lead, chromium, and cadmium, were well within the Nema limits for disposal to the sewer. Colour was however prominent and was the first pollutant to be identified, an indication that colour removal techniques were inadequate. High concentration of TDS and TSS can be attributed to intense colour and may be major sources of heavy metals, while sulphides are potential air pollutants. The results for Mann-Whitney test for two independent groups, Z (-1.825) was less than α (0.05) as shown in Table 4.7. It is therefore follows that there was significant difference in concentration of the polluting substances contained in the untreated wastewater as compared to the pretreated. At the same time, the untreated wastewater exhibited a higher mean rank of 22.79, an indication of high concentration as compared the pretreated wastewater mean rank of 16.21. Comparing the difference in concentration of the pretreated wastewater to NEMA standards under Mann-Whitney test showed that there is a difference in concentration levels of pre-treated wastewater samples compared to NEMA standards for Z (-0.829), was less than α (0.05). NEMA sample had the highest mean rank (17.88) hence high concentration of pollutants as compared to the

pretreated sample with mean rank (15.30) as shown in Table 4.5. This further indicates the suitability of the pretreated wastewater for discharge to the sewer. However, the BOD: COD ratio of the pre-treated wastewater, expressed as $173.3/573.3=0.3022$ was out of the recommended range of < 0.5 for a biodegradable effluent treatment. Since the ratio was higher than 0.30, which is the threshold for chemical treatment, this therefore implies the need for chemical pre-treatment prior to disposal according to (Jadeja, 2013).

5.3 Recommendations

1. Wastewater characterisation: this is key since each process wastewater stream is unique in its characteristics. It is important therefore that each is considered separately in order to optimize treatment and reuse possibilities. Once the characteristics of the separate streams are known, it can be decided which streams may be combined to improve treatability and increase reuse options. For instance, the combination of acidic and alkaline streams could result to pH correction thereby avoiding extra chemical treatment and consequently saving on the cost of treatment.
2. Cleaner production: a combination of water recycling and reuse and resource optimisation: Opportunities for water recycling and re-use need to be explored in order to minimize fresh water abstraction and subsequently lower the production cost. For instance, rinsing waters were less contaminated and could therefore be used for cleaning purposes. Steam water loss could be minimized by providing a condensate line at each machine connected to the condensate tank thereby leading to substantial saving. Steam leakage can be kept at minimum by ensuring the machines are in good working condition devoid of leakages. The wastewater from the treatment lagoon can be pumped back to the factory for printing machine use. Good housekeeping is vital to minimize wastage of resources, thereby reducing consumption and treatment load. Such practices may include: Collecting all unused print pastes for bulking-up and avoiding dumping of print pastes to effluent drain, in order to reduce the waste load in the dyeing wastewater;

Carrying out leak tracing and repairs on water pipes and valves; and checking non-return valves for reverse leakage.

3. Chemical treatment of the effluent at the wastewater treatment plant may be necessary in order to reduce the concentration levels of BOD, TDS, TSS, colour and sulphides in the pretreated wastewater to the acceptable limits.

This study recommends the following areas for further research:

1. Alternative biodegradations methods that are effective in removing dyes from large volumes of effluents, and or possible alternatives for eco-dyes and chemicals .This is because the chemical and physical processes used for colour removal are often very costly and lead to accumulation of concentrated sludge, thus creating a disposal problem.
2. This study did not take into account the seasonal changes, the volumes of effluent discharged and toxicity analysis, further study in these areas is therefore important.
3. A study on the strategies to reduce wastewater generation is important for reducing waste load contained in the wastewater.
4. Review of existing environmental policy in order to give provision for incentive system for green manufacturing.

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APPENDICES

Appendix 1: Process Identification and Data Collection Sheet

Parameter. Process	Readings		
	1	2	3
Sample code			
Date			
Time			
pH			
Temperature (°C)			
Turbidity (NTU)			
Conductivity (mS)			
Dissolved oxygen			

Appendix 2: Fifth Schedule: Standards for effluent discharge into public sewers

Parameter	Max Allowable Limits (Mg/ where applicable)
Suspended solids	250
Total dissolved solids	2000
Temperature °C	20-35
pH	6-9
Substances with an obnoxious smell.	Shall not be discharged into the sewers
Biological Oxygen Demand BOD 5 days at 20 °C	500
Chemical Oxygen Demand COD	1000
Lead	1.0
Cadmium	0.5
Chromium (Total)	2.0
Copper	1.0
Zinc	5.0
Nitrates	20
Phosphates	30
Sulphides	2
Phenols	10
Colour	< 40

Source: *GoK (2006)*.