UNIVERSITY OF NAIROBI

ASSESSMENT OF PHYSICO-CHEMICAL PROPERTIES OF SAGANA TANNERIES EFFLUENT AND ITS EFFECT ON RIVER SAGANA WATER QUALITY: KIRINYAGA COUNTY, KENYA

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Dedication

This thesis is humbly dedicated to my loving parents, Mr. James Wachira Muriithi and Mrs. Margaret Muthoni Wachira for their unwavering support, providing me with endless love, encouragement, financial support and guidance. Your dedication to my growth and success has shaped me into the person I am today, and I am forever grateful.

Above all, I dedicate this thesis to Almighty God. He has all the power and the glory.

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Lastly, I am deeply grateful to my parents for being the driving force behind my achievements. This thesis is a testament to your resolute faith in me.

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Acronyms

Al	Aluminium
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
Cu	Copper
Cr	Chromium
EMCA	Environmental Management and Coordination Act
KIRDI	Kenya Industrial Research and Development Institute
KLDC	Kenya Leather Development Council
N	Nitrogen
NEMA	National Environment Management Authority
P	Phosphorous
Pb	Lead
WHO	World Health Organization
WRA	Water Resource Authority
Zn	Zinc

Abstract

The tanning industry uses many complex chemicals and has a high demand for water, this makes it a pollution intensive sector that requires strict regulation and monitoring. Sagana Tanneries Limited discharges treated effluent in River Sagana and, residents downstream have in the past complained about water pollution characterized by change in water color and death of fish. River Sagana is a domestic water source and therefore, assessment of physico-chemical properties of the effluent and the river was undertaken. Management strategies and technology adopted by the tannery were also evaluated together with challenges and opportunities facing environmental management in the tanning industry. Raw and treated effluents from the entire wastewater treatment section were sampled and analyzed to ascertain the level of pollutants. Water from River Sagana was also collected at intervals of 500 m and the toxicity load was determined to inform on the impact of treated effluent disposal into the river. Assessment of samples was done to determine levels of pH, chemical oxygen demand, biochemical oxygen demand, phosphorus, nitrogen, chromium, lead, copper and zinc. The results revealed that the effluent discharged from the tannery TLG9 satisfied legal standards for pH 7.42, chromium 1.1 ppm and copper 0.41 ppm. For parameters COD 630 ppm, BOD 236.7 ppm, P 5.2 ppm, N 53.5 ppm, Pb 0.07 ppm and Zn 0.85 ppm, all were above prescribed NEMA standards. River water analysis revealed TR1, TR2, TR3 and TR4 had: pH at 7.24, 7.17, 7.25 and 7.32 respectively. COD ranged from 172 ppm - 412 ppm while BOD was between 66.4 ppm - 209.1 ppm. P ranged from 5.6 ppm - 11.8 ppm and highest level of N was at TR4 307 ppm. The highest level of Cr was at TR4 3.35 ppm, Pb at TR4 0.23 ppm, Cu at TR2 0.48ppm and Zn at TR3 1.71ppm. Pollution of River Sagana is a reality. River water upstream is polluted and although free from tannery effluent, it contains high amounts of pollutants. Disposal of treated effluent into the river is not safe since the tannery effluent contributes to direct pollution of the river. The tannery should minimize wastewater production by recycling chrome baths and refining in-plant production processes. Additionally, it should remedy chromium contamination of effluent by ensuring effluent streams don’t mix. Inadequate human resource capacity of regulatory bodies like NEMA is a challenge. This, coupled with lack of essential scientific ability to set up laboratories for analysis results in inefficient and irregular monitoring. To help improve environmental compliance, enforcement of existing regulations should be implemented by responsible authorities and proper mainstreaming executed in all tanneries. Additionally, an environmental audit of all existing tanneries in Kenya should be conducted to help understand the current environmental status of the tanning industry. Policy documents should also be reviewed and updated to incorporate specific environmental guidelines for the tanning industry as guided by technological research on cleaner production, effluent treatment and waste management. Further research is recommended on the impact of chrome sludge disposal on the environment around dumpsites and the effect on ground water. An in-depth analysis of the chemical properties of leather manufacturing chemicals used in local industries is also recommended so as to ascertain the specific sources of heavy metals in tannery effluent.

CHAPTER ONE

1.0 INTRODUCTION

Tanneries are a prominent source of chromium pollution to the aquatic environment (Islam *et al*., 2013) and among the largest ecosystem polluters. This is caused by the numerous complex chemicals used coupled with tanneries' high demand for water. Acids, alkalis, chromium salts, tannins, sulfides, dyes, solvents and auxiliaries used in tanning are not completely fixed by the hides and skins and therefore remain in the effluent (Hassen & Woldeamanuale, 2017). The tanning process discharges large volumes of water with toxic effluent (Muhammad *et al*., 2015) and involves chemicals that are known to be carcinogenic such as anthracene, chromium, formaldehyde, azo dyes, sodium dichromate and short chain chlorinated paraffins (Dixit *et al.*, 2015).

Tannery effluent contains high levels of suspended solids, chemical oxygen demand, variable pH, electrical conductivity, biochemical oxygen demand, tannins (Gupta *et al.,* 2012; Mohammed *et al.,* 2017), heavy metals and other pollutants. These pollutants contribute to the overall physico-chemical properties of wastewater and that of receiving surface water bodies. In a study on tannery waste water canals in Bangladesh by Islam *et al*., (2013), the lead concentration ranged between 7.77 mg/L and 8.03 mg/L. Chromium levels in the canals ranged between 10.45 mg/L and 23.73 mg/L which was higher than the permissible level of 2 mg/L for tannery effluent. The highest level of iron was determined at 7.95 mg/L and it was also higher than the standard limit in Bangladesh.

Wosnie & Wondie (2014) characterized effluent from Bahir Dar tannery and reported mean levels of biochemical oxygen demand at 342 mg/L and chemical oxygen demand at 850 mg/L. Both were above Ethiopian Environmental Protection Authority standards of 200 mg/L and 500 mg/L respectively. Robertsson & Andersson (2014) also investigated wastewaters from a local tannery in Malawi and found 0.251 mg/L of chromium which was above the 0.05 mg/L standard for in industrial effluent in Malawi. However, the levels of aluminium, magnesium, copper, zinc, iron, manganese and lead were all below trace levels.

Effluent treatment methods include chemical precipitation, adsorption, ion exchange, electrolysis, biological methods, floatation, coagulation, flocculation and membrane filtration (Abbas *et al*., 2014; Barakat, 2011; Islam *et al*., 2013; Jacob *et al*., 2018; Wang, 2018). However, conventional treatment methods have secondary effluent impacts on recipient environments (Islam *et al*., 2013), are costly (Noorjahan, 2014) and resource intensive (Robertsson & Andersson, 2014), therefore, they are not well suited for developing and under developed countries.

Most tanneries in Africa lack the technical expertise, adequate space to install waste management facilities and adequate capital to build individual wastewater treatment plants (Oruko *et al*., 2018) and Kenya faces this similar challenge. According to Minas *et al*., (2017), 10% of the tanneries in Ethiopia partially treat their effluent while 90% do not treat before discharging into surface water bodies. Nyabaro *et al*., (2013) studied effluent from Nakuru Tanners Limited and heavy metal levels: chromium 945 mg/L, lead 6.50 mg/L and iron 5.40 mg/L were found to be higher than recommended values set by National Environment Management Authority (NEMA) for industrial effluent.

This study investigated the effluent emitted from Sagana Tanneries Limited with inclination to pH, nitrogen (N), phosphorous (P), biochemical oxygen demand (BOD), chemical oxygen demand (COD) and heavy metals: chromium (Cr), lead (Pb), copper (Cu) and zinc (Zn). These parameters were selected because they are deleterious to the receiving environment and have prescribed discharge limits by various health and environmental bodies. The purpose was to assess the level of pollutants in the wastewater, the effect of discharging treated effluent in the recipient surface water body and in-plant treatment and management of effluent.

1.1 STATEMENT OF THE PROBLEM

Surface waters are susceptible to pollution due to easy accessibility for effluent disposal (Ahmed *et al.,* 2011), consequently, poorly regulated and untreated effluent has resulted in global pollution of rivers (Whitehead *et al*., 2019). Sagana Tanneries Limited is located along river Sagana which is its source of water and the recipient body for treated effluent. Residents downstream of river Sagana have in the past complained about water pollution by effluent discharged from the local tannery. There was a significant change in water color and the death of fish thus signifying potential toxicity of the wastewater discharged into the river. River Sagana is a source of water for domestic use, it therefore becomes a looming hazard to the health and general wellbeing of the population.

Sagana tanneries utilizes aerated lagoons with a combined treatment process employing biological, physical and chemical methods to treat effluent. The likelihood of heavy metals persisting in effluent was unknown and was determined to evaluate the effectiveness of the adopted treatment technology. Tanneries use organic materials and therefore there is possibility of existence of nitrogen and phosphorous in the effluent occurring from breakdown of organic matter. The oxygen demand for the decomposition of pollutants was also determined.

Previous studies on the tanning industry have mainly focused on the general analysis of certain properties of tannery effluent and solid waste such as sulfide, nitrogen, oil and grease, chromium, suspended solids, COD and BOD. However, this study paid special attention to presence of heavy metals in treated the tannery effluent discharged into the environment.

1.2 RESEARCH OBJECTIVES

1.2.1 General objective

The objective of this study was to assess the level of selected pollutants in Sagana tanneries effluent and their environmental impact on river Sagana.

1.2.2 Specific objectives

1. To analyze the physico-chemical properties of effluent discharged from the tannery
2. To analyze the physico-chemical properties of river Sagana
3. To assess the effluent management strategies and technology used by the tannery
4. To assess the challenges and opportunities facing the leather industry's environmental management.

1.3 RESEARCH QUESTIONS

1. What are the physico-chemical properties of effluent discharged from the tannery?
2. What are the physico-chemical properties of river Sagana?
3. What are the strategies and technologies applied in the management of tannery effluent?
4. What are the challenges and opportunities facing the leather industry in environmental management?

1.4 JUSTIFICATION

According to Naidansuren *et al.*, (2017) there are many studies on the tanning industry but there is paucity of data on heavy metals in effluent aside from chromium. This study went ahead to assess the levels of heavy metals in discharged wastewater and a step further to characterize the pollution load in the recipient water body.

As the actors in charge of the environment and public health, the findings will be of paramount importance to the Government of Kenya, county governments and environmental agencies because of the interlinkage between industrial development, the environment, agriculture, irrigation, the health of the community and industrial effluent management. The results will also be important to the tannery management as a critical analysis of their effluent treatment and its impact on the environment. This may inform their future management decisions and be factored in improvement of their effluent treatment plant thereby enhancing accountability, responsibility and efficiency.

This study also addresses the need for interdisciplinarity in terms of addressing the complex issues about environmental governance. Combining science, social science and policy is important in providing data to support improved environmental governance.

1.5 SCOPE AND LIMITATIONS

This study assessed the efficiency of effluent management technology like chemical precipitation by characterizing pollutants load in treated effluent from Sagana Tanneries Ltd. and the pollutants in river Sagana. Specifically, levels of pH, nitrogen, phosphorous, BOD, COD, Pb, Cu, Cr and Zn were determined and the results compared to the set permissible maximum standards by NEMA and other local and global environmental agencies.

Environmental actors like NEMA officials, county environmental officers, Water Resource Authority (WRA) officers and the tannery management were interviewed to inform on their management strategies and their role in monitoring water pollution. There was anticipated low responsiveness by industry managers and institution officers because this study elicited information that challenged the credibility of their work.

Effluent sample collection and analysis was done in one instance and therefore limiting the spatial and temporal analysis that would have provided a broader scope to the different levels of pollutants emanating from the tannery and the impact of these pollutants to the river Sagana.

CHAPTER TWO

2.0 LITERATURE REVIEW

Tanning is achieved through a series of mechanical and chemical operations that involve a mix of many toxic chemicals, with each production section discharging toxic effluent. EMCA defines effluent as treated or untreated gaseous waste, water, liquid or other fluid of agricultural, trade or industrial origin that is discharged directly or indirectly into the aquatic environment. Nyabaro (2013) describes tannery effluent as the liquid waste produced from each process and the subsequent washing after each tanning operation.

Pickling and tanning are the most pollution causing processes in the leather industry (Faki *et al*., 2018). Nearly 70% of the pollution loads of total dissolved solids, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are produced from soaking, liming, degreasing, pickling and tanning processes (Islam *et al.*, 2013) and according to Madanhire & Mbohwa (2015), it is the chrome tanning and finishing operations that generate heavy metal pollutants during leather production.

2.0.1 Pollutants in the tanning industry

Kenyan leather industry is experiencing progressive growth as the demand for leather and leather products increases locally and globally. The Kenya Vision 2030 under the economic pillar aims to transform Kenya into an industrialized country. In it, the construction of leather parks in different parts of the country will enhance the contribution of the manufacturing GDP to the national economy. There is also a targeted move to establish six additional tanneries at Wajir, Garissa, Kanduyi, Isinya, Mogotio and Makueni (EPZA, 2015). Odhiambo *et al*., (2016) and Ahsan *et al*., (2019) however expresses alarm that rapid industrial development leads to the increasing discharge of industrial effluents and this raises public health and environmental concerns.

Like many tanneries globally, the Kenyan tanning industry faces challenges of poor environmental compliance and negative implications to biota and the natural environment. According to Mwinyihija *et al*., (2005) information on hazardous waste production, waste disposal and waste management practices in developing countries is inadequate. Technologies used for the proper management and treatment of effluents are also too expensive and the scientific knowledge of operations is scarce. The lack of effective implementation of legislative control measures and poor industrial processing practices further adds to pollution problems (Chowdhury *et al*., 2015). Despite these challenges, discharge standards should be adhered to as they are important in ensuring the protection of receiving systems (Odhiambo *et al*., 2016).

Chemical impurities in effluent comprise of inorganic salt cations (iron, sodium, copper, calcium and zinc), anions such as PO_4^{3-}, NO_3^-, SO_4^{2-}, parameters such as dissolved oxygen, total suspended solids, total dissolved solids (Ahmed *et al.,* 2011), COD, BOD, turbidity (Hasan *et al*., 2019) pH, phosphorous, oil and nitrogen. A study of effluent in Dhaka by Jahan *et al*., (2014) confirmed the presence of impurities as it showed Cu levels of 0.4112 mg/L, Zn at 1.5241 mg/L and pH at 8.3.

Chemical oxygen demand measures the oxygen equivalent of the organic matter content that is prone to oxidation by a strong chemical oxidant (Ni`mah *et al*., 2021). High COD value indicates the toxic state of effluent along with the presence of biologically resistant organic substances (Paltahe *et al.,* 2019; Amanial, 2016; Wosnie & Wondie, 2014). In Brazil, Gutterres *et al*., (2015) found COD 8523 mg/L and BOD 4073 mg/L in tannery effluent and Parveen *et al*., (2017) from India studied tannery waste water and determined COD at 3154 mg/L and BOD at 1248 mg/L.

A study by Amanial (2015) from Ethiopia found 132.03 mg/L of Cu, 0.17 mg/L of Cr, 1.99 mg/L of Zn. The level of copper was above the prescribed 2 mg/L Ethiopian standard but the level of Pb in the effluent was not detectable. However, Nabila & Ibrahim (2019) characterized effluent in Kano, Nigeria and found 0.83 mg/L of Pb. Nyabaro (2013) from Kenya also found 4.5 mg/L of Pb and 700 mg/L of Cr in wastewater from Nakuru Tanners Ltd, the levels were above the prescribed 0.01 mg/L for Pb and 0.05 mg/L for Cr NEMA standards for treated effluent discharge into the environment.

2.0.2 River pollution

The tanning industry is a water intensive sector and large quantities of effluent is discharged into water streams thus causing severe environmental damage (Hailu *et al.,* 2018). High levels of pollutants in river water leads to an increase in BOD, TSS, COD, toxic metals like Cd, Ni, Pb and Cr. Halim *et al*., (2011) studied Buriganga river, which receives tannery effluent and found phosphorous levels of 1.58 mg/L, Zn 574.2 mg/L, Pb 221 mg/L, Cr 22.2 mg/L and Cu 20.5 mg/L. The levels of Zn, Pb, Cr and Cu were all above the World Health Organization (WHO) standards for drinking water. Amanial (2015) from Ethiopia also characterized water from Modjo river and found Cu 0.12 mg/L, Zn 1.22 mg/L and Cr 72.14 mg/L with Cr being above WHO’s 0.05 mg/L drinking water standard.

According to Wosnie & Wondie (2014) and Amanial (2016) from Ethiopia, high amounts of organic matter from various chemicals used in leather processing causes heightened levels of COD and BOD in wastewater. Wosnie & Wondie (2014) investigated the Blue Nile River in Ethiopia and results showed COD 206 mg/L, BOD 73.4 mg/L, P 6 mg/L, N 67.5 mg/L and the pH was 7.15. An elevated COD level indicates that receiving water may become unsuitable for habitation by aquatic organisms because of depletion of dissolved oxygen.

Sodium sulphide, soda ash and lime used in leather manufacture majorly contribute to the pH of the effluent. Assessment of pH is crucial because it impacts on other physico-chemical parameters and the availability of metal ions (Amanial, 2016). This is backed by literature in Ali *et al.,* (2015) that shows most metals become soluble in water at low pH. Toxic elements also become mobile and easily available for uptake by aquatic biota at low pH.

2.0.3 Effluent Management

Improved environmental performance of an industry is dependent on the successful use of sufficient technologies for production (Ingle *et al*., 2011). Cleaner production, relocation of tanneries to designated industrial zones with adequate environmental management measures and implementation of common effluent treatment plants in tannery agglomerations has been done in Turkey, India, China and Spain (Hu *et al*., 2011). Efficiency in proper management and application of technology in effluent treatment is achieved by analyzing a recognized set of chemical and physical parameters to assess the quality of wastewater, which then informs on a suitable method of treatment. The choice of treatment technology is also dependent on cost, efficiency (Yusif *et al*., 2016) and its environmental implications.

Low waste production methods such as advanced chrome management systems, ammonia free deliming and bating, use of salt free preserved raw hides and skins and hair save liming have shown reductions of COD and BOD by more than 30%, ammonia nitrogen by 50%, sulphates by 65%, chromium by up to 90%, chlorides by 70% and sulphides by 80 - 90% (Buljan & Kral, 2011). According to Gupta *et al*., (2018) Veera Tannery Ltd in Aurangabad utilizes pollution prevention techniques including not using hazardous chemicals like basic chromium sulphate for leather production. It therefore does not generate toxic waste and produces easily biodegradable leather.

Circular economy is practiced in Dongming Bright Cattle Co. Ltd in China where a chrome liquor recycling system recycles 30.8% of the spent chrome liquor thereby reducing about 47.1 x 10^4 kg chrome float annually (Hu *et al.*, 2011). It also recycles 6 x 10^5 kg hairs annually that are treated as organic fertilizer.

2.0.4 Effluent treatment

Tannery effluent treatment methods are classified as either physical, chemical or biological processes and are optionally used in combination for optimum treatment results. Adsorption involves chemical and/or physical interactions (Barakat, 2011) and works on preferential ability of certain solids to concentrate specific substances from a solution and onto their surface. In India, Nithya & Sudha (2017) experimented using chitosan as a bio-polymer adsorbent and it showed potential removal of 97.8% Cr from the effluent and also reduced Pb by 20.93%. Mekonnen *et al.*, (2017) also conducted a study in Ethiopia using scoria (volcanic ash) a low-cost adsorbent. He tested for BOD, COD, TSS, ammonium, nitrate, nitrite, sulfide, sulfate and Cr and concluded that scoria substrate has a potential to treat tannery effluent.

Abbas *et al.*, (2014) defines biosorption as a process in which micro-organisms are used to remove heavy metals from aqueous solutions or simply as the removal of substances from a solution using biological matter. A study by Kuzhali *et al.*, (2012) in India on the applicability of mushrooms in biosorption showed the following efficiency: *Pleurotus florida* exhibited 88.5% efficiency for Cr, 68.4% for Zn and 58.8% for nickel while *Caloycbe indica* exhibited 55%, 37.9% and 49.1% biosorption efficiency of Cr, Zn and nickel respectively. Kuzhali et al (2012) concluded that mushrooms are a potential biosorbent of heavy metals. Another study in Malawi by Robertsson & Andersson (2014) on the use of *Moringa Oleifera* also showed 72% reduction potential of Cr depicting the potential applicability of micro-organisms as an innovative method for heavy metals reduction in industrial effluent.

Chemical precipitation can be achieved through sulfide precipitation or hydroxide precipitation (Zhao *et al*., 2016) but the former produces toxic hydrogen sulfide gas thus making it less viable treatment option. For hydroxide precipitation, hydrated lime and limestone are mostly used as precipitants (Barakat, 2011; Wang, 2018), the metal hydroxides are then removed by flocculation or sedimentation. Minas *et al*., (2017) studied an alternative chemical precipitation process for removal and recovery of trivalent chromium from tannery wastewater in Ethiopia. Sodium hydroxide, calcium hydroxide and magnesium oxide were used and their removal efficiency results were, 99.97%, 99.97% and 99.98% respectively.

A constructed wetland is a combination of water, plants, media, microorganisms and other living organisms that acts as a biofilter eliminating pollutants like heavy metals and organic pollutants from effluent (Yusif *et al.,* 2016). When applied in treatment of tannery effluent, physical, biological and chemical processes combine to remove contaminants from the effluent. Calheiros *et al*., (2013) reports that the use of constructed wetland in Portugal has shown great efficiency for the treatment of effluent with high organic load. The wetland uses a subsurface flow system with expanded clay as the main media and is vegetated with *P. australis* or *A. donax* or *T. latifolia*. A hybrid wetland system in Bangladesh studied by Saeed *et al* (2012) showed 98% efficiency removal of BOD and COD. This provided evidence that constructed wetlands can be applied as an energy efficient and low-cost method of effluent treatment.

2.1 Theoretical framework

This study was anchored on the theory of environmental policy by William J. Baumol and Wallace E. Oates 1975. Environmental policy informs and is applied to the political, social and economic spheres of modern living. The model adapted for this study was the economic theory of environmental policy as discussed by Batabyal & Beladi (2002). The principal issues arising from policy are economic development and sustainable development. Conflicting interests emerge from competing interests between the former and the latter.

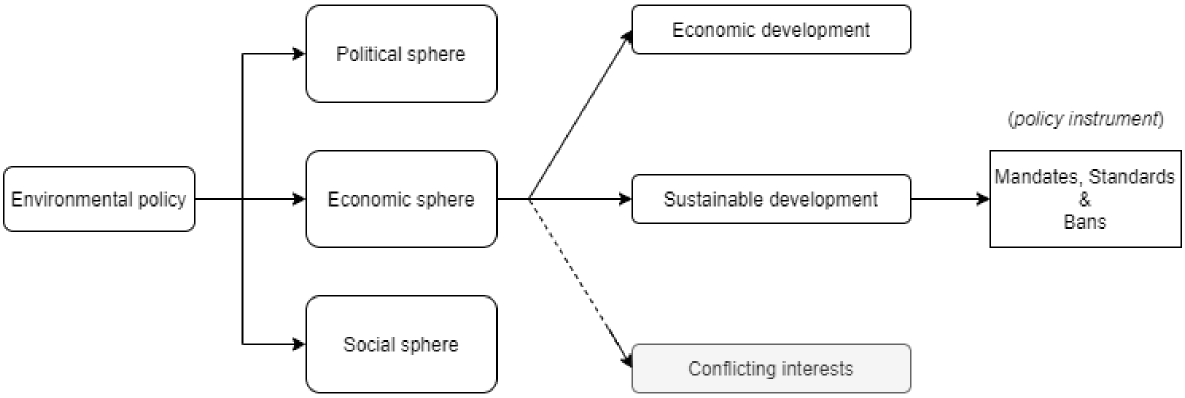

Figure 1.2: Theoretical framework (Source: Batabyal & Beladi (2002))

Environmental policy focuses on formulation of standards for management of the environment. Tanneries involve the economy of tanning raw hides and skins into value added leather, and in the process, they utilize many chemicals that contain toxic substances. The companies normally have to think of how to produce at break-even point in profit and how much they want to invest in cleaning the effluent. Governments, firms, and entities make choices based on costs incurred and the benefits anticipated but ignore the consequences on people outside their decision-making purview (Graff-Zivin & Krumholz, 2018). Sustainable development has the ultimate goal of protecting the environment. Herrera (2020) adds that effluent treatment plants must be efficient and sustainable economically, ethically and environmentally. Graff-Zivin & Krumholz (2018) opine that the prime non-price instruments used for environmental protection are mandates, standards and bans.

2.2 Conceptual framework

Tanneries use organic material i.e., hides and skins as their principal raw material for the production of leather (Figure 2.2). They also utilize many chemicals that contain toxic heavy metals, organic compounds and inorganic components that eventually manifest in the effluent generated from different production sections (Figure 2.2). Physical, chemical and biological methods are incorporated to treat and neutralize the pollutants in the effluent (Figure 2.2) but inefficiency, non-compatibility of the treatment process and persistent pollutants cause the treated effluent to contain inorganic chemical pollutants and organic contaminants like BOD, COD, Cr, Zn, P, N, Pb and Cd in higher levels than the prescribed environmental standards.

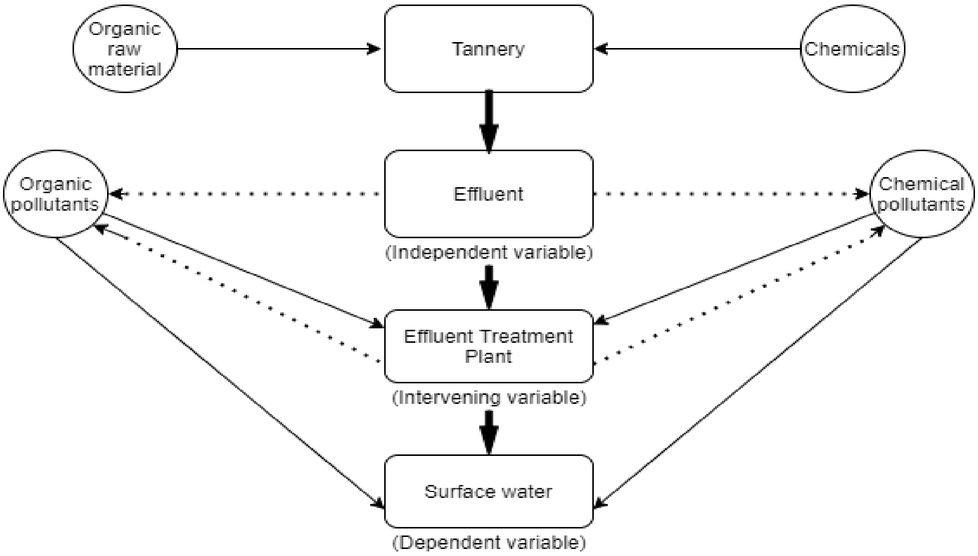

Figure 2.2: Conceptual framework. Dependent variable – surface water, independent variable - effluent (Source: Author)

The treated effluent is then discharged into the environment (Figure 2.2) while still containing high concentrations of toxins that negatively impact the ecosystem. When discharged into surface water, these pollutants cause an imbalance in the physico chemical composition of the water and in the end, flora, fauna, soil and people using the water are negatively affected.

CHAPTER THREE

MATERIALS AND METHODS

3.0 Study area

Sagana town

Sagana town (Figure 3.3) is 100 km north of Nairobi and derives its name from river Sagana (Muchiri, 2019). It is located in central Kenya, the west part of Kirinyaga county; Ndia subcounty and is a border town to Murang'a county. Sagana town is served by River Sagana, a transboundary resource between Murang'a and Kirinyaga counties (Figure 3.3). The water from River Sagana is used for domestic use, agriculture, industrial manufacturing, fishing, crocodile farming and recreational activities.

Kirinyaga county is a highland area with fertile volcanic soils and experiences a tropical climate and equatorial rainfall pattern. There are two rainy seasons; the long rains occurring between March to May average at 2146 mm and the short rains average at 1212 mm and occur between October to November. The climate favors agriculture where the crops grown include tea, coffee, maize, rice, beans, tomatoes, bananas and rice. Kirinyaga county has a total population of 605,630 people (KNBS, 2019) and they practice both traditional and contemporary cultures. 98% of the inhabitants are Gikuyu and Christianity is the main religion (Munyagia, 2017).

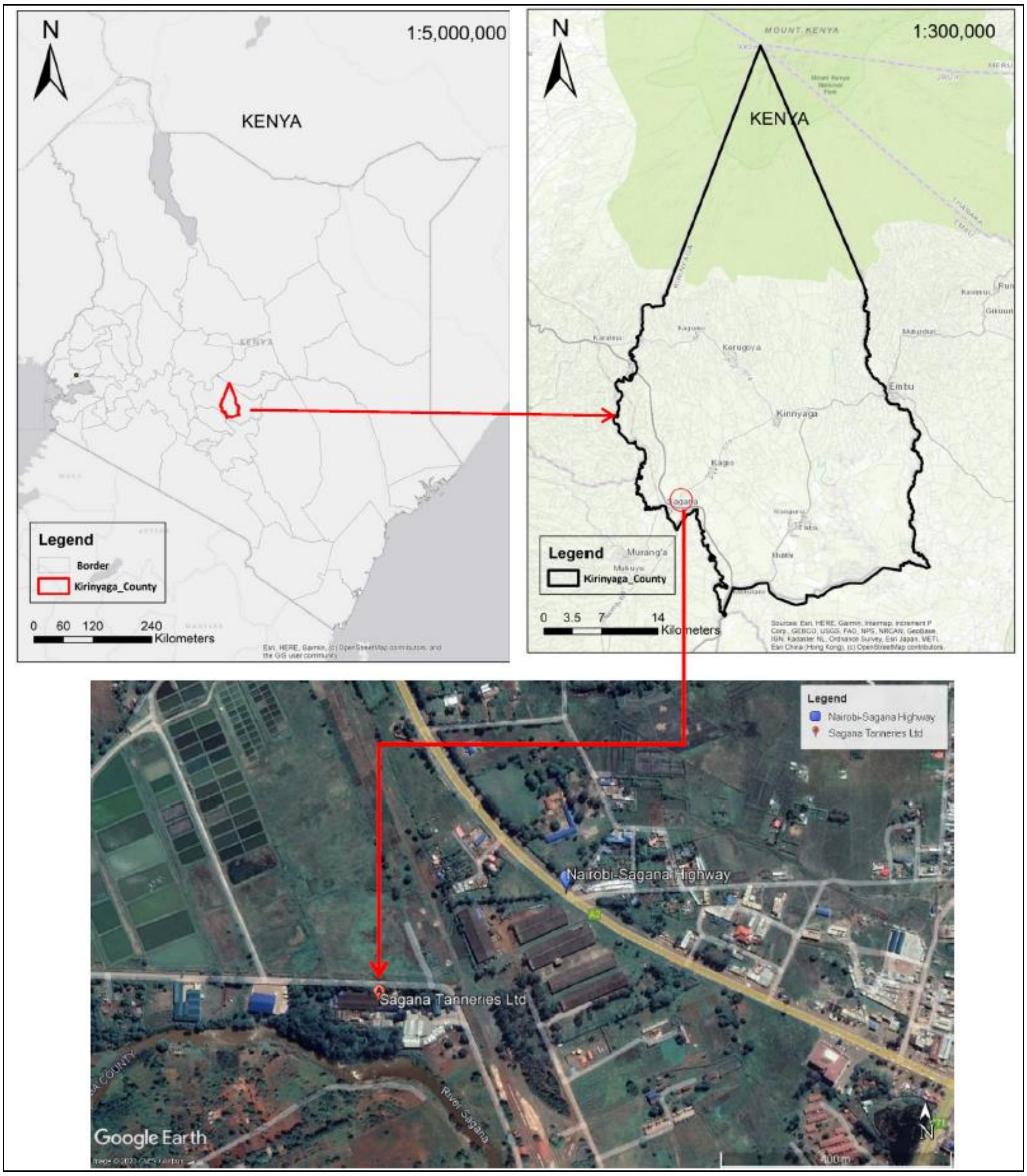

Figure 3.3: Location of study site. Kirinyaga County and Sagana town

(Source: Data.humdata.org; Google earth pro)

The local tannery located in Sagana town was started in 1976 (Kihonge, 2014) and processes hides and skins to wet blue and finished leather for export and local markets. In 1989, the production capacity was 6,000 hides and 24,000 skins per day with an output of around 90,000 square feet per year (UNIDO, 1994). Mwinyihija *et al*., (2005) estimated the effluent discharge to be at 943.2 m^3 per day, however, the discharge volume is speculated to be currently higher because of the gradual increase in demand for leather and leather products.

3.1 Research design

This study adopted a descriptive research design because both qualitative and quantitative data was collected. In order to investigate the objectives conclusively, data collection involved the use of key informant interviews and natural science methods all which were the primary sources of data. Secondary data was obtained from desktop review of peer-reviewed journals and published literature as this provided reference to international practice.

3.2 Sampling and sample size

Tannery effluent was sampled from the effluent treatment plant (Figure 4.3). The sampling of the tannery effluent is presented in Table 1.3.

Table 1.3: Tannery effluent sampling

Sample Batch	Number of samples collected	Area of sampling
1	1	Liming effluent stream (TL1)
2	1	General water stream (TG1)
3	1	Chrome effluent stream (TC1)
4	2	Lime tank (TL2)
5	2	General water tank (TG2)
6	1	Chrome tank (TC2)
7	2	Chrome sedimentation tank (TC3)
Dry chrome sludge (Solid block)	1	Chrome dry bed (TC4)
8	2	Equalization tank (TLG3)
9	1	Sedimentation tank (TLG4)
Dry lime sludge (Solid block)	1	Lime dry bed (TLG5)
10	1	Lagoon 5 (TLG6)
11	1	Lagoon 6 (TLG7)
12	1	Lagoon 7 (TLG8)
13	1	Effluent discharge point (TLG9)

River water samples were collected on both sides of the river bank at all sampling areas (Figure 4.3). The samples were collected 500 m upstream (TR1) from the effluent discharge point, at the effluent discharge point (TR2), 500 m downstream (TR3) from the effluent discharge point and 1 Km further downstream (TR4) from the effluent discharge point (Figure 4.3). The water upstream was believed to be free of the tannery effluent and therefore served as the reference point and control sample.

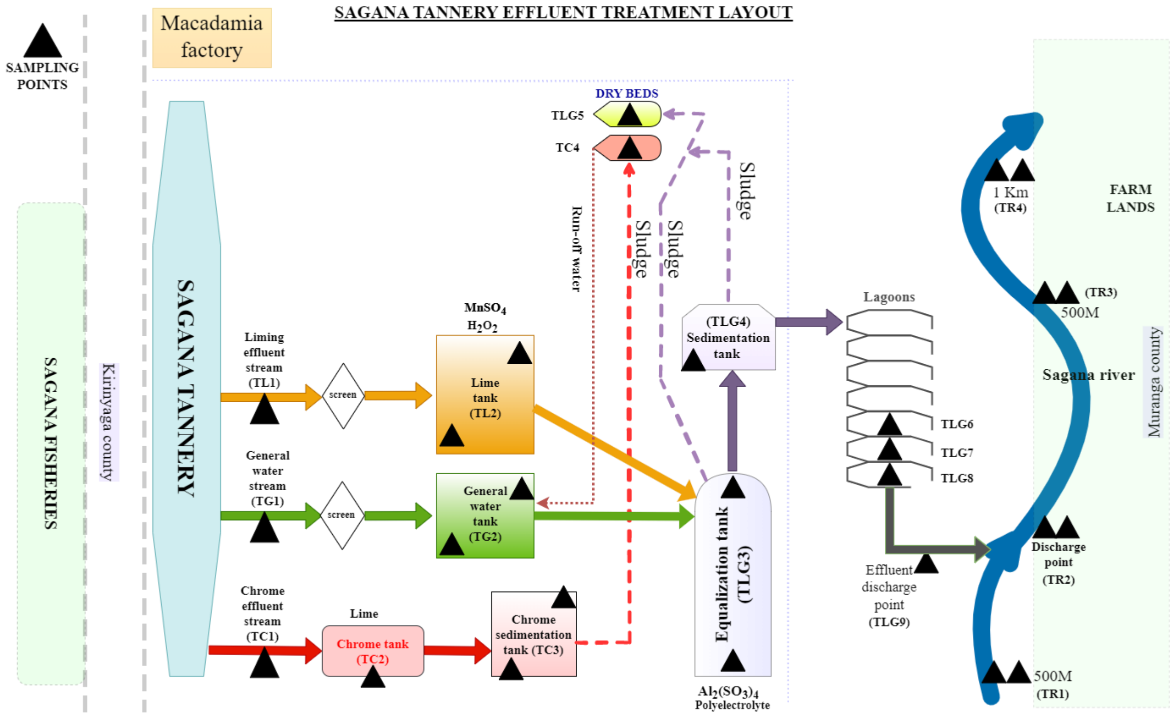

Figure 4.3: Tannery effluent and river water sampling points

The sample population comprised of 20 key informants. 7 interviews were held with Sagana tanneries management and these involved 3 managers, 2 effluent treatment workers, 1 post tanning operator and 1 tan yard operator. The rest of the interviews were held with: 2 NEMA officials, 2 Kenya Leather Development Council officials, 3 county environment officers, 4 WRA officers and 2 Kenya Industrial Research and Development Institute officers.

3.3 Data collection

Effluent sample collection

Two litres of effluent samples were collected in 2-litre plastic jerricans that were filled to the brim and corked tightly. The jerricans were rinsed with distilled water prior to sample collection and the effluent was agitated first before collection of the samples. The effluent samples were collected and labelled as in Table 2.3.

Table 2.3: Tannery effluent samples collection and labelling.

Sample Batch	Number of samples collected	Area of samples collection	Amount collected (Litres)	Label
1	1	Liming effluent stream	2	TL1
2	1	General water stream	2	TG1
3	1	Chrome effluent stream	2	TC1
4	2	Lime tank	2	TL2A
			2	TL2B
5	2	General water tank	2	TG2A
			2	TG2B
6	1	Chrome tank	2	TC2
7	2	Chrome sedimentation tank	2	TC3A
			2	TC3B
8	2	Equalization tank	2	TLG3A
			2	TLG3B
9	1	Sedimentation tank	2	TLG4
10	1	Lagoon 5	2	TLG6
11	1	Lagoon 6	2	TLG7
12	1	Lagoon 7	2	TLG8
13	1	Effluent discharge point	2	TLG9

The lime dry sludge and chrome dry sludge (Table 1.3) were stored in large envelopes labelled as TLG5 and TC4 respectively. The samples were then transported in a cool ice box to the University of Nairobi, Department of Land Resource Management and Agricultural

Technology (LARMAT) and stored in a fridge under temperatures of between 2°C – 4°C awaiting laboratory analysis of heavy metals and the other physico chemical properties.

River water sample collection

Two litres of river water samples were collected in 2-litre plastic jerricans that were filled to the brim and corked tightly. The jerricans were rinsed with distilled water prior to sample collection. The water samples labels were tagged A to show sampling done on the same side as the bank where effluent is discharged and B to show sampling done on the opposite bank of the river from the effluent discharge point.

Sample collection was as shown in Table 3.3

Table 3.3: River water samples collection and labelling

Sample Batch	Number of samples collected	Area of samples collection	Amount collected (Litres)	Label
1	2	500 m upstream	2	TR1A
			2	TR1B
2	2	Discharge location	2	TR2A
			2	TR2B
3	2	500 m downstream	2	TR3A
			2	TR3B
4	2	1 Km downstream	2	TR4A
			2	TR4B

The samples were then transported in a cool ice box to the University of Nairobi, Department of Land Resource Management and Agricultural Technology (LARMAT) and stored in a fridge under temperatures of between 2°C – 4°C awaiting laboratory analysis of heavy metals and the other physico chemical properties.

3.4 Laboratory analysis

Determination of heavy metals Cr, Cu, Zn and Pb

For Cr Cu, Zn and Pb, 100 mL portion of individual samples was taken, filtered through Whatman 42 filter paper and then acidified with concentrated HNO_3 to bring down the pH up to 2.0. A 100 mL of sample was taken and 5 ml concentrated HNO_3 added. The mixture was digested in a closed chamber for 30 minutes then the volume made up to 100 mL with distilled water. The Cr (VI), Cu, Zn and Pb concentrations in the samples were determined calorimetrically by using flame atomic absorption spectrophotometer method.

Determination of pH

The pH of all samples was measured in situ immediately after the samples were collected. This was done using a pH meter following standard procedure.

Determination of COD

The standards, samples and blanks were heated at 150 0C in a closed reactor for two hours in the presence of acid dichromate solution. The samples were then oxidized by digesting in sealed reaction tubes with sulphuric acid and potassium dichromate in the presence of silver sulphate catalyst. The amount of dichromate reduced was proportional to the COD of each sample. A reagent blank was prepared prior to each batch of tubes in order to compensate for the oxygen demand of the reagent itself.

Over the range of tests, a series of different colors was produced with the colors being indicators of the COD of each sample and were measured using a photometer. The results were expressed as parts per million of oxygen consumed.

Determination of BOD

The DO content was determined and recorded and then the bottles were incubated for five days at 20°c. At the end of the five days, the final DO content was determined and the difference between the final DO reading and the initial DO reading calculated for each sample. The decrease in DO reading for each sample was collected for sample dilution and the difference represented the BOD of the samples.

The minimum DO depletion and the 1.0 mg/L residual DO, BOD for each test bottle meeting the 2.0 mg/L was calculated as follows (APHA, 1995):

When dilution water is not seeded:

$$\text{BOD, mg/L} = \frac{\text{D1} - \text{D2}}{P}$$

When dilution water is seeded:

$$\text{BOD, mg/L} = \frac{(D1 - D2) - (B1 - B2)\,f}{P}$$

Where:

$D1$ = DO of diluted sample immediately after preparation, mg/L,

$D2$ = DO of diluted sample after 5 days incubation at 20oC, mg/L,

P = decimal volumetric fraction of sample used,

$B1$ = DO of seed control before incubation, mg/L,

$B2$ = DO of seed control after incubation mg/L, and

f = (volume of seed in diluted sample)/ (volume of seed in seed control)

Determination of phosphorous (P)

Determination of P was achieved using a UV-Vis spectrometer (model DR 200). 50 mL of individual samples was transferred into a clean Erlenmeyer flask and 1 mL of conc. Sulphuric acid added. A 0.40 g ammonium per sulphate was added and then the mixture was boiled gently until a final volume of about 10 mL was reached. The mixture was first cooled and diluted approximately to 40 mL then filtered.

The total phosphorus in each sample was determined by measuring the absorbance at 650 nm with flame atomic absorption spectrophotometer model and then determining the phosphorus concentration from the standard curve.

Key informant interviews

Data from the interviews was collected using a recorder and through making written notes the responses. Manual forms (Appendix 1) with questions tailored to the respondent were printed out and used to note down the responses.

3.5 Data analysis

The data from the effluent and river water samples is presented in data tables and bar charts and, the mean of different pollutants was calculated to provide a general outlook of the efficiency of the treatment process and the state of pollution of the river. The effluent and water samples were also analyzed across the sampling points for their statistical difference using ANOVA.

The results from the tannery effluent were compared to the set discharge standards by NEMA and international environmental bodies. A similar comparison was applied to the river water samples results using water standards set by WRA and WHO.

Recorded interview data was transcribed and together with the rest of the interview data, they were used to provide an overview of the management scenario in Kenya.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Physicochemical properties of tannery effluent

The physicochemical analysis of the tannery effluent indicated a range of appearance in color, with the liming effluent stream (TL1) and general water stream (TG1) having a dark brown appearance. This was due to the presence of biodegradable organic compounds and high amounts of inorganic chemicals like sodium used in the tanning process (Mohammed *et al*., 2017). The chrome effluent stream (TC1) had a dark green appearance suggesting the presence of high concentration of chromium resulting from the chromium salts used in the tanyard. The treated effluent discharged from the tannery (TLG9) was colorless and odorless depicting the efficiency of the treatment process.

The effluent further revealed the presence of COD, BOD, P, N, Cr, Pb, Cu, Zn and pH in different concentrations (Table 4.4). The sample parameters are presented in ppm (parts per million) except pH.

pH

All sections of the treatment plant from the raw effluent drainage channels to the treated effluent discharge point had different pH values. The pH of the raw effluent streams TL1 (liming effluent stream), TG1 (general water stream) and TC1 (chrome effluent stream) were 7.47, 6.09 and 4.37 respectively (Table 4.4). This is in tandem with Hassen & Woldeamanuale (2017) who also concluded that raw wastewater from beamhouse, tanyard and finishing operations consists of pollution of varying pH values. The chrome effluent stream TC1 before chemical treatment showed the lowest pH in the entire treatment plant. This is because during chrome tanning, formic acid and sulphuric acid are used to raise pH of the water and therefore, the effluent generated from chrome tanning is acidic.

The lime tank TL2 had a pH of 7.81, TG2 had 8.57 and in the chrome tank (TC2) the acidic levels were at 5.34. After treatment of chrome effluent in TC3, the pH rose to 9.97 and its dry sludge in TC4 had 6.34. The chrome sedimentation tank (TC3) had the highest pH depicting elevated alkaline conditions. This could be attributed to the alkalinity of the lime used for treating chrome effluent.

Within the sampling area from TLG3 to TLG9, the pH was near-neutral ranging between 6.89 and 8.16. The treated effluent before discharge into the river (TLG9) had a pH of 7.42 (Table 4.4) and was within the NEMA Kenya (6.5 – 8.5), Ethiopia EPA (6.0 – 9.0) and France (6.5 – 8.5) effluent discharge standards (Table 7). Shaibu & Audu (2019) also recorded pH of 8.87 in Fata tannery effluent in Nigeria, which was within the discharge guidelines but Mamuda tannery effluent in Challawa industrial estate, Nigeria, had a pH of 9.33 and therefore exceeded the set standards in that country.

Table 4.4: Mean values of physicochemical properties of Sagana Tanneries effluent. All physicochemical parameter values are presented in ppm except pH.

SAMPLES	pH	(ppm) COD	(ppm) BOD	(ppm) P	(ppm) N	(ppm) Cr. T	(ppm) Pb	(ppm) Cu	(ppm) Zn
Liming effluent stream (TL1)	7.47	3234	859.5	5.7	1044	3.8	0.13	0.2	4.461
General water stream (TG1)	6.09	5098	1223.6	5.9	468	1.3	0.9	0.52	3.059
Chrome effluent stream (TC1)	4.37	6846	1254.3	7	1520	39.4	1.4	0.57	7.01
Lime tank (TL2)	7.81	2331	636.1	3.75	1189	3.78	0.1	0.64	3.693
General water tank (TG2)	8.57	2604	790.7	6.05	172.3	2.38	0.43	0.53	2.575
Chrome tank (TC2)	5.34	2814	969	5.8	978.2	43.2	2.29	0.6	7.88
Chrome sedimentation tank (TC3)	9.97	2583	1007.7	6.15	910.5	23.3	1.16	0.28	5.905
Chrome dry sludge (TC4)	6.34	-	-	15.2	16000	18.2	2.26	4.42	12.6
Equalization tank (TLG3)	7.7	1974	681.5	5.15	302.4	1.63	0.4	0.49	3.911
Sedimentation tank (TLG4)	8.16	966	275.5	6.4	518	11.15	0.55	0.12	2.23
Lime dry sludge (TLG5)	6.89	-	-	6.68	12500	7.65	1.85	3.59	7.58
Lagoon 5 (TLG6)	7.6	462	123.1	6.5	1205	1.55	0.1	0.39	0.69
Lagoon 6 (TLG7)	7.76	336	113.6	4.7	420	1.08	0.13	0.25	0.51
Lagoon 7 (TLG8)	7.42	420	126.9	8.6	224	1.25	0.07	0.19	0.37
Effluent discharge point (TLG9)	7.42	630	236.7	5.2	53.5	1.1	0.07	0.41	0.85

Chemical oxygen demand

Chemical oxygen demand (COD) is a measurement of the oxygen equivalent of the organic matter in the wastewater, which is affected by oxidation of a strong chemical oxidant. Significant levels of COD were found in the raw effluent streams TL1 (liming effluent stream), TG1 (general water stream) and TC1 (chrome effluent stream) coming from the tannery. According to Paltahe *et al*., (2019), a high level of COD depicts the presence of large amounts of organic matter and chiefly the existence of biologically resistant organisms. 3234 ppm of COD was measured at TL1, 5098 ppm at TG1 and the chrome effluent stream TC1 had the highest COD level of 6846 ppm (Table 4.4). This was due to the existence of great quantity of organic matter stabilized by the chemical reaction of chromium and the protein collagen in the hides that were being processed to leather.

At the effluent treatment sections TL2, TG2 and TC2, the concentration was 2331 ppm, 2604 ppm and 2814 ppm respectively while at TC3 (chrome sedimentation tank), 2583 ppm of COD was measured (Table 4.4). TLG3 exhibited 1974 ppm, which was lowered to 966 ppm in TLG4 after flocculation treatment. Along the series of lagoons at TLG6, TLG7 and TLG8, lower COD levels of 462 ppm, 336 ppm and 420 ppm respectively were detected. At TLG9, the treated effluent discharged from the tannery had a COD level of 630 ppm (Table 4.4). Sagana tanneries effluent therefore surpassed the 50 mg/L Kenyan standard by NEMA and the 250 mg/L Indian standard for industrial wastewater discharge into surface water (Table 7). This infers that the flocculation treatment process was unable to completely eliminate the toxic matter elevating the COD. There also is a possibility of secondary contamination that could be the cause of the increase in concentration between TLG8 lagoon 7 (420 ppm) and TLG9 effluent discharge point (630 ppm) (Table 4.4).

Biochemical oxygen demand

A high COD concentration in tannery effluent can also be an indication of the presence of a high amount of biochemical oxygen demand (BOD). The toxicity load of raw wastewater discharged from leather processing at TL1 was 859.5 ppm, TG1 had 1223.6 ppm and 1254.3 ppm was found at TC1 (Table 4.4). The substantial 1223.6 ppm of BOD at the general water stream (TG1) stemmed from the dung, dirt, blood and soluble proteins that are washed off during soaking. The highest concentration was found in the chrome effluent stream (TC1) emanating from the tan yard, an indication of organic pollution from flesh, fats and protein fibre matter from the processed hides. This was also previously recorded by Parveen *et al*., (2017) who found 1248 mg/L of BOD in effluent from a tannery in Kanpur district and opined that a high BOD points to the presence of voluminous organic substances i.e., hides and skins matter used as raw materials for leather production.

At the first sections of treatment TL2, TG2 and TC2, the concentration was 636.1 ppm, 790.7 ppm and 969 ppm respectively. The chrome sedimentation tank TC3 had 1007.7 ppm, a pointer to the high organic load discharged from the chrome tanyard. Along the treatment sections of the homogenized effluent from TLG3 to TLG8, the volume of BOD was lower, ranging between 113.6 ppm to 681.5 ppm.

The treated effluent discharged from the tannery TLG9 had a BOD concentration of 236.7 ppm (Table 4.4). The effluent therefore exceeded the NEMA Kenya standard of 30 mg/L. This indicates there was inadequate removal of organic matter at the sedimentation tank which then led to overloading in the lagoons. Therefore, insufficient breakdown of the organic matter occurred causing the high BOD. There could also be secondary contamination between TLG8 lagoon 7 and the discharge point TLG9 as deduced by the increase in BOD from 126.9 ppm to 236.7 ppm (Table 4.4). Similar observations were made by Gemada *et al*.,

(2020) where he sampled effluent from Hafde tannery in Ethiopia and recorded 462 mg/L of BOD. This also exceeded the Ethiopian discharge limit of 200 mg/L (Table 7).

Phosphorus

Mild levels of phosphorus were detected in the raw effluent discharged from the processing area where samples from TL1 (liming effluent stream), TG1 (general water stream) and TC1 (chrome effluent stream) had 5.7 ppm, 5.9 ppm and 7 ppm respectively (Table 4.4). In the second level of sampling, the amount of phosphorus in TL2 (lime tank) was 3.75 ppm, TG2 (general water tank) had 6.05 ppm while that of TC2 (chrome tank) was 5.8 ppm. Within the sampling area before agglomeration of the different effluent steams, the chrome effluent stream was found to have the highest amount of phosphorus. The chrome sedimentation tank TC3 showed 6.15 ppm and the dry sludge at TC4 had highly toxic levels of 15.2 ppm. High levels of phosphorus in effluent can be tied to the use of phosphoric acid or its salts as pre-tanning and re-tanning agents in chrome tanning (Kedlaya & Santappa, 1973), the use of polyphosphates as water softeners and the presence of phosphates in syntans.

Within the sampling area from equalization tank TLG3 to the last lagoon TLG8, the level of phosphorous ranged between 4.7 ppm to 8.6 ppm (Table 4.4). At TLG 9 where the treated effluent is disposed from the tannery, phosphorus levels of 5.2 ppm were detected. This was above both the Kenyan standard limit of 2 mg/L and Uganda’s guideline of 5 mg/L (Table 7). Therefore, the effluent treatment plant did not sufficiently reduce the phosphorus toxicity levels because of inadequate biological uptake of phosphorus by the microorganisms in the lagoons. Amanial (2016) investigated treated tannery effluent in Ethiopia and recorded 30.12 mg/L, this also exceeded the local Ethiopian standard of 10 mg/L. Based on standards set by UNIDO, the effluent from Sagana tanneries can be classified as mesotrophic since the phosphorus level is between 5 – 25 mg/L, while that of the Ethiopian tannery can be classified as eutrophic since the level was between 25 – 250 mg/L (Gemada *et al*., 2020).

Nitrogen

Tannery effluents constitute nitrogen as part of their chemical structure (Affiang *et al.,* 2018). Nitrogen is also contained in proteinaceous materials from liming operations of the beamhouse. The untreated raw effluent streams from the beamhouse TL1, TG1 an TC1 had 1044 ppm, 486 ppm and 1520 ppm of nitrogen respectively (Table 4.4). Results from the second level of sampling revealed nitrogen levels of 1189 ppm at TL2, 172.3 ppm at TG2 and 978.2 ppm at the chrome tank TC2. After chemical treatment of the chrome effluent, 910.5 ppm was detected in TC3 and in TC4, the resultant sludge containing settled proteinaceous material combined with chrome exhibited the highest level of 16000 ppm of nitrogen.

Within the plant's section from flocculation TLG3 to biological treatment at TLG8, nitrogen levels ranged from 224 ppm to a heightened level of 12500 ppm. The 12500 ppm in the lime dry sludge TLG5 was due to the accumulation of the hair, fats and flesh removed from the skin during the liming stage of tanning.

The level of nitrogen contained in the treated effluent discharged from the tannery at TLG9 was 53.5 ppm (Table 4.4) while in a study by Kumar *et al.,* (2022), the Common Effluent Treatment Plant (CETP) in Unnao district India exhibited 1788.27 mg/L of nitrogen in treated effluent. Sagana tanneries exceeded the 2 mg/L local guideline while the CETP had levels that exceeded the prescribed limits by India (100 mg/L), Bangladesh (100 mg/L) and Ethiopia (60 mg/L) (Table 7). The treatment plant did not achieve adequate removal of nitrogen because the biological reuse of this nutrient by microorganisms in the lagoons did not take place sufficiently.

Chromium

Chromium, a heavy metal and contaminant in tannery effluent is exceedingly detrimental to biota health (Nur-E-Alam, 2020). Chromium is not biodegradable and exists in tannery effluent due to the use of chromium salts as a major chemical input in tanning.

The effluent treatment plant was rigged with high concentrations of chromium. In the effluent streams TL1 (liming effluent), TG1 (general water) and TC1 (chrome effluent), the levels were 3.8 ppm near the tannery first pond, 1.3 ppm and 39.4 ppm respectively (Table 4.4). Secondary contamination in the drainage channels may have been the cause of the high levels in beam house effluents TL1 and TG1 that should ideally exhibit zero chromium concentration. This means that wastewater from the chrome effluent stream mixes with effluents from the lime and general wastewater streams. The lime tank TL2 had 3.78 ppm and the general water tank TG2 2.38 ppm while the chrome tank TC2 had the highest concentration at 43.2 ppm. Contrary to this study, Sawalha *et al*., (2020) sampled untreated effluent and the results showed that the soaking, liming and deliming sections all had zero chromium concentration. The untreated chrome effluent had 3600 mg/L of chromium which was higher than Sagana tanneries' effluent that had 39.4 ppm at TC1 and TC2 43.2 ppm before treatment. The treated chrome effluent at TC3 exhibited 23.3 ppm and the resultant sludge after dehydration in the dry beds TC4 had 18.2 ppm.

Within the sampling area from TLG3 to TLG8, the level of chromium detected ranged between 1.08 ppm and 11.15 ppm. The amount of chromium in the lime dry sludge TLG5 (7.65 ppm) was higher than in conventional effluent treatment plants due to secondary contamination in the raw effluent drainage channels TL1 and TG1 and the channeling of runoff water from the chrome dry beds into TG2 (general water tank). The least concentration was at the treated effluent discharge point before discharge into the river, TLG9 which had 1.1 ppm of chromium (Table 4.4).

Effluent discharged from Sagana tanneries satisfied the legal range of 2 mg/L in Kenya, India and Italy (Table 7). Similarly, Wambugu (2020) also found 0.08 mg/L from Leather Industries of Kenya which was within Kenya's guideline. However, the Kenya's prescribed 2 mg/L is higher compared to the set levels of 0.5 mg/L in Uganda and Bangladesh, and 0.1 mg/L prescribed by Ethiopia and WHO. Kumar *et al*., (2022) investigated a CETP in India and found 7.2 mg/L in treated effluent. Likewise, Parveen *et al*., (2017) found 68.01 mg/L in Kanpur district and 38.6 mg/L in Unnao district. Both studies were above the set industrial effluent discharge guidelines.

Lead

Traces of lead in different concentrations were present in the raw effluent discharged from the processing area, the collection ponds, the treatment ponds, the lagoons and in the treated effluent discharged into the river. The concentrations from the first level sampling before any treatment at TL1, TG1 and TC1 were 0.13 ppm, 0.9 ppm and 1.4 ppm respectively (Table 4.4). Lead in tannery effluent originates from the metal-based chemicals used in leather manufacture. Metal salts, dyes and pigments used in tanneries and textile industries are laced with lead despite it having no known use in leather manufacture and lead products being banned globally. Aslan & Üzüm (2015) add that in 2012, a manifesto of the European Union Commission placed a total ban on Pb, Cd, Cr (VI), As, Hg and their compounds in manufacture of textile and leather products.

At the lime tank TL2, 0.1 ppm of lead was detected while at the general water tank TG2 the amount was 0.43 ppm and the chrome tank TC2 had the highest amount at 2.29 ppm. In the entire treatment plant, the chrome section exhibited elevated lead concentrations since TC3 (chrome sedimentation tank) also showed 1.16 ppm and TC4 (chrome dry sludge) had 2.26 ppm. This meant that the chromium salts used as the principal agent in tanning were heavily laced with lead. In the sections from TLG3 to TLG9, the lead concentration was between 0.07 ppm and 1.85 ppm. The lime dry sludge TLG5 had a significant amount of lead (1.85 ppm) due to clustering and settling of heavy metals during sludge formation. The lowest level was found at TLG8 (lagoon 7) and at the effluent discharge point TLG9 where both results were 0.07 ppm (Table 4.4).

The 0.07 ppm of lead in the discharged treated effluent was above the limit in Kenya, Uganda, Bangladesh, India (Table 7) and WHO, all set at 0.01 mg/L. The results mirror studies by Nabila & Ibrahim (2019) who recorded lead levels of 0.83 mg/L and 0.67 mg/L from Challawa industrial area in Kano. Similarly, Mohammed *et al*., (2017) found 0.766 mg/L of lead in tannery effluent from Samaru-Zaria in Nigeria. The levels in the discharged effluent from Sagana Tanneries infer that the series of lagoons are unable to allow sufficient filtering and settling of lead. This is because of the high amount of lead coming in from the sedimentation tank. Enhancement of flocculation in the equalization tank and settling in the sedimentation tank would significantly reduce the toxicity load entering the lagoons. This will allow easy settling of heavy metal compounds and reduction to acceptable discharge levels.

Copper

Copper was evident all along the treatment plant sections in untreated and treated effluent. In the first tier of sampling before treatment, samples from TL1, TG1 and TC1 exhibited 0.2 ppm, 0.52 ppm and 0.57 ppm respectively (Table 4.4). At the onset of treatment of the wastewater, TL2 had 0.64 ppm of copper, TG2 had 0.53 ppm and the chrome tank TC2 had 0.6 ppm.

Within the sampling area after chemical treatment from TC3 to TLG8 the level of copper detected ranged between 0.12 ppm to 3.59 ppm. The lowest amount (0.12 ppm) in the sedimentation tank TLG4 (Table 4.4) was because precipitation and settling of copper at the bottom of the tank had already occurred, therefore, low levels were present in the effluent. The dry sludge contained the highest levels of copper with the chrome dry sludge TC4 having 4.42 ppm and the lime dry sludge TLG5 having 3.59 ppm. The sludge contained high loads of copper since the removal of copper in tannery effluent is through precipitation and the subsequent accumulation and disposal of sludge.

Kenya’s effluent discharge guideline for copper is set at 1 mg/L. Sagana’s discharged effluent at TLG9 had 0.41 ppm copper (Table 4.4) and therefore met the legal discharge requirement. Mohammed *et al*., (2017) had near-similar results in Nigeria where he found 1 mg/L copper in tannery effluent. Sagana’s effluent was therefore within the legal ranges in Kenya (1 mg/L), Uganda (0.5 mg/L), Bangladesh (0.5 mg/L) and India (3 mg/L) (Table 7).

Zinc

According to Juel *et al*., (2016), heavy metals like copper, arsenic and zinc exist in tannery wastewater from the use of re-tanning agents, syntans, pigments and dyes in leather manufacture. Samples obtained along the raw effluent discharge channels TL1, TG1 and TC1 were found to have zinc amounting to 4.461 ppm, 3.059 ppm and 7.01 ppm respectively (Table 4.4). In the second level of sampling, the toxicity load in TL2 was 3.693 ppm, TG2 had 2.575 ppm and in TC2, 7.88 ppm was detected. Within the final stages of chrome wastewater treatment, the chrome sedimentation tank TC3 exhibited 5.905 ppm of zinc and the chrome dry sludge TC4 had the highest level of 12.6 ppm.

Zinc also manifests in tannery effluent from the use of contaminated water and/or the use of tanning chemicals laced with high concentrations of the heavy metal, especially the tanning salts of chromium. This explains why the chrome effluent treatment section exhibited the highest levels because TC1 had 7.01 ppm, TC2 had 7.88 ppm, TC3 had 5.905 ppm and the chrome dry sludge TC4 had the highest concentration of 12.6 ppm. The elevated concentration in TC4 was also because the elimination zinc in the effluent is through chemical precipitation and accumulation in sludge and therefore explains the levels in the chrome dry sludge.

Along the treatment section after combined treatment of the different effluent streams, the amount of zinc from TLG3 to TLG8 ranged between 0.37 ppm to 7.58 ppm. The lime dry sludge at TLG5 contained a significant amount of zinc of 7.58 ppm and this is because the removal of zinc in effluent is through chemical precipitation and accumulation in sludge.

The treated effluent discharged from Sagana tanneries at TLG9 had 0.85 ppm of zinc (Table 4.4), an amount higher than Kenya’s standard of 0.5 mg/L for industrial effluent. There was inadequate removal of zinc at the sedimentation tank TLG4 which, if reduced significantly would have otherwise helped to ease the load getting into the lagoons. Studies by Saha & Azam (2021) determined the average zinc concentration in RMM leather industry in Bangladesh at 1.52 mg/L while Kumar *et al*., (2022) from India found 0.094 mg/L in treated tannery effluent. All the studies exhibited levels below the prescribed limits by India and Bangladesh of 5 mg/L for zinc (Table 7).

4.1 Effect of tannery effluent on River Sagana

Industrial activities consume water and in turn generate effluent, which introduces contaminants into water bodies (Nur-E-Alam, 2020). River Sagana, just like Nairobi River (Mbui *et al.*, 2016), is used for domestic and agricultural purposes by people living downstream. Pollution makes water become less apposite for drinking, domestic, agricultural, recreational, industrial, wildlife and other uses for which it would have been otherwise fit in its natural unaltered state (Awash Basin Authority, 2018).

In the efforts to determine the impact of tannery effluent on river Sagana, the physicochemical properties of the river were analyzed across sampling points each 500 meters apart as follows; TR1 (500 m upstream), TR2 (effluent discharge point), TR3 (500 m downstream) and TR4 (1 Km downstream). The mean resource water quality results are presented in Table 5.4 and Table 6.4.

pH

pH is a critical characteristic since any minor changes can render water unfit for drinking and other purposes (Parveen *et al*., 2017). The pH of aquatic ecosystems is also connected to its biological productivity. Young organisms are sensitive to acidic waters for example, fish eggs cannot hatch when exposed to a mild pH of 5 (UNEP 2008). Amanial (2016) adds that evaluation of pH is key because it influences other physicochemical parameters and the availability of metal ions in water.

The level of pH at the upstream control sampling point before injection of tannery effluent TR1 was 7.24 and at TR2 where the treated tannery effluent joins the river, the pH was determined at 7.17 (Table 5.4). Further downstream at sampling points TR3 and TR4, the level of pH was 7.25 and 7.32 respectively (Table 5.4). According to NEMA and WHO guideline value of 6.5 – 8.5 for drinking and domestic water, the river was within the recommended standards. It also satisfied the guidelines for irrigation water by NEMA 6.5 – 8.5, FAO 6.5 – 8.4, Egypt's standard of 7.0 – 8.5 for surface water and NEMA 6.0 – 9.0 standard for recreational water.

Table 5.4: Mean levels of physicochemical properties of river Sagana. All river water physicochemical parameter values are presented in ppm except pH.

SAMPLES	**pH**	**(ppm)** **COD**	**(ppm)** **BOD**	**(ppm)** **P**	**(ppm)** **N**
500 m upstream (TR1)	7.24	172	116.6	6.1	58.35
Discharge point (TR2)	7.17	412	209.1	7.25	69.55
500 m downstream (TR3)	7.25	294	100.1	11.8	77.6
1 Km downstream (TR4)	7.32	210	66.4	5.6	307

Chemical oxygen demand

The levels of COD were determined at 172 ppm, 412 ppm, 294 ppm and 210 ppm at the upstream TR1, discharge point TR2 and downstream TR3 and TR4 sampling points (Table 5.4). NEMA and WHO have no set guideline value for COD but Egypt has a quality standard value of 10 mg/L for inland surface water. Therefore, in all the upstream, discharge point and downstream samples, river Sagana had COD levels above the Egyptian standards.

The concentration of COD at the discharge point TR2 denoted an increase compared to the upstream sample TR1 (Figure 5.4), this indicated a surge in organic compounds from the tannery effluent. The river also showed decreased concentration downstream (Figure 5.4) due to dilution.

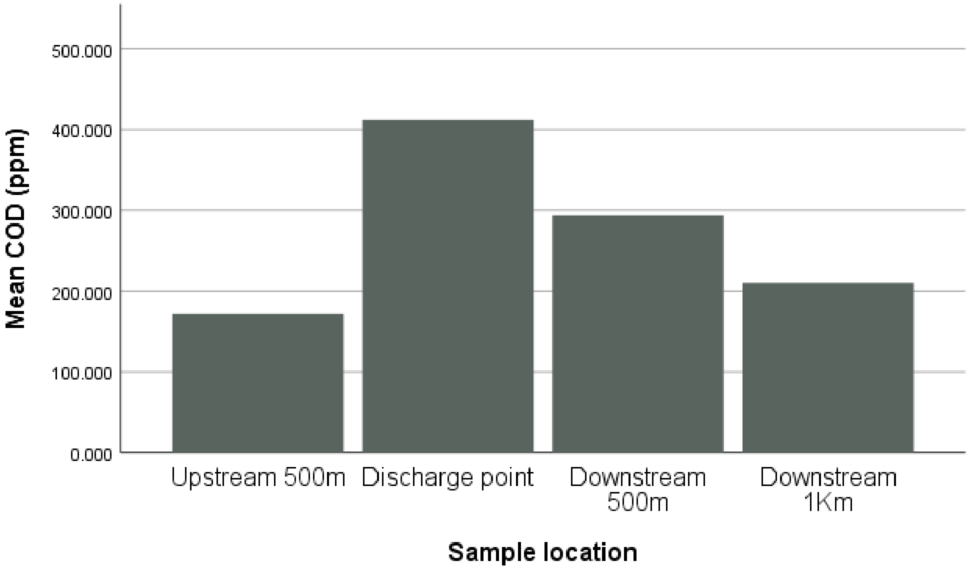

Figure 5.4: Mean COD concentration along the river sampling locations

A high COD level indicates high strength of oxidizable organic matter which leads to reduction in dissolved oxygen according to Al Sharabaty & Sarsour, (2017) and Hassan *et al*., (2021). The anoxic conditions threaten aquatic life and allows heavy metals adhered to bottom sediments of the river to dissociate and dissolve back into the water. The treated wastewater from the tannery is a primary point source for COD pollution for river Sagana since it exceeded levels set by NEMA for industrial effluent discharge into surface water bodies.

Biochemical oxygen demand

A study by Hassen and Woldeamanuale (2017) indicates that presence of high BOD promotes anaerobic action leading to accumulation of toxic compounds in water bodies. Inversely, a low BOD value in water indicates that there is little oxygen being utilized, thus indicating better quality and purity of the water.

River Sagana had a BOD level of 116.6 ppm at the upstream sampling point TR1 before injection of tannery effluent into the river (Table 5.4). At TR2 where the tannery effluent joins the river, 209.1 ppm of BOD was detected and the downstream samples at TR3 and

TR4 exhibited 11.1 ppm and 66.4 ppm respectively (Table 5.4). There was an increase in BOD level at the treated effluent discharge point when compared to the upstream sampling point, this indicated direct organic pollution by the tannery (Figure 6.4). Decreased levels of BOD at the 500 m downstream and 1 Km downstream sampling points were also observed and were the result of dilution (Figure 6.4).

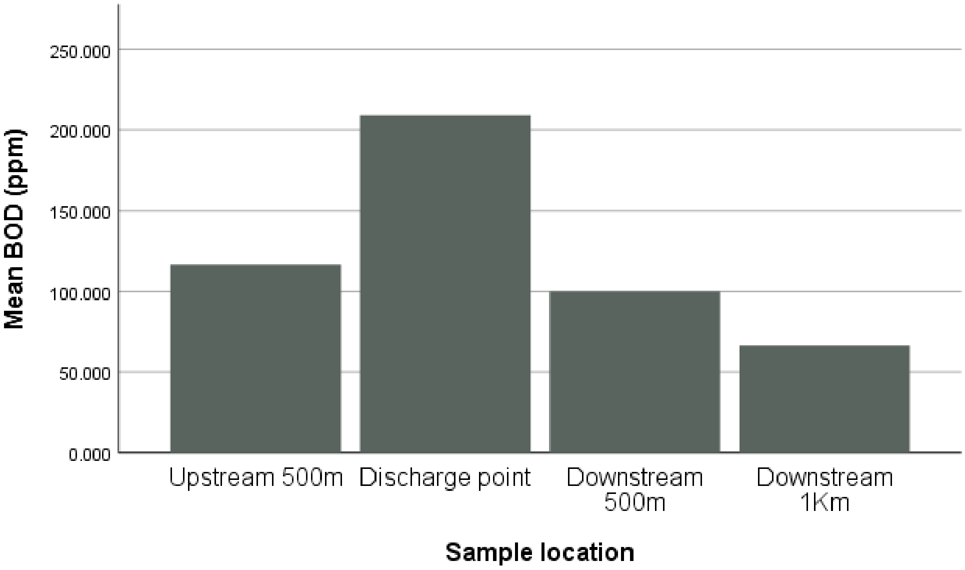

Figure 6.4: Mean BOD concentration along the river sampling locations

According to Tanzania's guideline value of 2 mg/L for BOD in drinking water, river Sagana water is not fit for direct consumption.

Notably, the treated wastewater from the tannery is a primary point source for BOD pollution for river Sagana since, it exceeded levels set by NEMA for industrial effluent discharge into surface water bodies.

Phosphorus and Nitrogen

Phosphorus and nitrogen present major environmental problems due to their contribution to eutrophication in fresh water bodies. Bali & Gueddari (2019) term eutrophication as a condition where high nutrient concentrations overstimulate growth of plants thereby degrading aquatic ecosystems. Affiang *et al.,* (2018) adds that as the many plants die, the breakdown of the high loads of organic matter outstrips the natural oxygen supply leading to the death of fish, plants and aero bacteria.

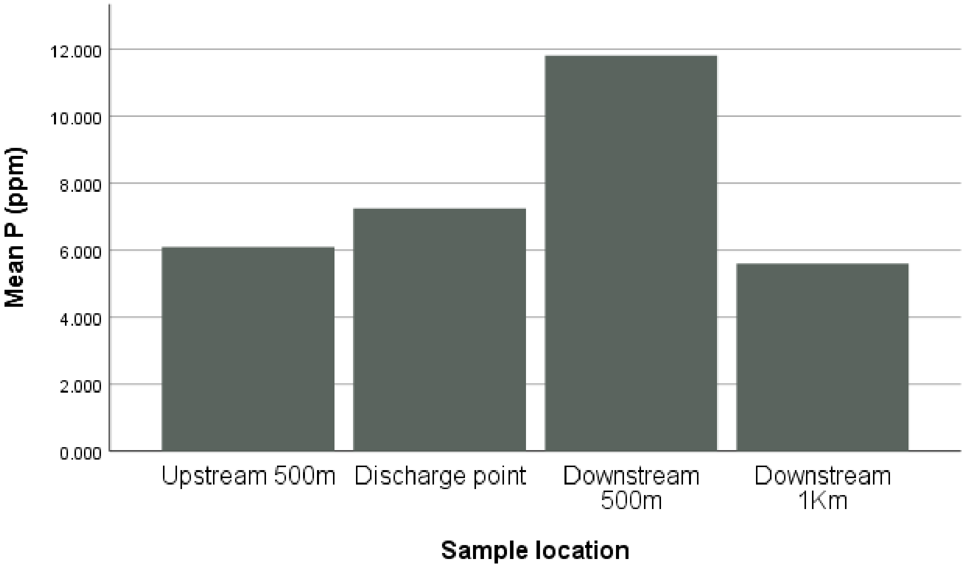

Figure 7.4: Mean phosphorus concentration along the river sampling locations

Phosphorus contamination of surface water is through run off waters from human activities in agricultural and urban areas (UNEP, 2008) and is present in all natural waters chiefly as phosphates. The level of phosphorus along the river was 6.1 ppm in the upstream sample before injection of tannery treated effluent TR1. 7.25 ppm at the discharge point TR2, 11.8 ppm at TR3 500m downstream and at TR4 further downstream, 5.6 ppm was detected (Table 5.4). Figure 7.4 depicts an increase in concentration at the discharge point, a result of the release of effluent containing elevated levels of phosphorus above NEMA industrial effluent discharge standards.

There is also a significant increase at 500 m downstream (Figure 7.4) and this may be attributed to agricultural chemicals runoff from farms on the riparian banks of the river. However, this was not measured and could be a critical area that requires further research. River Sagana did not meet the threshold for water suitable for irrigation since the standard set by FAO is 2 mg/L. Phosphorus is an essential nutrient for plant growth, but a high concentration in irrigation water would also stimulate excessive weed growth therefore, creating competition for nutrients with the cultivated plants.

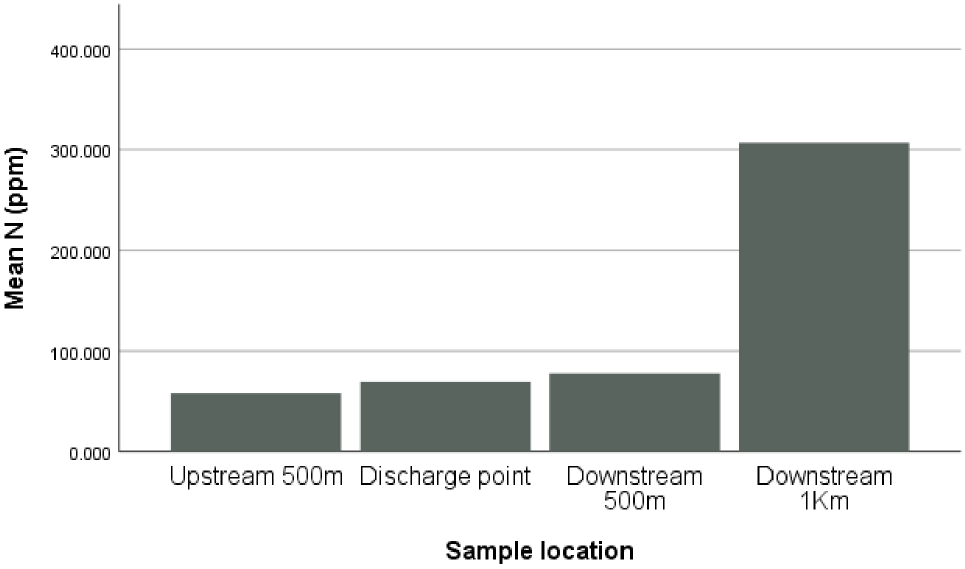

Figure 8.4: Mean nitrogen concentration along the river sampling locations

Nitrogen concentration in the river was measured at 58.32 ppm at the control upstream sample TR1, 69.55 ppm in the waters at the discharge point TR2, 77.6 ppm in the downstream sample at TR3 and 307 ppm in TR4 a kilometer downstream.

Nutrient pollution was also evidenced by an increase in nitrogen concentration at the discharge point when compared to the level measured 500m upstream (Figure 8.4). This was caused by the discharge of treated tannery effluent with extreme nitrogen levels above the required NEMA standard of 2 mg/L. Cultural eutrophication also led to the observed increase in nitrogen concentration at 500 m downstream and the sharp increase observed 1 Km downstream (Figure 8.4). At the 1 Km sampling point, the river is used for domestic activities not limited to bathing, washing of clothes, car washing and motorcycle washing, all which could be the contributing factor to the high nitrogen concentration.

At all points investigated in this study, river Sagana had extreme loads of nitrogen that were beyond the 1 mg/L guideline value for potable water in Tanzania and the standard for natural surface water in Egypt. Nitrogen in excess concentration causes nutrient enrichment that leads to abundance of cyanobacteria (UNEP, 2008) and extreme blooming of algae and aquatic plants. Toxins produced by cyanobacteria are a threat to human and animal health while eutrophication threatens the existence of aquatic species with high oxygen needs and causes bad odour and taste in water. Water meant for recreational activities may also be rendered unusable because of the bad odour and development of slime.

Heavy Metals Concentration

Metal pollutants are considered toxic as they are not biodegradable and they accumulate easily in plants and animals. Heavy metals function at low concentration as biogenic elements but at the same time are considered pollutants when in higher amounts than the prescribed limits (Czikkely & Fogarassy, 2018).

Table 6.4: Mean levels of heavy metals concentration in river Sagana. All river water physicochemical parameter values are presented in ppm.

SAMPLES	(ppm) Cr. T	(ppm) Pb	(ppm) Cu	(ppm) Zn
500 m upstream (TR1)	0.75	0.095	0.17	1.465
Discharge point (TR2)	0.9	0.11	0.48	1.64
500 m downstream (TR3)	0.3	0.075	0.2	1.71
1 Km downstream (TR4)	3.35	0.23	0.36	0.88

Chromium

In the first level of sampling TR1, 0.75 ppm of chromium (Cr) was detected, while 0.9 ppm was detected at second level of sampling TR2 (Table 6.4). The third level of sampling done at TR3 exhibited 0.3 ppm and elevated levels of 3.35 ppm were found in the fourth sampling level TR4 (Table 6.4). Despite the effluent discharged from the tannery being within prescribed NEMA standards of 2 mg/L, there was an increase in Cr levels observed at the discharge point when compared to upstream levels (Figure 9.4). This means that the treated effluent from the tannery still contributed to chromium pollution of river Sagana.

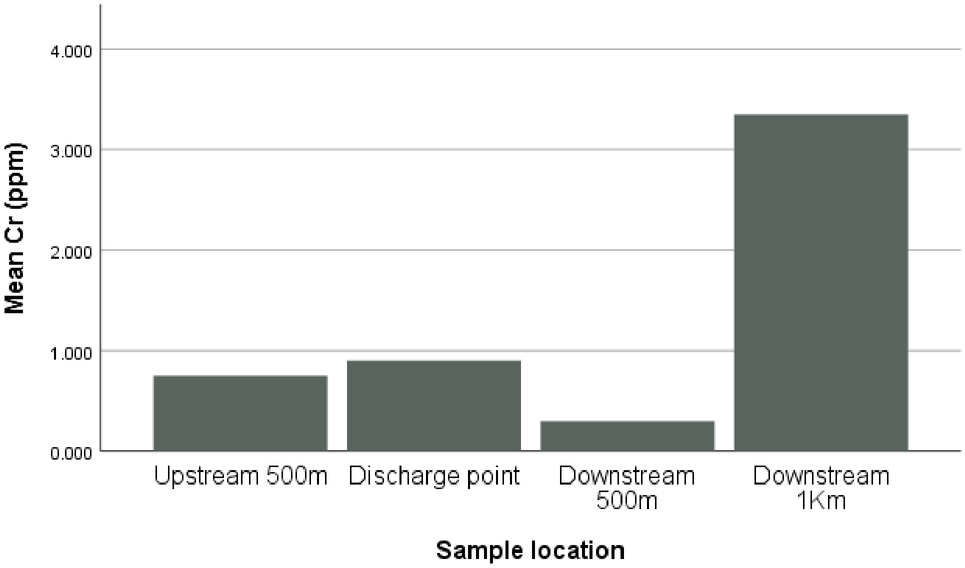

Figure 9.4: Mean chromium concentration along the river sampling locations

There was a decrease in Cr 500 m downstream (Figure 9.4) and this according to Amanial (2016) is due to dilution and adsorption of the metal by sediments and organic matter present in the river. This additionally means that Cr is still present in the aquatic ecosystem and could be a threat to aquatic organisms.

Very high amounts of heavy metal have been detected at near bottom levels of lake Mashu in Japan (UNEP 2018) therefore making it critical for water quality monitoring of heavy metals to also examine concentrations in the water close to the river bed and sediments at the bottom. At 1 Km downstream, the level rose excessively (Figure 9.4) and this can be attributed to the domestic nature of water use by the community. The high amount of nutrients (phosphorus and nitrogen) at this point could have caused eutrophication which would in turn result in reduction of dissolved oxygen in the water. These conditions could suitably have facilitated the dissociation of chromium adhered to bottom sediments, making it dissolve back into the river hence the observed elevated levels.

In comparison to the WASREB, Rwandan, Canadian and WHO potable water standard of 0.05 mg/L for Cr, river Sagana is not an ideal source of domestic water and neither does it satisfy the Egyptian natural water standard of 0.05 mg/L. Chromium in high amounts is toxic to living organism due to its ability to accumulate in the body. Hassan *et al*., (2021) also adds that some fishes and algae have been found to be delicately sensitive to chromium.

Lead

The lead (Pb) concentration in river Sagana's upstream sample before addition of tannery effluent TR1 was 0.095 ppm and that of TR2 at the effluent discharge point was 0.11 ppm (Table 6.4). Downstream samples TR3 and TR4 also showed toxicity levels of 0.075 ppm and 0.23 ppm respectively (Table 6.4).

The effluent released from the tannery contained Pb levels above the prescribed NEMA limit of 0.01 mg/L for industrial effluent discharge and consequently, this increased the Pb level at the discharge point as compared to the 500m upstream sampling point (Figure 10.4). The reduction of Pb at the 500 m downstream point (Figure 10.4) was as a result of self-cleaning of the river, sedimentation and possible uptake of lead by aquatic organisms.

At the 1 Km sampling point, there was a steep increase in concentration to 0.23 ppm (Figure 10.4) caused by contamination from the nature of river use by people in Sagana. This section also exhibited elevated levels of COD, phosphorus and nitrogen which may have led to the lack of dissolved oxygen in the water. Heavy metals like lead dissociate from river sediments and dissolve back in host waters under anoxic conditions and therefore causing the high concentration.

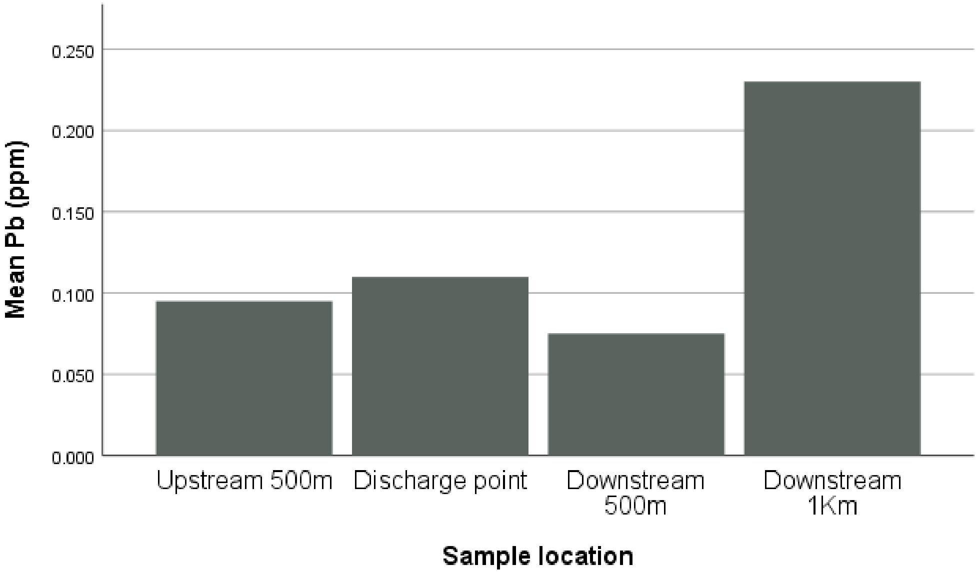

Figure 10.4: Mean lead concentration along the river sampling locations

Lead present in all sampling points of river Sagana was high and above the domestic water guideline values set by NEMA Kenya 0.05 mg/L; WHO, Ethiopia and Rwanda 0.01 mg/L and 0.005 mg/L Canadian standard. It also surpassed the Egyptian natural water standard of 0.05 mg/L. Fauna is less tolerant to lead than flora. Irrigation water standards by NEMA Kenya, FAO and Rwanda are set at 5 mg/L. Exposure to such levels in human beings may cause behavioral defects in children, increased blood pressure and renal disfunction in adults.

Copper

Physicochemical analysis of the water sample free from tannery effluent TR1 detected 0.17 ppm of copper (Cu) (Table 6.4). Additionally, samples collected after discharge of effluent into the river at TR2, TR3 and TR4 exhibited toxicity loads of 0.48 ppm, 0.2 ppm and 0.36 ppm respectively (Table 6.4).

The treated effluent discharged into the river was below the 1 mg/L discharge guideline set by NEMA but it still contributed to the elevation of Cu concentration as depicted by the rise at the discharge point (Figure 11.4). Therefore, more copper becomes readily available for uptake by aquatic microorganisms and may also increase copper toxicity in the bottom sediments. Dilution caused the Cu concentration to decrease 500 m downstream but later the amount of Cu increased 1 Km downstream (Figure 11.4) because of the anthropogenic activities and nature of river use at the sampling point. These activities may have led to the development of an anoxic environment due to high COD level and eutrophication which in turn favored the availability of copper in the water.

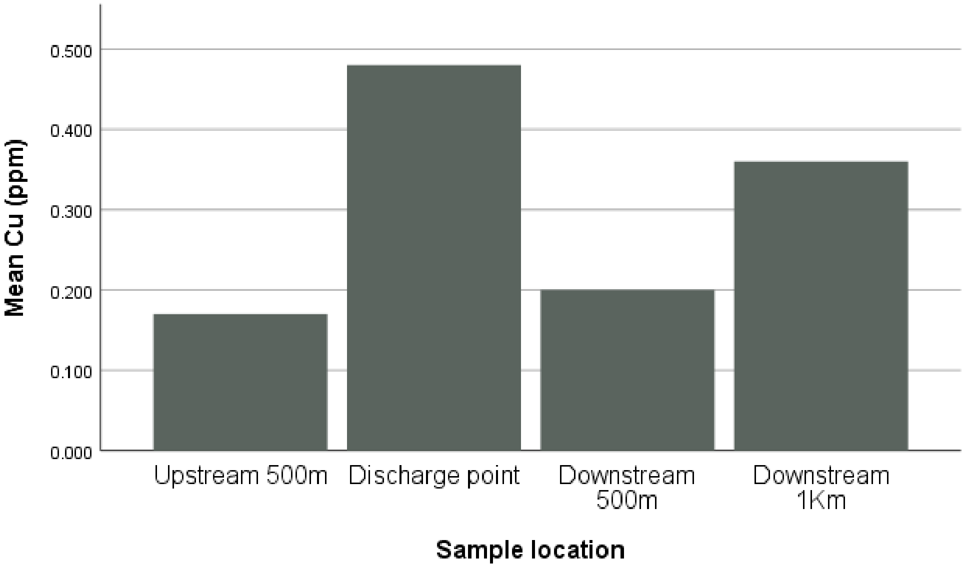

Figure 11.4: Mean copper concentration along the river sampling locations

According to FAO and Rwanda irrigation water standard of 0.2 mg/L, the water upstream was fit for use in agriculture but upon reaching the discharge point, the Cu levels rose beyond the guideline value rendering the water unusable downstream. Kenya’s standard for irrigation water is 0.05 mg/L and this means that the entire river system in this study would not be suitable as a source of water for crop cultivation. The river at all sampling points also contained Cu levels above the 0.05 mg/L by NEMA Kenya and 0.1 mg/L WASREB limit for domestic water sources. Ingestion of water containing copper causes gastro intestinal problems and leads to liver and kidney damage in humans while in plants, it reduces plant growth and depresses iron concentration in leaves.

As Amanial (2016) opines, though the Cu released in the discharged effluent is within standards of WHO and NEMA, there is still an increase in concentration of the element (Figure 11.4) and this may increase the accumulation of the metal on the sediments and organic matter present in the river.

Zinc

The river water upstream free from tannery effluent TR1 contained 1.465 ppm of zinc (Zn) which was lower than the concentration of 1.64 ppm at the treated effluent discharge location TR2 (Table 6.4). Higher levels of 1.71 ppm were found in TR3 while further downstream, decreased amounts of 0.88 ppm were detected at TR4 (Table 6.4).

Figure 12.4 parades an increase in the level of Zn at the discharge point meaning the tannery contributed directly to Zn pollution of river Sagana. Additionally, the discharged effluent was also above the 0.5 mg/L NEMA Kenya standard for wastewater discharged into surface waters. At 500m downstream, runoff water containing residues of agricultural inputs from the cultivated riparian banks may have led to the increase in Zn as observed in Figure 12.4.

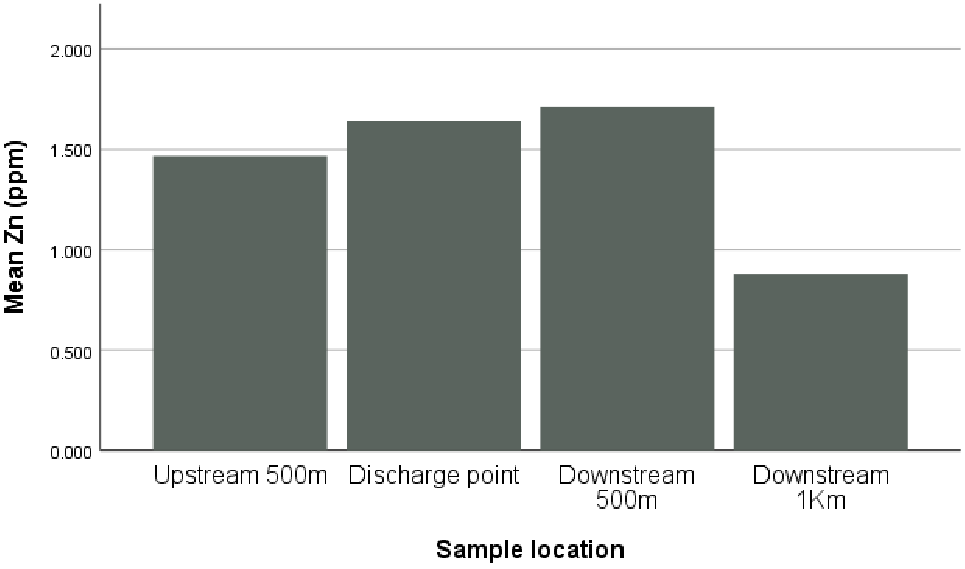

Figure 12.4: Mean zinc concentration along the river sampling locations

At 1 Km downstream, the Zn level dipped (Figure 12.4) meaning that the self-cleaning capacity of the river was adequate enough minimize the toxicity to levels below the acceptable domestic water guideline of 1.5 mg/L by NEMA Kenya and the 1.0 mg/L surface water quality threshold in Egypt. The amount of zinc in river Sagana was also within the acceptable 2.0 mg/L standard for irrigation water by NEMA Kenya, FAO and Rwanda.

4.2 Effluent management in the tannery

Industrial effluent is toxic, and its treatment is a multi-stage process that purposes to decontaminate the water before it is reused for different purposes or, released into the environment. Tannery effluent is mainly produced from raw hides and skins preparation and tanning processes of wet operations in leather production (Zhao & Chen, 2019). The goal of treatment is to eliminate nutrients, organic matter, heavy metals like chromium and lead, and other pollutants because their existence in high loads can degrade the receiving environment.

Sagana Tanneries Limited effluent treatment plant is designed to treat effluent according to the main streams of production. The effluent treatment section operator described the effluent streams as follows; the liming and unhairing wastewater from the beamhouse, the general effluent from soaking, washing and other post tanning operations, and the chrome effluent from the tanyard (Figure 13.4). The operator added that the wastewater from the different sources is collected in separate channels during production and then pre-treated before being mixed and subjected to additional treatment. UNIDO indicates that it is vital to isolate the effluent streams and to pre-treat them according to their physicochemical constituents in order to; avoid possible safety risks like hydrogen sulphide formation, reduce treatment costs, and to enable safe sludge disposal by preventing contamination of primary sludge with chromium.

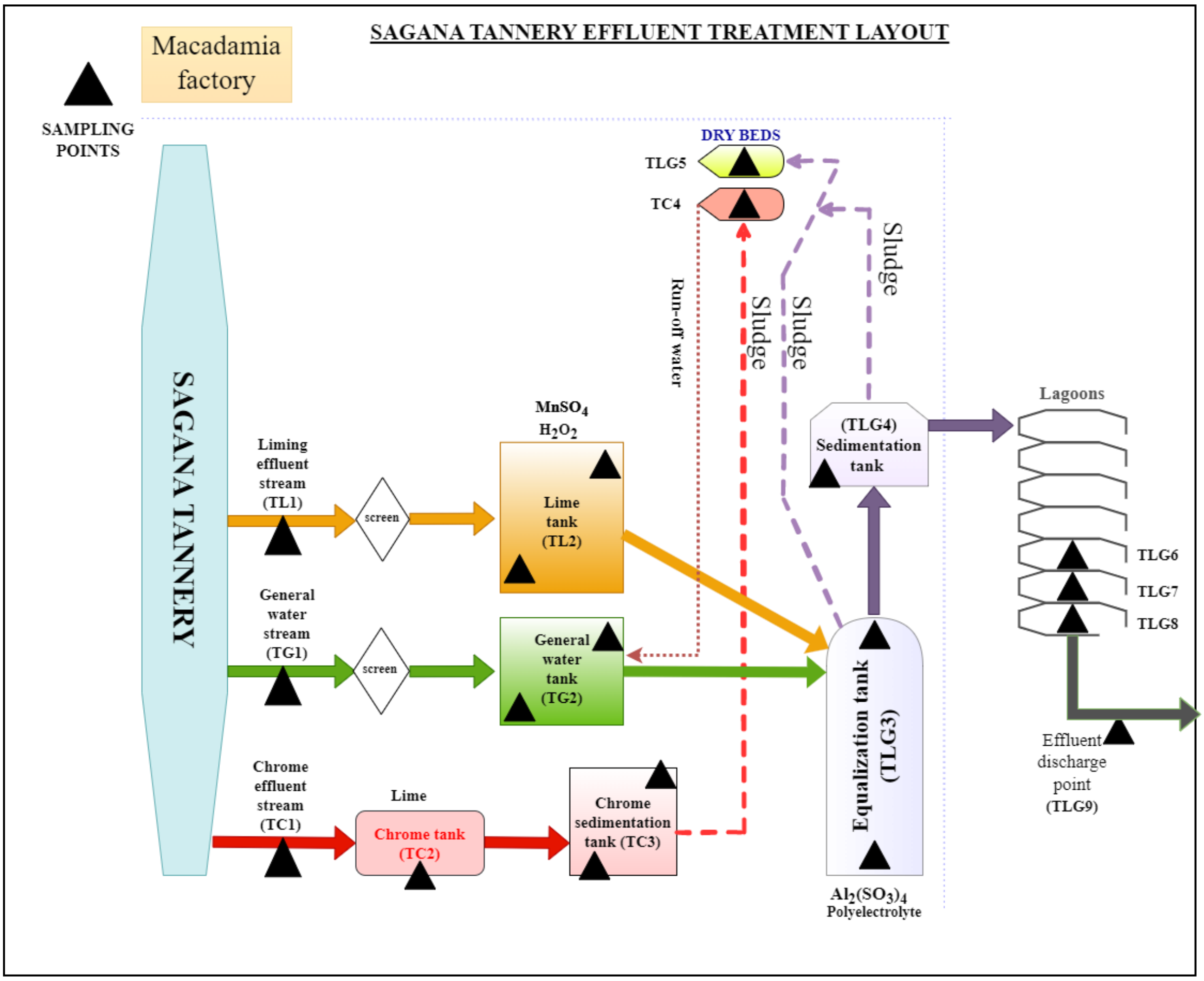

Figure 13.4: Sagana Tannery effluent treatment plant layout

The three effluent streams are subjected to preliminary treatment that entails the removal of large pieces of fleshings, papers and huge solid particles by handpicking before the wastewater is subjected to primary treatment. According to the treatment section operator, the fleshings from the beamhouse are dipped in a bath of water and sulphuric acid and then fed into a biogas digester. The energy from the digester is used to heat water that is then used to maintain optimum temperature needed for the digester to function. The management cited plans to have the biogas digester upscaled in order to ensure that the energy produced is utilized in mainstream tannery processes and to run machinery like the dryer.

Chrome effluent undergoes chemical treatment with lime $Ca(OH)_2$, a common flocculant that supports the clustering of organic matter and chromium particles to form sludge. The generally used coagulants in tannery wastewater treatment are commercial iron sulphate $(FeSO_4)\cdot 7H_2O$, commercial ferric chloride $FeCl_3\cdot 6H_2O$, commercial aluminium sulphate $Al_2(SO_4)_3\cdot 18H_2O$ and industrial calcium hydroxide $Ca(OH)_2$ generally referred to as lime (Paltahe *et al*., 2019, Bishnu *et al*., 2017, UNIDO).

The effluent in the chrome tank is stirred by an overhead mixer and then flows to the chrome sedimentation tank (Figure 13.4) where sludge forms and settles at the bottom the tank. The sludge is then pumped to dry beds (Figure 13.4) where natural drying occurs. The floors of the beds are lined with sand to allow seepage of excess water and as explicated by the treatment section operator, the excess water from the beds is eventually channeled back to the general water tank (Figure 13.4).

Chromium salts are precipitated as chromium hydroxide at mildly acidic pH 5.34 (Table 4.4) and persists to form sludge. According to Minas *et al*., (2017), this causes a buildup of chromium III hydroxide in the sludge which is undesirable as sludge and is commonly used as fertilizer. However, the researcher in this study does not recommend the use of chromium sludge as fertilizer because of the high chromium content 18.2 ppm (Table 4.4) and also due to the high concentration of other heavy metal pollutants. The dry sludge in Sagana Tanneries is scrapped, packed in sacks and stored in a temporary shed awaiting accumulation into sizeable loads for disposal at a dumpsite. The manager of the tannery cited this as a challenge in efficient environmental management of chrome waste in the facility.

Liming and general effluent wastewaters are passed through self-cleaning rotary brush screens so as to eliminate coarse materials that can clog transfer pipes and pumps in the subsequent treatment stages. Lime effluent proceeds to the lime tank (Figure 13.4) and is treated with manganese sulphate $MnSO_4.H_2O$ and hydrogen peroxide H_2O_2 which works to neutralize lime and to oxidize the sulphide content in the effluent. The function of this treatment stage is to adjust pH and eliminate the sulphide load that could negatively affect sensitive bacteria involved in biological treatment. The effluent is then aerated by blowing in air using turbine aerators that also serve to stir up the effluent. The treated effluent is later pumped to the equalization tank (Figure 13.4). The wastewater in the general water tank (Figure 13.4) is also aerated to allow for bio digestion of organic matter by micro-organisms in the effluent before being pumped to the equalization tank that functions as the primary sedimentor.

Primary treatment of effluent allows different wastewater streams to be mixed together to form homogenized effluent that can be treated in a consistent manner. In the equalization tank (primary sedimentor), wastewater from the lime tank and general water tank (Figure 13.4) is collected and treated with aluminium sulphate $((Al_2(SO_4)_3)\cdot 18H_2O)$ as a primary flocculant that improves and accelerates the settling of suspended solids. A polyelectrolyte is then added to serve as a flocculant aid. UNIDO defines flocculant aids as water soluble organic polyelectrolytes that support agglomeration of colloidal and fine suspended matter thereby enhancing sludge formation.

The effluent in the primary sedimentor is aerated to permit proper amalgamation for optimal sludge formation conditions. Sludge is formed and then pumped to the lime dry beds (Figure 13.4) for natural air drying. The wastewater left behind is pumped to the sedimentation tank, a secondary sedimentor that is deep to allow settling, thickening and collection of sludge from the treated effluent. The sludge formed is bulkier and more difficult to dewater and is also pumped to the lime dry beds to allow drying. The remaining effluent is pumped to aerated lagoons for final biological treatment. Upon drying, the dehydrated blocks of lime sludge are collected and given to farmers to use as manure in their farms. According to the effluent section operator, this serves as an innovative way to manage solid waste (dry lime sludge blocks) within the facility. Sagana Tanneries management stated that they advise farmers to consult agricultural extension officers and to have their farm's soil tested prior to the application of the lime sludge from the tannery.

Aerated lagoons are a series of open pits with a slow rate of flow that allows maximum exposure of the treated effluent to natural conditions and biological metabolism so as to successfully reduce the concentration of pollutants in the effluent. The main objective is to reduce the quantity of organics, nutrients and other substances present in the effluent after primary treatment, thereby satisfying the limits for discharge into surface water. As in Table 4.4, there is a significant reduction in all pollutants load in the final discharged effluent except copper, when compared to the amounts in the sedimentation tank after the wastewater goes through the series of lagoons.

Strategies

The manager at Sagana Tanneries Limited mentioned they safeguard that effluent is treated effectively to set guidelines by; ensuring step by step monitoring of intricate details of the treatment plant through appropriate and accurate dosing of chemicals, on the spot investigation of factors like pH that are influenced by chemicals added during treatment and following strict timelines as per the set treatment schedules. According to the waste water treatment section operator, they have effective and streamlined in-house communication between production sub-sections to ensure timely information is shared whenever there are changes in the production process.

Moreover, the manager added that the effluent is channeled in individual streams to create room for adequate pre-treatment before homogenization of the different streams, to prevent contamination of sensitive biological processes in the treatment plant and to curtail the formation of toxic chemical compounds. The manager also stated that the tannery primarily treats individual drum loads of waste water separately before being homogenized in the equalization tank. This allows for specialized attention to the effluents' pollutants load that may differ based on the adopted tanning processes.

Additionally, Sagana Tanneries uses self-assessment as a method to guarantee conformity to environmental laws in Kenya and to evaluate the efficiency of the adopted treatment technologies. Effluent from all the treatment stages is analyzed yearly while that from the lagoons are tested quarterly and the results compared to the regulations guiding the tanning industries. Credibility of the obtained results is maintained by using NEMA accredited laboratory facilities like Kenya Industrial Research and Development Institute (KIRDI).

4.3 Challenges and opportunities in environmental management of the leather industry

Water in the earth is comparable to blood in the human body (Nur-E-Alam, 2020), incongruously, the direct or indirect impairment of water quality is due to human activities. The leather industry suffers from the negative impact that stems from the pollution it causes to the environment and this manifests as a pressing problem restricting the development of the leather tanning industry. Environmental management and pollution control therefore become major aspects of development processes especially in the domain of sustainable development (Jemal *et al*., 2020).

In the effort to satisfy the statutory guidelines for effluent discharge and the need to control the quality of wastewater, Sagana Tanneries uses a combination of effluent treatment and management techniques in order to meet its environmental obligations. However, the efforts are impeded by many challenges.

Challenges

The production manager of the tannery stated that running costs of effluent treatment are very high and at times economically strenuous. Effluent treatment is a highly mechanized process requiring pumps, aerators and mixers that run on electricity for extended periods thereby consuming a lot of energy. According to the Economic Survey by Kenya National Bureau of Standards (2023), Kenya has imposed high electricity tariffs on consumers and therefore, this making effluent treatment expensive. For example, in 2022, the price for consumption of 200 Kw/h electricity was Ksh. 4681.58 which is higher than the 2018 price of Ksh. 4269.52 (KNBS, 2023).

Additional costs to effluent treatment are also brought about by deterioration of equipment. The effluent treatment operator highlighted that the saline conditions at the treatment section of the tannery causes rusting, wear and tear of the machines and guard rails and this, adds up the running costs of effluent treatment. Additionally, the production manager said that fluctuation of the cost of chemical and mechanical inputs causes challenges in wastewater quality control.

Climate change was cited as a negative factor in treatment of effluent. Erratic rainfall especially extended rainy periods causes a buildup of storm water which leads to a voluminous increase in the quantity of effluent in the treatment tanks. This demands for application of more treatment chemicals inputs and an upsurge in energy consumption. It also leads to tanks overflow that causes contamination of separated treatment sections and spewing of untreated effluent into the river. Storm water complicates the schedule of effluent treatment because running procedures and timelines are interfered with for example, the drying beds fill up with water causing the sludge to persist as slurry.

Local tanneries suffer from the lack of feasible innovative ways to handle chrome effluent. The production manager and the effluent section operator acknowledged challenges in effective treatment of chrome effluent. Chrome sludge blocks are non-biodegradable and hence accumulate fast into large quantities. The available disposal mechanism is discarding in dumpsites which does not only transfer pollution but also adds to the toxicity of dumpsites. The effluent section operator also mentioned that during storage of the dry chrome sludge blocks, they dissociate into fine dust that is sometimes blown off by wind. Knowing the toxic effects of chrome, he was afraid that the dust may cause harmful effects to the people in the tannery.

An informant from NEMA pointed out that the authority faces challenges in full enforcement of the set regulations. Poor and total lack of compliance to standards in the leather sector by tanneries and businessmen was brought up as a key subject. The regulatory body noted that some local tanneries do not entirely strive to meet the required legal limits for effluent discharge and altogether have poor solid waste management practices. This situation makes it problematic to have a workable foundation for agreeable improvement commitment plans with the tanneries.

There lies a general perception that the negative impacts of the leather sector outweigh the positive impacts. A key informant from the NEMA pointed to the fact that there is an imbalance in the economic versus social gains from the leather tanning sector. With the environmental perils still a glaring reality, the social costs to communities living around tanneries is higher compared to the economic benefit the sector contributes to the economy. Therefore, when it comes to enforcement of regulations, the first and automatic response is usually to close down the tanning establishments as opposed to gradual improvement towards compliance. This has led to many closures of tanneries in Kenya for example Leather Industries of Kenya and consequently slow growth of the leather sector in Kenya.

On the question on what are the challenges faced in ensuring proper management of the environment in reference to tannery effluent, an officer from Kenya Leather Development Council (KLDC) highlighted gaps in policy documents and development programmes that curtail proper guidance and implementation of environmental duties. The Hides, Skins and Leather Trade Act 1987 (Revised 2012) has provisions for licensing as well as regulations for quality and standards of the tanning process and leather products. The Act however fails on the waste treatment and disposal discourse. Similarly, effluent discharge regulations on industrial wastes hardly focus on how monitoring and treatment of hazardous waste will be carried out before discharge into the environment. Informants from NEMA all stated challenges in carrying out thorough inspection and monitoring of industrial activities. Scheduled or unscheduled monitoring of tannery effluents is not effectively done. Occasionally, NEMA as an authority relies on demand monitoring when there are upsets and disruptions like during demonstrations and uproar by the public. Even then, their response is at times slow and ineffective.

From the interview with a licensing department officer at NEMA, she agreed that NEMA's environmental discharge guidelines fall below comparable global standards with the back-end reason that they are tailored to match Kenya's economic, administrative and technological capacity and capability. Awash Basin Authority supports this idea and opines that unrealistic and non-enforceable regulations may do more harm than having no standards. It recommends that standards should be gradually tightened as the economic and technological capacity of a county progresses. However, the researcher agrees with Nur-E-Alam (2020) that strong environmental laws will compel industries to invent sustainable technologies to efficiently remedy hazardous pollutants below discharge guidelines. The monitoring guideline by NEMA also does not indicate as mandatory the monitoring of hexavalent chromium, lead, zinc and copper despite tanneries giving off significantly high levels of these toxic pollutants in the effluent.

A key informant from Kenya Industrial Research and Development Institute (KIRDI) and an officer from NEMA mentioned that there is lack of adequate personnel with specialized skills tailored for the leather sector who understand the primary issues causing the leather industry’s poor environmental performance. The informants from KIRDI and NEMA both pointed to the fact that tanneries and monitoring agencies do not have the human resource capacity that binds the science of tanning and leather production to effective wastewater treatment so as to satisfy legal requirements. Even with compliance assistance programmes, tanneries are still unable to meet specific discharge guidelines.

Impunity and corruption of industry players, challenges enforcement and the sustainability of the leather industry. EMCA requires tanneries to carry out effluent discharge quality and quantity monitoring as per methods and sampling procedures outlined by the authority and submit quarterly records. An officer from NEMA mentioned that some tanneries are crafty and that they collect and analyze samples from clean water sources like tap water. This gives results below guidelines while the establishments continue to discharge toxic effluent. In the same light, Wambugu (2020) gives an example of Leather Industries of Kenya that used to discharge effluent into river Chania in the morning and afternoon hours. After public outcry, they resorted to discharging at night thus by morning, no upsetting traces of pollutant residues could be found in the river. Other industries purely do not comply to standards and opt to bribe enforcement officers. These tanneries are also known to deny premise access to researchers and environmental organizations concerned with effluent standards and environmental quality. Such deceitful practices only tarnish the image of the leather industry and slow down efforts by government to develop the sector.

Opportunities

The Government of Kenya through its stakeholders and partnerships with environmental agencies have pro-environment and pro-economic plans to improve the leather sector. An informant from KLDC mentioned that to tackle pollution, the government is constructing a centralized industrial leather park at Kinanie where majority of the tanning activities will be conducted. This park will have a modern common effluent treatment plant that will handle waste water from all the establishments and treat it to standard. Nur-E-Alam (2020) mentions a similar project where upon realization of the impact of tannery wastes on humans and environment, the Bangladesh government decided to shift tanneries from Hazaribagh tannery complex to Savar tannery estate where all wastes coming from these tanneries would be treated in a common effluent treatment plant.

To enhance acquiescence to discharge guidelines, the licensing department officer from NEMA cited that the authority has a compliance assistance program that helps industries conform to standards and safeguard the environment. Partners like Kenya Cleaner Production are also involved where they provide advice on technological aspects of cleaner production for industries. Targets are set based on achievable discharge limits and the industries are given the opportunity for self-improvement in order to meet the goals. Proper implementation of this program within tanneries in Kenya will enhance sustainability and cleaner production of leather. As a result, conflicts between industries and the public will be minimized and the image of the sector will improve.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Summary of results

This study focused of the assessment of physico-chemical properties of Sagana Tanneries effluent and its effect on river Sagana water quality. From the results obtained, the effluent streams can be classified in order of toxicity as; chrome effluent stream > liming effluent stream > general water stream. The lowest pH concentration in the tannery effluent was in the chrome effluent stream (TC1) 4.37 while the highest was found in the chrome sedimentation tank (TC3) 9.97 (Table 4.4). The treated discharged effluent had a pH of 7.42 (Table 4.4) and was within the NEMA standards for industrial effluent discharged into surface water. In river Sagana, the lowest pH was 7.17 at the discharge point (TR2) while the topmost concentration was 1Km downstream (TR4) 7.32 (Table 5.4).

Analysis of COD showed that the highest level 6846 ppm was in TC1 (Table 4.4). The discharged effluent had 630 ppm of COD (Table 4.4) and therefore did not satisfy the set guidelines by NEMA. The river water exhibited the highest level of COD at TR2 412 ppm (Table 5.4). The peak concentration of BOD was found in TC1 which had 1254.3 ppm while that of the discharged effluent was 236.7 ppm (Table 4.4). The BOD released from the tannery was above Kenyan standards. River Sagana showed the most elevated level of BOD 209.1 ppm at TR2 (Table 5.4).

Nutrient pollution was as follows; largest amount of phosphorus (P) was 15.2 ppm in the chrome dry sludge (TC4), the effluent discharged from the facility had 5.2 ppm (Table 4.4) and this was above the legal standard in Kenya. In the river, the top toxicity level of 11.8 ppm of P was found 500M downstream (TR3) (Table 5.4). Elevated levels of nitrogen (N) were found in TC4 16000 ppm (Table 4.4). Nitrogen in the discharged effluent 53.5 ppm (Table

4.4) was found to be more than the NEMA Kenya discharge standard. River Sagana had the top amount of N at 1 Km downstream (TR4) 307 ppm (Table 5.4).

The highest levels of heavy metals were found in the chrome tank (TC2). Based on legal limits, the level of heavy metals in the discharged tannery effluent can be ranked in order of toxicity as lead > zinc > Chromium > Copper. The uppermost concentration of Chromium (Cr) was 43.2 ppm in TC2 (Table 4.4). The discharged effluent with 1.1 ppm of Cr (Table 4.4) was within NEMA standards. In the river water, the top amount of Cr was in TR4 at 3.35 ppm (Table 6.4). Lead (Pb) was found in highest toxicity in TC2 2.29 ppm while that of the discharged effluent was 0.07 ppm (Table 4.4). This was above discharge limits in Kenya. River Sagana had a peak Pb elevated level of 0.23 ppm in TR4 (Table 6.4).

Copper in the largest amount was detected at 4.42 ppm in TC4 and the discharged effluent satisfied the NEMA limits as it contained 0.41 ppm of Cu (Table 4.4). The river had the highest amount of Cu at the discharge point (TR2) 0.48 ppm (Table 6.4). The uppermost amount of Zinc (Zn) in the effluent was 12.6 ppm at TC4 while that of the discharged effluent 0.85 ppm (Table 4.4), was found to be higher than the prescribed NEMA discharge standards. In the river, the highest level of Cu was found in TR3 at 1.71 ppm (Table 6.4).

Pollution levels determined from the discharged effluent reveal that COD, BOD, Nitrogen, Pb and Zn were above the prescribed NEMA Kenya standards. This was despite a significant reduction in concentration during treatment. Based on the sample results, River Sagana is contaminated. The river water upstream is polluted and although it is free from tannery effluent, it contains high amounts of pollutants like heavy metals. However, the treated tannery effluent discharged into River Sagana still contributes to the direct pollution of the river.

5.1 Conclusion

The treated effluent from Sagana Tanneries does not satisfy the legal requirements for disposal into surface waters. Pollution of River Sagana is a reality and the disposal of effluent into the river is not safe since it alters the physicochemical properties thereby creating a harmful aquatic environment. The people residing downstream are also at risk of facing detrimental health effects due to the toxicity load of the discharged effluent even on dilution by the river.

The tannery uses conventional means to treat its effluent and has a well-organized treatment plant which contributes to the substantial reduction of toxic elements in the waste water. However, some elements still persist and are responsible for environmental degradation. There is an apparent lack of innovation, advanced and modern technology in the tannery that would have otherwise resulted in efficient treatment.

Inadequate capacity including human resource capacity of regulatory bodies like WRA, NEMA and the Kirinyaga County government is a challenge. This, coupled with the lack of essential scientific ability to set up laboratories for analysis results in inefficient and irregular monitoring. Some local tanneries then take advantage of this and release substandard effluent into the environment.

The environmental discharge guidelines by in Kenya fall below comparable global standards. Monitoring guidelines and schedules do not match international practice and therefore, this status does not nudge industries to invent sustainable technologies to efficiently remedy hazardous pollutants.

5.2 Recommendations

Research recommendations

Further research is recommended on the in-depth analysis of the chemical properties of leather manufacturing chemicals so as to investigate the source of heavy metals in tannery effluent.

Research should be conducted on the impact of chrome sludge disposal on the environment around dumpsites including the impact on ground water.

Management recommendations

The tannery should minimize wastewater production by recycling chrome baths and refining in-plant production processes as a priority over the traditional end of pipe treatment.

The tannery should remedy the chromium contamination of effluent within the treatment plant. Drainage channels should be reconstructed to ensure individual effluent streams, especially that from the chrome tanyard, does not mix with the other streams.

The excess water draining from the chrome dry beds should not be reverted to the general water tank as it contaminates the subsequent treatment stages.

The lime dry sludge should not be given to farmers for use as fertilizer until the tannery ensures that the sludge is free from heavy metal contamination.

The tannery should replace all the guard rails and access ladders around treatment ponds to minimize safety risks. The materials used should be resistant to weather, rust and the saline conditions in the treatment plant.

An environmental audit of all existing tanneries in Kenya should be conducted to help understand the current environmental status of the tanning industry.

Policy recommendations

Enforcement of existing regulations should be implemented by all responsible authorities and proper mainstreaming executed across all leather manufacturing establishments.

Policy documents should be reviewed and updated to incorporate specific environmental guidelines for the tanning industry as guided by technological research on cleaner production, effluent treatment and waste management.

REFERENCES

Abbas, S. H., Ismail, I. M., Mostafa, T. M., & Sulaymon, A. H. (2014). Biosorption of Heavy Metals: A Review. *Journal of Chemical Science and Technology*, *3*(4), 74-102.

Affiang, S. D., Ggamde, G., Okolo, V. N., Buba, M. A., & Pascallina, P. L. (2018). Environmental effects of the main constituents of tannery effluents (A Review). *American Journal of Engineering Research (AJER)*. Vol. 7, Issue 4, pp 210-214.

Ahmed, M. K., Das, M., Islam, M. M., Akter, M. S., Islam, S., & Al-Mansur, M. A. (2011). Physico-chemical properties of tannery and textile effluents and surface water of River Buriganga and Karnatoli, Bangladesh. *World Applied Sciences Journal*, *12*(2), 152-159.

Ahsan, M. A., Satter, F., Siddique, M. A. B., Akbor, M. A., Ahmed, S., Shajahan, M., & Khan, R. (2019). Chemical and physicochemical characterization of effluents from the tanning and textile industries in Bangladesh with multivariate statistical approach. *Environmental monitoring and assessment*, *191*(9), 1-24.

Al Sharabaty, R., & Sarsour, S. (2017). Leather Manufacturing Wastewater Characterization and Cleaner Production Options.

Ali, M., Naher, U. H. B., Chowdhury, A. M., Rahman, G. M., & Hasan, M. (2015). Investigation on Physicochemical Parameters of Tannery Effluent. *Universal Journal of Environmental Research & Technology*, *5*(3).

Amanial, H. R. (2015). Study on the pollution levels of trace metals from Modjo Tannery effluent in the surrounding river water and soil. *Science Journal of Analytical Chemistry*. Vol. 3, No. 5, pp. 56-60. doi: 10.11648/j.sjac.20150305.13

Amanial, H. R. (2016). Physico-chemical characterization of tannery effluent and its impact on the nearby river. *Journal of Environmental Chemistry and Ecotoxicology*, *8*(6), 44-50.

Aslan, A., & ÜZÜM, N. O. I. (2015). Determining the heavy metal contents of natural and artificial upholstery leathers. *Textile and Apparel*, *25*(1), 33-37.

Awash Basin Authority. (2018). The study of water use and wastewater discharge charge. Treated wastewater discharge charge. Final Report.

Ayers, R. S., & Westcot, D. W. (1985). *Water quality for agriculture* (Vol. 29, p. 174). Rome: Food and Agriculture Organization of the United Nations.

Bali, M., & Gueddari, M. (2019). Removal of phosphorus from secondary effluents using infiltration–percolation process. *Applied Water Science*. https://doi.org/10.1007/s13201-019-0945-5

Barakat, M. A. (2011). New trends in removing heavy metals from industrial wastewater. *Arabian journal of chemistry*, *4*(4), 361-377.

Batabyal, A. A., & Beladi, H. (2002). Aspects of the theory of environmental policy in developing countries. *Discrete Dynamics in Nature and Society*, *7*.

Baumol, W. J., & Oates, W. E. (1988). The Theory of Environmental Policy. *Cambridge University Press*.

Bedasa, T. B., & Assosa, E. (2017). Determination of the concentration of Pb, Cu, Cr, Zn and Cd in the wastewater (effluent) discharged from the Ethiopian Tannery. *Chemistry and Materials Research*, *9*(1), 19-25.

Bishnu, C. B., Hashem, A., & Juel, I. A. (2017). Tannery wastewater treatment using low cost coagulants with simple coagulation-filtration process. Engineering International. 5(2) DOI:10.18034/ei.v5i2.1084

Buljan J., & Kral I. (2011). Introduction to treatment of tannery effluents. UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION (UNIDO) Vienna.

Calheiros, C. S., Rangel, A. O., & Castro, P. M. (2013). Constructed wetlands for tannery wastewater treatment in Portugal: Ten years of experience. *International journal of phytoremediation*, *16*(9), 859-870.

Chowdhury, M., Mostafa, M. G., Biswas, T. K., Mandal, A., & Saha, A. K. (2015). Characterization of the effluents from leather processing industries. *Environmental Processes*, *2*(1), 173-187.

Czikkely, M., & Fogarassy, C. (2018). Urban wastewater management in focus of heavy metal contamination. YBL Journal of Built Environment. Vol. 6 No. 1, pp. 103-113 https://doi.org/10.2478/jbe-2018-0007

Dixit, S., Yadav, A., Dwivedi, P. D., & Das, M. (2015). Toxic hazards of leather industry and technologies to combat threat: a review. *Journal of Cleaner Production*, *87*, 39-49.

EPZA: SEA Process in the masterplan for the Leather Industrial Park-1st Draft 2015.

Ethiopian Standard, (2003). National Drinking water—specification, 2nd edition. Quality and Standards Authority of Ethiopia.

Faki, F. E., Musa, A. E., Gasmelseed, G. A., & Elamin, I. H. (2018) Recycling of spent chrome tanning liquor. *International Journal of Engineering and Applied Sciences (IJEAS).*

Fernandez-Luqueno, F., López-Valdez, F., Gamero-Melo, P., Luna-Suárez, S., Aguilera-González, E. N., Martínez, A. I., García-Guillermo, M.D.S., Hernández-Martínez, G., Herrera-Mendoza, R., Álvarez-Garza, M.A. & Pérez-Velázquez, I. R. (2013). Heavy metal pollution in drinking water-a global risk for human health: A review. *African Journal of Environmental Science and Technology*, *7*(7), 567-584.

Gemeda, F. T., Guta D. D., Wakjira F. S., & Gebresenbet, G. (2020). Physicochemical characterization of effluents from industries in Sabata town of Ethiopia. *Heliyon*. https://doi.org/10.1016/j.heliyon.2020.e04624

Graff-zivin, J., Krumholz, S., (2018). Environmental Policy-Making; Theory & Practice. Rockefeller Foundation Economic Council on Planetary Health. Available at https://www.planetaryhealth.ox.ac.uk/wp-content/uploads/sites/7/2018/06/Envtl-Policy-Making.pdf.

Gupta, K., Gaumat, S., & Mishra, K. (2012). Studies on phyto-genotoxic assessment of tannery effluent and chromium on Allium cepa. *Journal of Environmental Biology*, *33*(3), 557.

Gupta, K. S., Gupta, S., and Gayathiri, S. (2018), "“Pollution prevention” is the key to drive sustainability: Preliminary findings from a tannery unit in India", *Management of Environmental Quality*, Vol. 29 No. 3, pp. 416-426. https://doi.org/10.1108/MEQ-10-2017-0124

Gutterres, M., Benvenuti, J., Fontoura, J. T., & Ortiz-Monsalve, S. (2015). Characterization of raw wastewater from tanneries. *J. Soc. Leather Technol. Chem*, *99*(6), 280-287.

Hailu, T., Abebaw, A., & Minilu, D. (2018). Quantification of some physico-chemical characteristics of waste water effluent from Batu Tannery Industry at different batch, Addis Ababa, Ethiopia. *Journal of Environmental & Analytical Toxicology* 8: 592. doi:10.4172/2161-0525.1000592

Halim, M. A., Sumayed, S. M., Majumder, R. K., Ahmed, N., Rabbani, A., & Karmaker, S. (2011). Study on groundwater, river water and tannery effluent quality in southwestern Dhaka, Bangladesh: Insights from multivariate statistical analysis.

Hasan, M., Alam, M., Haque, M., Moly, H. H., & Tanji, M. (2021). Impacts of textile and leather effluent on environment: An assessment through life cycle of fishes and plants. *J. Text Eng. Fash Technol*, *7*(3).

Hasan, M. K., Shahriar, A., & Jim, K. U. (2019). Water pollution in Bangladesh and its impact on public health. *Heliyon*, *5*(8), e02145.

Hassen, A. S., & Woldeamanuale, T. B. (2017). Evaluation and characterization of tannery wastewater in each process at Batu and Modjo tannery, Ethiopia. *International journal of Rural Development, Environment and Health Research (IJREH)*, 1, 17-26.

Health Canada (2022). Guidelines for Canadian Drinking Water Quality—Summary Tables. Water and air quality bureau, healthy environments and consumer safety branch, health Canada, Ottawa, Ontario.

Herrera, M. J. A. (2020). Sustainable wastewater treatment systems (2018–2019). *Sustainability* doi:10.3390/su12051940.

Hu J., Xiao Z., Zhou R., Deng W., Wang M., Maa S. (2011). Ecological utilization of leather tannery waste with circular economy model. *Journal of Cleaner Production*, 19, 221-228.

Ingle, K. N., Harada, K., Wei, C. N., Minamoto, K., & Ueda, A. (2011). Policy framework for formulating environmental management strategy for sustainable development of tanneries in India. *Environmental health and preventive medicine*, *16*(2), 123-128.

Islam, S., Islam, F., Bakar, M. A., Das, S., & Bhuiyan, H. R. (2013). Heavy metals concentration at different tannery wastewater canal of Chittagong city in Bangladesh. *International Journal of Agriculture, Environment and Biotechnology*, 6 (3), 355-362.

Jacob, J. M., Karthik, C., Saratale, R. G., Kumar, S. S., Prabakar, D., Kadirvelu, K., & Pugazhendhi, A. (2018). Biological approaches to tackle heavy metal pollution: a survey of literature. *Journal of environmental management*, *217*, 56-70.

Jahan, M. A. A., Akhtar, N., Khan, N. M. S., Roy, C. K., Islam, R., & Nurunnabi, M. (2014). Characterization of tannery wastewater and its treatment by aquatic macrophytes and algae. *Bangladesh Journal of Scientific and Industrial Research*, *49*(4), 233-242.

Jemal A. F., Fangninou F. F., & Mwamba R. (2020). Effectiveness assessment of industrial effluent standard implementation in Addis Ababa City, Ethiopia. *International Journal of Scientific and Research Publications*. Volume 10, Issue 6. http://dx.doi.org/10.29322/IJSRP.10.06.2020.p10218

Juel, M. A. I., Chowdhury, Z. U. M., & Ahmed, T. (2016). Heavy metal speciation and toxicity characteristics of tannery sludge. In *AIP Conference Proceedings* (Vol. 1754, No. 1, p. 060009). AIP Publishing LLC.

Kedlaya, K. J., & Santappa, M. (1974). Phosphorous compounds in leather industry. *Leather Science*, *21*, 75-80.

Kenya National Bureau of Statistics. (2019). 2019 Kenya Population and Housing Census Volume I: Population by County and Sub-County.

Kihonge, E. (2014). Le rôle des petites et moyennes entreprises (PME) des petites villes dans les relations villes-campagne: étude de cas de Sagana et Karatina, région du Mount Kenya (Kenya) (Doctoral dissertation).

Kumar, S., Yadav, A., Maurya, A., Pratap, S. G., Singh, P. K., & Raj, A. (2022). Characterization of tannery effluents by analyzing the recalcitrant organic pollutants and phytotoxicity assay *Journal of Applied Biology & Biotechnology*. 10 (2) Pp 91-99. DOI: 10.7324/JABB.2022.10s210

Kuzhali, S. S., Kadan, N. M., & Kumuthakalavalli, R. (2012). Biosorption of heavy metals from tannery effluent by using macrofungi. *Elixir International Journal*, 47.

Madanhire, I., & Mbohwa, C. (2015). Investigation of waste management practices and cleaner production application in a tannery: case study.

Mbui, D., Chebet, E., Kamau, G., & Kibet, J. (2016). The state of water quality in Nairobi River, Kenya. *Asian Journal of Research in Chemistry*, *9*(11), 579.

Mekonnen, B., Seyoum, L., & Mohammed, M. K. (2017). Treatment of tannery wastewater to remove hazardous pollutants by scoria (Volcanic ash) a low-cost adsorbent. *International Journal of Environment, Agriculture and Biotechnology*, Vol-2, Issue-6.

Minas, F., Chandravanshi, B. S., & Leta, S. (2017). Chemical precipitation method for chromium removal and its recovery from tannery wastewater in Ethiopia. *Chemistry International*, *3*(4), 291-305.

Mohammed, S. S. D., Orukotan, A. A., & Abdullahi, H. (2017). Physicochemical and Bacteriological Assessment of Tannery Effluent from Samaru-Zaria, Kaduna State, Nigeria. *Journal of Applied Sciences and Environmental Management*, *21*(4), 734-740.

Muchiri, E. (2019). Effects of Work-Related Stress on Alcoholism Among Student Nurses in Sagana Sub-County Hospital in Kirinyaga County Kenya. (Doctoral dissertation, Pan Africa Christian University).

Muhammad, A., Rakhshan, K., Ikhtiar, K., & Asma, S. (2015). Effect of heavy metals from tannery effluent on the soil and groundwater using multivariate analysis in district sheikhupura, Pakistan. *Research Journal of Chemistry and Environment*, 19(1), 48-55.

Munyagia, S. M. (2017). Criminal Gangs and Their Socio-economic Effects on Micro and Small Enterprises (Mses) in Kenya- a Case of Mungiki Gang in Kirinyaga County, Central Kenya. [Master's thesis].

Mwinyihija, M., Strachan, N. J., Meharg, A., Killham, K., and Aberdeen, A. (2005). Ecological risk assessment of the Kenyan tanning industry. *J Am Leather Chem Assoc*, 100, 380-395.

Nabila, T. I., & Ibrahim, S. (2019). Physico-chemical properties of tannery effluents from Challawa industrial area in Kano and evaluation of bioremediation potentials of *Spirogyra porticalis* and *Chlorella vulgaris* on the effluents. *Bayero Journal of Pure and Applied Sciences,* 12(1): 156 - 161 ISSN 2006 – 6996.

Naidansuren, E., Dondog, A., Erdenesaikhan, B., & Byambanyam, E. (2017). Heavy metal pollution near a tannery in Ulaanbaatar, Mongolia. *Journal of Health and Pollution*, *7*(16), 2-11.

National Environment Regulations. (2020). Standards for Discharge of Effluent into Water or Land) Regulations, Kampala, Uganda.

Ni'mah, S. A., Setiani O., & Suhartono. (2021). Spatial analysis of Gandong River water pollution from leather industry at Magetan district. *International Journal of Health, Education & Social (IJHES)*, *4*(7), 1-12.

Nithya, R., & Sudha, P. N. (2017). Removal of heavy metals from tannery effluent using chitosan-g-poly (butyl acrylate)/bentonite nanocomposite as an adsorbent. *Textiles and Clothing Sustainability*, *2*(1), 7.

Noorjahan, C. M. (2014). Physicochemical characteristics, identification of bacteria and biodegradation of industrial effluent. *Journal of Bioremediation and Biodegradation*, *5*(3).

Nur-E-Alam, M., Abu, S. M. M., Ahmad, F., & Mafizur, R. M. (2020). An overview of chromium removal techniques from tannery effluent. *Applied Water Science*. https://doi.org/10.1007/s13201-020-01286-0

Nyabaro, O. M. (2013). Pollutant levels in waste water from tannery effluent: A (Doctoral dissertation). University of Eldoret.

Nyabaro, O. M., Mosoti, D., Muthoka, T. M., & Onyancha, E. (2013). Determination of Pollution Levels of Waste Water from Nakuru Tanners, Kenya. *African Journal of Education, Science and Technology*, *1*, 200-210.

Odhiambo, J., Yusuf, A., & Onyatta, J. (2016). Assessment of selected parameters for industrial effluents from some industrial sites in Nairobi, Kenya.

Oruko, R. O., Odiyo, J. O., & Edokpayi, J. N. (2018). Chromium tanning, management challenges and environmental legislation in Sub Saharan African tanneries.

Paltahe, A., Cornelius, T., Sambo, B., Christian, D., Teri, T., Rallet, D., & Wahabou, A. (2019). Physico-Chemical Characterization of Local Tannery Waste Water Before and After Flocculation Treatment. *International Journal of Chemistry*, *11*(2), 77-85.

Parveen, S., Bharose, R., & Singh, D. (2017). Assessment of physico-chemical properties of tannery waste water and its impact on fresh water quality. *International Journal of Current Microbiology and Applied Sciences*, *6*(4), 1879-1887.

Republic of Kenya. (2000). Environmental Management and Coordination Act, No 8 of 1999. Government Printer, Nairobi.

Republic of Kenya. (2006). Environmental Management and Co-ordination (Water Quality) Regulations. Legal Notice No. 120. Kenya Gazette supplement No. 68.

Robertsson, J., & Andersson, C. (2014). Characterization and removal of heavy metals in tannery effluents through the use of local materials.

Rwanda standards Board. (2018). Water quality - Irrigation water -Tolerance limits.

Rwanda Water and Forestry Authority. (2019) Water quality monitoring in Rwanda phase II final report (February – March 2019).

Schütz, J. (2013). Water quality in Malawi.

Saeed, T., Afrin, R., Muyeed, A. A., & Sun, G. (2012). Treatment of tannery wastewater in a pilot-scale hybrid constructed wetland system in Bangladesh. Chemosphere 88:1065-1073.

Saha, B., & Azam, F. A. B. (2021). Probable Ways of Tannery's Solid and Liquid Waste Management in Bangladesh - An Overview. *Textile & Leather Review*. 4(2):76-95. https://doi.org/10.31881/TLR.2020.25

Sawalha, H., Al-Jabari, M., Elhamouz, A., Abusafa, A., & Rene E. R. (2020). Tannery wastewater treatment and resource recovery options. *Waste Biorefinery*. https://doi.org/10.1016/B978-0-12-818228-4.00025-3

Shaibu A. N., & Audu A. A. (2019). Evaluation of physiochemical parameters and some heavy metals from tannery effluents of Sharada and Challawa Industrial Areas of Kano State, Nigeria. *Nigerian Journal of Basic and Applied Science*. 27(2): 162-171 DOI: http://dx.doi.org/10.4314/njbas.v27i2.22

United Nations Environment Programme Global Environment Monitoring System. (2008). Water Quality for Ecosystem and Human Health, 2nd Edition. ISBN 92-95039-51-7

United Nations Industrial Development Organization (1994). Regional hides and skins, leather and leather products improvement scheme. Terminal report.

United Nations Industrial Development Organization. (2011). Introduction to treatment of tannery effluents. Vienna.

United Republic of Tanzania. (2007). The environmental management (water quality standards) regulations.

United States Agency for International Development. (1999). Revision of law 48 of 1982 for the protection of the Nile River and its waterways from pollution. *Tranche III Water Benchmark C8 Report.*

Wambugu E. W. (2020). Analysis of barriers to the enforcement of hazardous waste regulations in the leather industry: A case study of Thika industrial area, Kiambu county, Kenya.

Wang, J. (2018, December). Reuse of Heavy metal from industrial effluent water. In *IOP Conference Series: Earth and Environmental Science* (Vol. 199, No. 4, p. 042002). IOP Publishing.

Water Services Regulatory Board – Drinking Water Quality and Effluent Monitoring Guideline.

Whitehead, P. G., Bussi, G., Peters, R., Hossain, M. A., Softley, L., Shawal, S., Jin, L., Rampley, C. P. N., Holdship, P., Hope, R., & Alabaster, G. (2019). Modelling Heavy Metals in the Buriganga River System, Dhaka, Bangladesh: Impacts of Tannery Pollution Control. *Science of the Total Environment*, *697*, 134090.

World Health Organization. 2017. Guidelines for drinking-water quality: Fourth edition incorporating the first addendum. Geneva. Licence: CC BY-NC-SA 3.0 IGO.

Wosnie, A., & Wondie, A. (2014). Bahir Dar tannery effluent characterization and its impact on the head of Blue Nile River. *African Journal of Environmental Science and Technology*, *8*(6), 312-318.

Yusif, B. B., Bichi, K. A., Oyekunle, O. A., Girei, A. I., Garba, P. Y., & Garba, F. H. (2016). A Review of Tannery Effluent Treatment. *International Journal of Applied Science and Mathematical Theory*, *2*(3), 29-43.

Zhao, M., Xu, Y., Zhang, C., Rong, H., & Zeng, G. (2016). New trends in removing heavy metals from wastewater. *Applied microbiology and biotechnology*, *100*(15), 6509-6518.

Zhao, C., & Chen, W. (2019). A review for tannery wastewater treatment: some thoughts under stricter discharge requirements. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-019-05699-6

APPENDICES

Appendix 1: Key informant questionnaire

Industry managers

1. How do you ensure the proper management of effluent with priority to water pollution?
2. What are the challenges faced in effluent management?
3. How do you evaluate the efficiency of your adopted treatment process?
4. What external factors/plans would help to have better management of tannery effluent (short term and long term)

Environment and development officers

1. What is your capacity to ensure proper management and monitoring of proper tannery effluent environmental guidelines?
2. What are the challenges faced in ensuring proper management of the environment in reference to tannery effluent?
3. What can be done to improve the current environmental situation in regards to tannery effluent?
4. What is your view on the environmental sustainability of the current leather sector development in Kenya?

Appendix 2: Effluent discharge guidelines

Table 7: Effluent discharge guidelines by environmental bodies in different countries

STANDARD	**pH**	**COD (mg/L)**	**BOD (mg/L)**	**P (mg/L)**	**N (mg/L)**	**Cr. T (mg/L)**	**Pb (mg/L)**	**Cu (mg/L)**	**Zn (mg/L)**	**Reference**
NEMA Kenya	6.5 - 8.5	50	30	2	2	2	0.01	1	0.5	
Uganda	5.0 - 8.5	70	50	5	10	0.5	0.1	0.5	2	
EPA (Ethiopia)	6.0 - 9.0	500	200	10	60	0.1	-	-	-	Amanial (2016), Hassen & Woldeamanuale (2017)
France	6.5 - 8.5	125	30	-	30		-	-	-	UNIDO (2011)
India	5.5 - 9.0	250	30	-	-	2	-	-	-	UNIDO (2011)
Italy	5.5 - 9.5	160	40	-	-	2	-	-	-	UNIDO (2011)
Bangladesh	6.0 - 9.0	200	50	8 - 15.0	100	0.5	0.1	0.5	5	Ali *et al.*, (2015)
India BIS	5.5 - 9.0	250	30	1	100	2	0.1	3	5	Parveen *et al.*, (2017), Gemada *et al.*, (2020)