THE CONTAMINATING EFFECTS OF COFFEE PROCESSING HONEY WATER, CASE OF OTHAYA COFFEE SOCIETY, NYERI COUNTY, KENYA

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A Thesis Submitted to the School of Science and Technology in Partial Fulfillment of the Requirements for the Conferment of the Degree of Master of Science in Agriculture and Rural Development of Kenya Methodist University.

SEPTEMBER, 2024

DECLARATION

I declare that this research thesis is my original work and has not been presented for a degree or other award from any other university.

Signed.. Date..

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RECOMMENDATION

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

Signed…………………………………………………. Date...

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Signed………………….. Date...

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DEDICATION

I dedicate this research study to my beloved father, whose unwavering support and boundless inspiration have been the driving force behind my academic journey.

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ABSTRACT

The release of untreated honey water from green coffee processing poses a significant threat to surface water contamination, directly impacting the livelihoods of downstream communities. This study aimed to evaluate the contaminating effects of honey water emissions from coffee processing on surface waters. Specifically, the study sought to determine the levels of contaminants in honey water from coffee processing, assess the degree of pollution caused by these emissions, and examine the socio-economic impacts on affected populations. A mixed-methods research design was employed for this study. The research site was divided into experimental units, with four blocks (I–IV) and three treatments (K–M) per block, each containing three sub-samples (1–3). To minimize variability across tests from the same target area, the study employed a total squares randomized design with four combined replicates to create a test turnover table, which was used to determine variability between test objectives ($p < 0.05$). The study collected a total of sixteen samples: twelve surface water samples from upstream, midstream, and downstream locations, and four untreated honey water samples from coffee processing lagoons. The physicochemical properties of these samples were thoroughly analyzed. In addition, the study incorporated qualitative data through open and closed-ended questionnaires. Descriptive statistics were used to analyze responses from 79 members of the Othaya Coffee Society Management and 30 nearby households, focusing on their perceptions of the contaminating effects of honey water on surface waters. The findings revealed that coffee processing operations by the Othaya Coffee Society had detrimental effects on the local communities by polluting nearby surface waters with untreated coffee waste. The physicochemical analysis indicated that the water sources had elevated acidity, high organic matter content, increased chemical oxygen demand, and elevated concentrations of nutrients (nitrates, phosphates), as well as suspended solids—all of which contributed to deteriorating water quality. The analysis further confirmed that the effluents discharged by the wet coffee processing industry did not meet the World Health Organization's standards for treated effluent released into surface waters. Based on these findings, the study recommended that the Othaya Coffee Society and other coffee industries in the region implement proper wastewater treatment facilities to ensure that only treated effluent is discharged into water bodies. Furthermore, continuous enforcement of wastewater discharge regulations by authorities such as the National Environmental Management Authority is essential. The study also called for further research to examine the effects of coffee pulp on water contamination and to evaluate the role of urban planning policies in managing industrial wastewater in areas like Othaya town.

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ABBREVIATIONS

AFA-CD	Agriculture and Food Authority-Coffee Directorate
ANOVA	Analysis of Variance
APHA	American Public Health Association
CIDP	County Integrated Development Plan
EMCA	Environmental Management and Coordination Act
ICO	International Coffee Organization
GIS	Geographical Information System
GPS	Global Positioning System
KALRO-CRI	Kenya Agricultural and Livestock Research Organizations-Coffee Research Institute
KNBS	Kenya National Bureau of Statistics
NACOSTI	National Commission for Science, Technology & Innovation
PASW	Predictive Analytic Software
SDG	Sustainable Development Goals
UNEP	United Nations Environmental Programme
WARMA	Water Resources Management Authority
WHO	World Health Organization
WWAP	World Water Assessment Programme

CHAPTER ONE

INTRODUCTION

1.0 Background of the Study

Surface water contamination is a critical issue worldwide, driven by both natural and human-induced factors. Global warming has intensified this problem by altering weather patterns, leading to droughts and floods that deplete and degrade the quality of lakes, rivers and other vital surface water bodies. Additionally, human activities such as industrial agriculture, urbanization and mining have dramatically increased the contamination of these resources. Bisekwa et al. (2021) emphasized that while water is fundamental to human welfare and economic development, these activities continue to pollute water bodies globally posing serious risks to human health, aquatic life, and ecosystem sustainability.

In Africa and particularly in countries like Kenya, industrial effluents from coffee processing, manufacturing and poor agricultural practices significantly contribute to surface water contamination. Tonui (2018) highlights that the absence of adequate wastewater management systems in urban centers results in the indiscriminate discharge of industrial waste into rivers and lakes, further exacerbating contamination issues. This problem is compounded by the limited adoption of environmentally friendly technologies designed to mitigate the release of harmful industrial effluents.

Agriculture, a crucial driver of economic growth is also one of the largest sources of surface water contamination. Globally, agriculture accounts for approximately 70% of surface water contamination, with chemical runoff from fertilizers and pesticides serving as major contaminants. This agricultural pollution not only affects water quality but also has cascading effects on biodiversity and ecosystem health. Similarly, industrial activities such as coffee processing, contribute significantly to water contamination by releasing organic and chemical pollutants that degrade water quality, harm aquatic ecosystems and pose health risks to local populations (United Nations Environmental Programme [UNEP], 2016).

The impact of contaminated surface water extends beyond environmental degradation; it has profound socioeconomic implications. Communities that rely on contaminated water sources for drinking, irrigation and fishing face heightened health risks, including waterborne diseases and reduced agricultural productivity. These factors can lead to economic instability and decreased quality of life for affected populations. In Kenya for instance, downstream communities that depend on rivers for their livelihoods are particularly vulnerable to the adverse effects of untreated industrial effluents.

Recognizing the severity of this issue, the 2030 Agenda for Sustainable Development (SDG 6.3) has set a global target to improve water quality by reducing contamination and eliminating the dumping of hazardous materials into surface waters by 2030. This goal reflects the international community's commitment to tackling water contamination and protecting surface water resources. However, achieving this target requires stronger national policies, particularly in developing countries, to regulate industrial discharges and promote sustainable agricultural practices.

1.1 Coffee Farming in Kenya

Coffee is a cornerstone of Kenya’s agricultural sector, playing a crucial role in the country’s economic development through its significant contributions to foreign exchange earnings, livelihoods for family farmers, job creation and food security (Agriculture and Food

Authority - Coffee Directorate [AFA-CD], 2021). Annually, the coffee sector generates approximately Kshs 23 billion in foreign exchange, making it Kenya's fourth-largest export earner after tourism, tea and horticulture (International Coffee Organization [ICO], 2021). This vital sector not only bolsters the economy but also serves as a lifeline for many rural households, where coffee farming is a primary source of income.

Recognizing the coffee sub-sector's strategic importance, the Kenyan government has integrated its development into the Vision 2030 blueprint and the Big 4 Agenda (AFA-CD, 2021). These frameworks aim to transform the country's economy through key sectors such as manufacturing, agriculture, healthcare and affordable housing, with coffee being a pivotal element in achieving these goals. The government's focus on enhancing coffee production includes improving research and development, promoting value addition, and facilitating access to international markets.

The history of coffee cultivation in Kenya dates back to 1893, when it was first introduced by missionaries in Bura, Taita Hills, before expanding to Kibwezi (AFA-CD, 2021). Over the years, coffee farming has evolved from small-scale subsistence farming to a more organized and structured sector. Coffee is now cultivated on approximately 119,675 hectares across 33 counties, reflecting the crop's adaptability to diverse environmental conditions, particularly in high-potential regions with optimal growing climates.

Kenyan coffee thrives in areas with altitudes ranging from 1,400 to 2,200 meters above sea level, where temperatures typically range between 15°C and 24°C. The ideal soils are deep, fertile, and well-drained, largely of volcanic origin, contributing to the unique flavor profiles and high quality of Kenyan coffee. These geographical and climatic conditions create a suitable environment for coffee cultivation, making it a sought-after commodity on the global market.

Arabica coffee accounts for over 99% of Kenyan coffee production, with main varieties including Scotland Laboratory 28, Scotland Laboratory 34, Kenya 7, Ruiru 11, Batian, and Blue Mountain (AFA-CD, 2021). These varieties are well-adapted to Kenya's highland climate and are highly prized worldwide for their superior quality, characterized by rich flavor profiles, bright acidity and a full-bodied texture. Kenyan coffee is often noted for its wine-like qualities, with unique taste notes that can include fruity, floral, and citrus flavors, further enhancing its desirability among coffee connoisseurs.

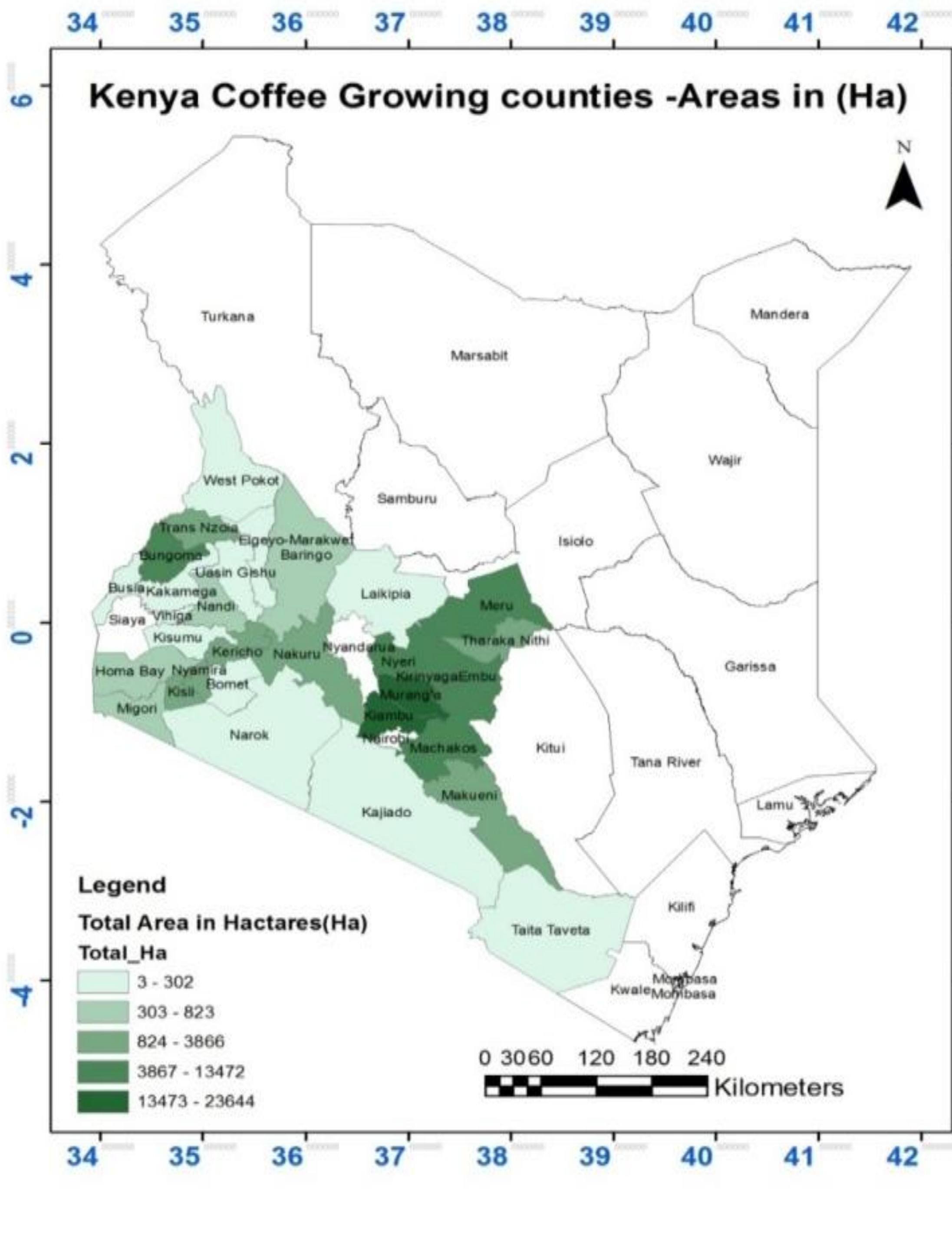
The high value of Kenyan coffee in the global market often commands premium prices due to its distinct taste and meticulous processing. The reputation of Kenyan coffee is further enhanced by stringent quality controls and the traditional methods of harvesting and processing, which include hand-picking ripe cherries and employing wet processing techniques that preserve the beans’ unique characteristics. These practices not only ensure high quality but also contribute to the overall sustainability of coffee production in the region.

Kenyan coffee production operates under two primary systems: Smallholder Farmers-organized into cooperative societies, smallholder farmers are responsible for a significant portion of national coffee production. These farmers typically own small plots of land and primarily rely on rain-fed agriculture. Cooperative societies play a vital role in providing these farmers with access to essential resources, including training, quality control and marketing opportunities. This organizational structure allows smallholders to pool their resources, improving their bargaining power and ensuring better prices for their coffee. These cooperatives also enhance the farmers' knowledge and skills through training programs focused on sustainable farming practices and quality improvement.

Private Estates-larger, privately owned coffee estates tend to adopt more modern farming techniques, including the use of irrigation systems to ensure a consistent water supply for both cultivation and processing (KALRO-CRI, 2017). These estates often invest in advanced agricultural practices and technologies that increase productivity and improve the quality of the coffee produced. However, the reliance on irrigation can lead to significant water demands, raising concerns about sustainability and resource management (AFA-CD, 2021). As the global demand for coffee continues to rise, balancing productivity with environmental stewardship becomes increasingly critical to ensure the long-term viability of the coffee sector.

Figure 1.1

Map of Coffee Growing Counties in Kenya



1.2 Coffee Processing and Surface Water Contamination

12.1 Coffee Processing

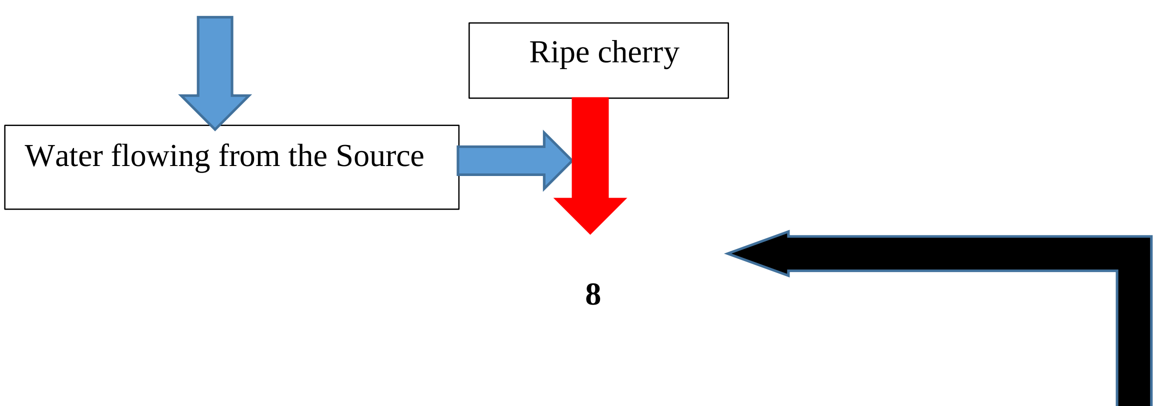
In Kenya, about 91% of the coffee produced undergoes wet processing, also known as pulping, which takes place in coffee refineries managed by cooperatives and plantation estates. The remaining 9% of the coffee is processed as dried Buni, which involves minimal water use. There are approximately 500 cooperative societies that operate around 1,010 washing stations, while estate plantations manage about 3,030 washing stations. Collectively, these stations process an average of 45,000 metric tons of clean coffee annually (AFA-CD, 2021). These washing stations are predominantly located near rivers and water bodies due to the high water requirements of coffee processing (KALRO-CRI, 2017). During the harvesting process, ripe coffee cherries are carefully hand-picked from the coffee trees.

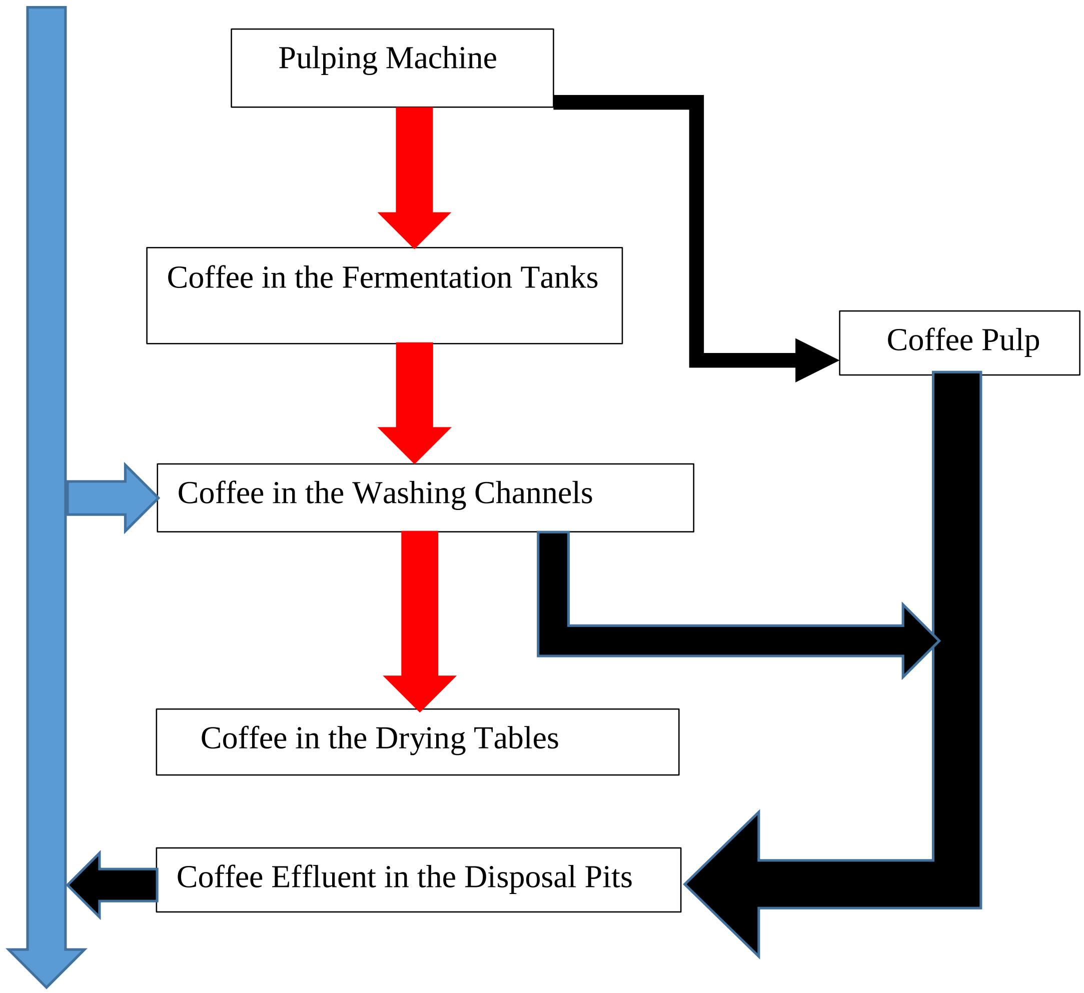
Selective harvesting ensures that only ripe berries are collected, which contributes to the quality of the final coffee product by separating them from unripe or diseased cherries (KALRO-CRI, 2017). Once the cherries are harvested, about 22,500 liters of clean water are used to pulp 1,000 kilograms of the outer red skin (pulp) from the beans. Inside the pulping machine, screens are used to separate the coffee beans from partially pulped cherries. After pulping, the beans, now called parchment, are separated through water density grading using the law of flotation. They are divided into different grades, including parchment 1, 2, 3, and lights, in various water-filled compartments. Even at this stage, the parchment beans still retain a silver skin layer, known as mucilage, which gives the coffee its sweet and honey-like qualities.

To remove the mucilage, the beans undergo a fermentation process that lasts between 24 to 36 hours. During fermentation, natural enzymes break down the sugars and pectin in the mucilage into acids, gases, and alcohols, which contribute to the coffee's characteristic wine-like taste (KALRO-CRI, 2017). The wastewater produced during this stage, known as "coffee processing honey water," is directed into waste disposal pits called lagoons. These lagoons are designed to handle the coffee honey water as a by-product, but they are often inadequately constructed. In periods of peak coffee processing, the lagoons may overflow, leading to significant surface water contamination, which poses environmental risks. The wet parchment beans, which still contain about 57% moisture content, are then dried either in the sun or through mechanical means to reduce their moisture level to between 10.5% and 12.5%. Sun-drying, a traditional method, involves spreading the beans on wooden or metallic drying tables. These tables are typically covered with polythene sheets to protect the coffee from re-wetting due to unexpected rainfall, helping to maintain the overall quality of the beans. However, the poor design of waste disposal pits continues to be a critical challenge in preventing contamination of water resources during the coffee processing cycle (See Figure 1.2).

Figure 1.2

States in the primary coffee processing chain





Key for the Arrows.

- Coffee flowing from the cherry hopper.

- Water flowing from the source

- Coffee effluent flowing back to the source of water

1.2.1 Surface Water Contamination

Coffee processing honey water, also known as coffee effluent, contains a range of contaminants that are potentially harmful to the environment (Bisekwa et al., 2021). The main pollutants found in this water include: High organic load: Coffee honey water contains organic matter from coffee pulp, mucilage, and skin, leading to elevated Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels. Acidity: Coffee effluent is often acidic (pH 4-5), which can lower the pH of receiving water bodies, leading to harmful conditions for aquatic life. Toxic compounds: Compounds like tannins, caffeine, and polyphenols can be toxic to aquatic organisms. Nutrients: Nitrogen and phosphorus in the effluent can lead to nutrient pollution, promoting eutrophication in surface waters. Suspended solids: These normally increase water turbidity and reduce light penetration, affecting aquatic ecosystems.

The discharge of untreated coffee honey water into surface water bodies can have several adverse effects, including: Oxygen depletion: The high BOD and COD from organic matter lead to reduced dissolved oxygen in surface water, creating hypoxic conditions that threaten fish and other aquatic life. Eutrophication: Excess nutrients, such as nitrogen and phosphorus, promote the growth of algae and aquatic plants. As algae die and decompose, they further reduce oxygen levels, exacerbating the problem (Workinesh, 2017). Water pH alteration: The acidity of honey water can lower the pH of rivers and streams, making the environment hostile for many aquatic organisms and altering ecosystem balance. Toxicity to aquatic organisms: The presence of tannins, polyphenols, and caffeine in honey water can be directly toxic to fish and other aquatic species, leading to reduced biodiversity and ecosystem collapse. Sedimentation and turbidity: Suspended solids in the honey water can increase the turbidity of surface waters, reducing sunlight penetration and impacting photosynthesis in aquatic plants.

The discharge of untreated coffee honey water has direct and indirect effects on downstream populations, especially in regions where communities rely on surface waters for drinking, agriculture, and daily use (Tesfalem et al., 2017). These include: Public health risks: Contaminated water sources increase the risk of waterborne diseases, particularly if communities use the affected water for drinking, bathing, or irrigation. Impact on agriculture: Farmers who rely on surface water for irrigation may face reduced crop yields due to poor water quality, particularly if the water is acidic or contains high levels of contaminants. Livelihoods: Fisheries may be severely impacted by reduced fish populations due to hypoxic conditions and toxic contaminants, threatening the livelihoods of communities dependent on fishing. Water availability: Water sources contaminated by coffee effluent may become unusable for households, forcing communities to seek alternative, possibly more expensive, water sources.

To mitigate the harmful effects of coffee honey water on surface waters, the following measures can be implemented (Minuta et al., 2017). Effluent treatment systems: Installing treatment facilities to process honey water before discharge can significantly reduce its contaminant load. Common treatment methods include anaerobic digestion, aerobic treatment, and filtration to lower BOD, COD, and nutrient levels. Constructed wetlands: These natural systems filter contaminants from effluent through vegetation and soil. Wetlands reduce organic load and nutrients, improving water quality before effluent enters surface water bodies. Water recycling and reuse: Recycling water within the coffee processing plant can minimize the amount of honey water generated, reducing the need for large-scale discharge. Bioremediation: Using biological organisms, such as algae or bacteria, to degrade harmful compounds in coffee effluent. This method can reduce toxicity and improve the overall quality of the effluent. Improved processing methods: Transitioning to less water-intensive methods, such as dry or semi-dry coffee processing, can drastically reduce the volume of honey water produced, thus lowering the overall environmental impact.

1.3 Statement of the Problem

Othaya in Nyeri County, Kenya, is a hub for industries like tea, horticulture, aquaculture, and notably, coffee production, which is crucial to the local economy. However, coffee processing generates untreated coffee honey water, a byproduct that poses a serious environmental threat when released into local water bodies. This effluent contaminates surface waters, impacting communities that rely on these resources for their livelihoods.

The honey water contains nitrogenous and phosphoric compounds that lead to eutrophication, triggering algal blooms and depleting oxygen in the water, which harms aquatic ecosystems. This degradation of water quality disrupts fishing and other water-based activities. Additionally, nitrates and ammonium in the effluent contribute to global warming by releasing greenhouse gases and pose health risks, such as blue baby syndrome, when high levels of nitrates contaminate drinking water.

While industrial effluents have been widely studied, the specific impact of coffee honey water on water resources remains a critical challenge, especially in Kenya. This study aims to assess the extent of contamination from untreated coffee honey water by the Othaya Coffee Society and propose mitigation strategies to protect both the environment and public health in the region.

1.4 Objectives of the Study

1.4.1 General Objective

To assess the effects of coffee honey water on surface water, focusing on the extent of contamination and its environmental and health consequences.

1.4.2 Specific Objectives

The specific objectives of the study were:

1. To determine the level of contaminants contained in coffee processing honey water.
2. To evaluate the impact of coffee honey water on the quality of surface water.
3. To examine the socioeconomic effects to the downstream population from discharge of raw coffee honey water.
4. To identify and propose effective measures to reduce the contaminating effects of coffee honey water.

1.5 Justification of the Study

The study focused on minimizing the contaminating effects of coffee processing honey water on surface water and its effects on downstream communities, addressing a critical environmental and public health issue. Given the significant role of coffee processing in Kenya's economy, the research established a comprehensive baseline for assessing the level of contaminants present in coffee honey water, which is a byproduct of coffee processing that, if left untreated, can pose severe risks to both the environment and human health.

By quantifying the levels of pollutants such as carbohydrates, proteins, and fibrous compounds in coffee honey water, the study provided vital insights into the organic load discharged into nearby water bodies. Understanding these concentrations is essential for assessing their potential impact on surface water quality. The research employed various methodologies, including physical and chemical assessments, to analyze key parameters like pH, oxygen demand, and total suspended solids. These metrics serve as critical indicators of water health and are instrumental in evaluating how the discharge of untreated coffee processing byproducts affects local ecosystems.

The research also delved into the socioeconomic consequences of discharging untreated coffee honey water into the environment. Communities downstream often rely on these water sources for drinking, irrigation, and fishing, making them particularly vulnerable to water contamination. The study highlighted how the degradation of water quality could lead to serious public health issues, including the risk of waterborne diseases, as well as economic repercussions for local livelihoods tied to agriculture and fishing. With many families depending on these activities for their sustenance and income, the findings underscored the urgent need for effective management practices.

The findings were instrumental in formulating strategies to mitigate further socioeconomic and environmental harm caused by the contamination of surface water. Recommendations included implementing sustainable wastewater treatment methods, such as sedimentation, filtration, and biological treatments, to reduce the pollutant load in coffee processing honey water before discharge. These measures not only aim to protect water quality but also enhance community health and economic resilience by ensuring the availability of safe water for consumption and agricultural use.

Furthermore, the study emphasized the importance of adopting best management practices within coffee processing operations. Training farmers and processors on environmentally friendly techniques and technologies can significantly minimize the generation of wastewater and its associated contaminants. Regular monitoring and compliance with established health guidelines are essential for maintaining water quality and safeguarding public health.

1.6 Research Questions

The study answered the following questions:

i. What could be the level of contaminants contained in coffee processing honey water?

ii. What could be the impact of coffee honey water on the quality of surface water?

iii. What could be some of the socioeconomic effects caused by discharge of raw coffee processing honey water to the population?

iv. What measures could be undertaken to reduce contaminating effects generated through discharge of raw coffee honey water?

1.7 Limitations of the Study

Some respondents, particularly industry owners and workers, initially showed reluctance, which could have hindered the study's progress by impeding the acquisition of relevant information and sample collection. However, the researcher successfully gathered sufficient data by clearly articulating the study's objectives and assuring respondents of the confidentiality of their information. The study was confined to residents living in areas where Othaya coffee society washing stations were situated. Additionally, it focused solely on one sampled Coffee Society out of the twenty-five coffee societies in Nyeri County. Time constraints posed limitations on data collection, as the coffee harvesting period occurs seasonally between April and June and between October and December. Nonetheless, the researcher managed to collect data diligently during these periods. A language barrier also presented a challenge; however, the researcher overcame this obstacle by training a native individual from the area to serve as a data collection assistant, facilitating communication and data collection efforts.

1.8 Delimitations of the Study

In the study, qualitative data was collected from respondents residing within the catchment area of the Othaya Coffee Society. Quantitative data collection employed a Randomized Complete Block Design, whereby units were blocked to minimize variations. The study focused on a study population comprising 100 respondents, ensuring a balanced approach to both quantitative and qualitative data collection methodologies.

1.9 Significance of the Study

It is anticipated that the findings of this study would enrich the existing pool of knowledge on the subject. These findings are poised to provide valuable insights to responsible institutions both within Othaya and across Kenya, enabling them to make informed decisions regarding the levels of contaminants stemming from untreated coffee honey water discharged into the River Tana, originating from Othaya Coffee Society, Nyeri County. Furthermore, the study's outcomes are expected to offer practical guidance to coffee industries in designing effective coffee wastewater management practices aimed at minimizing further contamination of surface water, particularly those associated with coffee honey waters.

This would contribute to the enhancement of environmental sustainability within the industry. Moreover, the findings of the study would be instrumental in informing policy makers, water consultants, regulatory bodies, civil society organizations, development partners, and other stakeholders. These stakeholders could leverage the study's insights to advocate for change within the coffee industry, urging for the treatment and proper management of generated coffee effluents. This collaborative effort would contribute to the preservation and protection of water resources, ensuring a healthier environment for all.

1.10 Assumptions of the Study

The researcher made key assumptions to ensure the study's validity. It was assumed that all respondents shared similar characteristics, ensuring uniformity in data collection and minimizing sample variations. Sixteen active washing stations were divided into four blocks, with samples randomly selected from diverse populations. Random assignment of subjects and treatments maintained consistency and reduced bias across groups.

Participants were assumed to fully understand interview questions and provide honest responses, ensuring reliable data. The instruments used were considered effective for accurate data collection. The researcher also assumed that some respondents were affiliated with the Othaya Coffee Society and had sufficient knowledge of its operations and benefits. This assumption allowed for deeper insights into how the society influenced household livelihoods.

Additionally, it was assumed that the economic benefits from the society extended beyond households to the community, contributing to regional development. Environmental factors, such as washing station efficiency, were not expected to significantly impact the study. These assumptions focused the research on the socioeconomic effects of the Othaya Coffee Society.

1.11 Operational Definition of Terms

A Conceptual Model: This is a theoretical construction of all expected interrelations of factors/ variables that cause and affect any natural, physical and social phenomenon (King'oriah, 2004).

Coffee Processing Honey Water: Also, referred to as Coffee Wastewater or Coffee Effluent is a by-product of coffee processing.

Complete Randomized Block Design (CRBD): is a type of experimental design used in statistics to control for variability among experimental units. It is particularly useful in outdoor agricultural experiments where researchers want to compare treatments while accounting for potential confounding variables.

Dependent Variable (Y): Alludes to a variable that endeavors to demonstrate add up to effect emerging from the impacts of an autonomous variable. It is in this manner a work of a free variable (King'oriah, 2004).

Independent Variable (X): Refers to a variable that can be manipulated to have an effect or influence on another variable (Kothari, 2004).

Intervening Variable: Refers to a factor that mediates/ explains a causal link between other variables (Kothari, 2004)**.**

Mixed Research Design: Refers to a method where an experiment is conducted quantitatively and descriptive data is also analyzed.

Population: Alludes to the whole gathering of sets, occasions or objects having some common discernible characteristics**.**

Pulping: Refers to the removal of the outer cover of the red and ripe coffee cherry.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

The chapter began by reviewing writings relating to contaminating effects of surface water by coffee honey water. The existing literature section highlighted what past researchers had done on contaminating effects of coffee honey water on surface water. The existing literature formed the basis for establishing existing gaps from the past research studies. The general objective was to assess contaminating effects of coffee honey water on surface water. It finally captured the conceptual model showing relationships of factors/variables under the study.

2.1 Theoretical Literature Review

The two theories guided the research study.

2.1.1 Industrial Effluent Management Theory

The theory is based on the principle that industries must treat and manage their effluents before discharging them into surface water bodies. Untreated industrial effluents, such as coffee honey water, can significantly harm aquatic ecosystems and the livelihoods of nearby communities. The theory provided a structured approach to the study's objectives, which included: Determining Contaminant Levels: Analyzing the types and concentrations of pollutants in coffee processing honey water is essential for understanding the extent of environmental degradation. Evaluating Impact on Water Quality: The theory supported detailed investigations into how coffee effluents affected the chemical, biological, and physical properties of surface water, influencing overall aquatic health and sustainability. Examining Socioeconomic Effects: The framework facilitated assessments of how contamination impacted downstream communities, particularly concerning clean water access, public health, and economic activities tied to water use. Identifying Mitigation Measures: The theory emphasized the need for practical recommendations focused on sustainable wastewater treatment practices to ensure compliance with local and international environmental regulations.

As highlighted by Hai et al. (2018) the theory offered valuable insights into various aspects of effluent management, including understanding contaminant levels in coffee honey water to assess environmental degradation. Evaluating the impact of coffee honey water on surface water quality and its effects on aquatic ecosystems. Assessing socioeconomic consequences for downstream populations, where untreated effluents can compromise access to clean water, public health, and local economic activities such as farming and fishing. The theory underscores the necessity for effective strategies to reduce effluent discharge and prevent water pollution, as supported by McIntosh et al. (2017). In the context of this study, the industrial effluent management theory played a crucial role in analyzing coffee honey water contamination, understanding its impacts on surface water, and formulating mitigation recommendations for the Othaya coffee society catchment area.

2.1.2 The Deterministic Theory of Cause-Effect Relationships

The deterministic theory of cause-effect relationships emphasizes the importance of understanding the direct links between actions and outcomes, which is critical for effective decision-making. In this study, the theory guided the researcher in quantifying the contaminating effects of coffee honey water on surface water, thereby supporting the development of informed industrial effluent management strategies. These strategies could range from simple to more complex interventions. For instance, preliminary actions, such as assessing contaminant loads, helped to prioritize reduction efforts based on cost-effectiveness (Mutamim et al., 2012). Additionally, mass contaminants could be quantified by estimating the pollutant loads from industrial sources while considering the water recovery capacity of the affected surface water bodies. By comparing the significance of different contaminant loadings, the theory guided the researcher in evaluate the contamination levels, leading to more targeted and effective measures for reducing contamination in receiving waters (Mutamim et al., 2012). The theory was particularly relevant to the study, as it provided a framework for understanding how industrial effluents from coffee processing impact surface water in the Othaya coffee society catchment area. By exploring the cause-effect relationships, the researcher was able to meet the study's primary objectives, which included:

Determining the level of contaminants contained in coffee processing honey water: The theory helped guide the researcher in quantifying contaminant loads from coffee effluent, which is essential for identifying the pollutants present in honey water. Evaluating the impact of coffee honey water on the quality of surface water: By understanding how the effluent loads influence surface water quality, the researcher could assess the overall impact on water chemistry, biodiversity, and ecosystem health. Examining the socioeconomic effects on downstream populations: The cause-effect framework allowed the researcher to investigate how surface water contamination from untreated coffee honey water affects communities downstream, particularly in terms of health, livelihoods, and access to clean water.

Identifying and proposing effective measures to reduce contaminating effects: The deterministic approach enabled the formulation of strategies to mitigate pollution, based on the understanding of pollutant sources and their impacts on the water system, which is key to ensuring compliance with environmental standards and protecting surface water resources. By applying the deterministic theory, the researcher was able to draw direct correlations between coffee honey water discharges and their environmental and socioeconomic consequences, leading to more informed recommendations for sustainable industrial effluent management. This approach ensures that both environmental protection and economic viability are balanced within the coffee processing industry.

2.2 Surface Water Contamination

Water is a vital resource for all life forms, including humans, and is protected under the Environmental Management and Coordination Act (EMCA) of 2015, which grants every citizen the right to access clean surface water. However, the contamination of surface water has emerged as a pressing global socioeconomic issue, particularly affecting many countries in Africa. Human-generated contaminants have significantly polluted surface water, threatening the rights of Kenyan citizens (Minuta et al., 2017).

In Kenya, inadequate access to clean surface water continues to be a persistent challenge, exacerbating contamination issues (Workinesh, 2017). Surface water contamination refers to any alteration in water quality caused by external toxic compounds, leading to detrimental effects on surrounding ecosystems and human health. In Kenya and other developing nations, this contamination poses a significant barrier to sustainable water resource management (Bisekwa et al., 2021). Major contaminants, such as nitrogenous and phosphoric chemicals, can degrade water quality and pose serious risks to human health (Tesfalem et al., 2017).

Effective control measures are essential for mitigating the effects of contamination at their source and improving surface water quality. These measures include comprehensive monitoring of water properties through physical, chemical, and microbiological assessments, ensuring adherence to health policy guidelines established by organizations like the World Health Organization (WHO) in 2016.

2.3 Parameters that Determine the Acceptable Quality of Surface Water

According to Minuta et al. (2017) surface water quality is determined by a combination of physical, chemical, and microbiological properties. Physical attributes, including temperature, color, taste, and odor, could be perceived through the senses of touch, smell, and sight. The geological composition of rocks and soils in the area also influences the chemical properties of surface water. Key parameters used to assess surface water quality encompass temperature, pH level, turbidity, electrical conductivity (EC), dissolved oxygen (DO) concentration, biochemical oxygen demand (BOD_5), total suspended solids (TSS), and chemical oxygen demand (COD).

2.3.1 Temperature

Temperature plays a crucial role in shaping various characteristics of water bodies, including their comfort, density, solubility, odor, and chemical reactions. It significantly impacts water chemistry by affecting parameters such as solvency and the concentration of dissolved oxygen and heavy metals. Chemical reaction rates are directly influenced by temperature, with higher temperatures generally leading to increased reaction rates. Additionally, temperature exerts an influence on biological activities within surface water bodies, highlighting its importance in regulating aquatic ecosystems (Workinesh, 2017).

2.3.2 Color

According to the American Public Health Association (APHA, 2017) dead organic matter from natural sources like vegetation and anthropogenic sources such as soil, stones, and rocks contribute color to water. The APHA manual on standard methods for surface water and effluent analysis outlines the procedure for determining water color by comparing the water sample with standard color solutions or colored glass slides. The true color is assessed after filtering the water sample to remove all suspended materials. Color is measured on a scale ranging from 0 (clear) to 70 color units, with pure water being colorless and equivalent to 0 color units.

2.3.3 pH

pH is a critical parameter to consider when assessing surface water quality. Studies by Workinesh (2017) and Tsigereda et al. (2013) define pH as the negative logarithm of the hydrogen ion concentration (H^+), representing the acidity of water. It indicates the level of acidity or alkalinity in water and impacts both biological and chemical reactions occurring within the solution. For example, low pH levels can inhibit microbial activity and growth, thereby affecting biological processes. The solubility and mobility of chemical constituents, such as nutrients and heavy metals, play a role in determining the pH of surface water.

2.3.4 Turbidity

Turbidity refers to the degree of visual clarity of water (Workinesh, 2017). It indicates the cloudiness of water, measuring the ability of light to pass through it (APHA, 2017). The presence of turbidity indicates that water contains particles other than water particles, which could contaminate surface water. It is a measure of the opacity of optical light, causing light to scatter rather than transmit through the sample without changing direction. The scattering of light increases in the presence of dissolved and suspended solids in the sample.

2.3.5 Electrical Conductivity (EC)

It is the ability of surface water to conduct electricity, also an indication of particles within the surface water source. This property serves as an indicator of surface water contamination because dissolved salts, like sodium chloride and potassium chloride, present in the water influence its ability to conduct electric current (Workinesh, 2017). Saline water typically exhibits higher electrical conductivity than pure water. Thus, the level of salinity is often measured through electrical conductivity (Kosgey, 2013).

2.3.6 Dissolved Oxygen (DO)

This term refers to the actual quantity of dissolved oxygen present in surface water. The water quality is closely linked to its oxygen concentration. The dissolved oxygen levels fluctuate depending on factors such as pressure, temperature, and salinity in the surface water. Introduction of organic matter, such as coffee processing honey water, into surface water leads to increased consumption of dissolved oxygen by microorganisms during the breakdown of organic material. The decrease in dissolved oxygen levels negatively impacts the aquatic life of these microorganisms (Tsigereda, et al., 2013; Dori, 2017).

2.3.7 Biological Oxygen Demand (BOD)

Biological Oxygen Demand (BOD_5) refers to the amount of oxygen that microorganisms utilize while oxidizing or decomposing organic matter in surface water. It serves as a measure to compare the contaminating potency of various organic substances. The biochemical oxidation process is conducted under specific conditions outlined in the methods for analyzing coffee processing honey water (APHA, 2017). BOD serves as a key indicator for the oxygen demand on the affected water source due to contamination by coffee processing honey water (Kosgey, 2013).

2.3.8 Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is the quantity of oxygen needed to oxidize both natural and synthetic compounds. It assesses the levels of contaminants from various sources of effluent contamination. Testing for COD involves using potent oxidizing agents like potassium dichromate, sulfuric acid, and heat. A contaminating effluent with a higher equivalent oxygen content exhibits higher COD values, indicating greater contaminating effects (Tsigereda et al., 2013; Kanyiri et al., 2017).

2.3.9 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) encompass both inorganic and organic compounds found in a contaminating source (Workinesh, 2017). Common origins of total dissolved solids in receiving surface waters include runoff from agricultural and residential areas, as well as discharges from industrial facilities (such as those processing coffee honey water) and sewage treatment plants.

2.4 Coffee Processing Honey Water

Coffee processing honey water is essential in the coffee production industry, but it presents significant environmental challenges. Bisekwa et al. (2021) emphasized that, despite its importance, this wastewater is a considerable source of contamination for water sources, primarily due to the high levels of carbohydrates, proteins, and fibrous compounds released during pulping and mucilage fermentation. Inline with objectives of the Study: Understanding the concentration of contaminants in coffee processing honey water is critical. Key characteristics influencing its quality include: Oxygen Demand: Elevated nitrogen and phosphorus levels, often resulting from organic matter, significantly impact oxygen demand

(Wubalem et al., 2021). High biochemical oxygen demand (BOD) can indicate potential ecological harm.

Physical and Chemical Properties: Factors such as pH, temperature, and total suspended solids (TSS) also play vital roles. pH affects microbial activity, while TSS can hinder light penetration, adversely affecting aquatic ecosystems. The discharge of raw coffee processing honey water into surface waters results in the emission of foul odors, primarily due to the breakdown of organic matter (Dessalegn et al., 2017). This not only diminishes the aesthetic quality of water bodies but also signifies underlying contamination, which can lead to further ecological degradation. The high concentration of contaminants poses risks to both human health and aquatic ecosystems. Contaminated water can threaten communities reliant on these sources for drinking and irrigation, resulting in waterborne diseases and health complications (Mburu, 2014).

Additionally, elevated nutrient levels can lead to eutrophication, causing oxygen depletion and harming fish and other aquatic organisms, thereby affecting the livelihoods of communities engaged in fishing and farming. Addressing these challenges requires effective management practices. Implementing sustainable wastewater treatment methods, such as sedimentation, filtration, and biological treatments, can significantly reduce pollutant loads in coffee processing honey water before discharge. Furthermore, adopting best management practices in coffee processing—such as optimizing fermentation processes and minimizing water use—can help reduce wastewater generation and its associated contaminants (Mburu, 2014; Wubalem, et al., 2021).

2.4.1 Physicochemical Characteristics of Conventional Coffee Effluent

Both WHO (2016) and APHA (2017) manuals affirm that conventional coffee effluent should contain the following physicochemical characteristics as shown in table 2.1.

Table 2.1

Physicochemical Parameters of Conventional Industrial Effluent

Parameter	Range
pH	3.92 - 4.43
Temperature (°C)	18 - 24
BOD_5 (mg/L)	1210 - 2130
COD (mg/L)	5470 - 6120
Nitrate (mg/L)	3.15 - 6.65
Phosphate (mg/L)	2.71 - 3.45
TSS (mg/L)	1564 - 2100
TDS (mg/L)	1580 - 2133
Conductivity (µS/cm)	663 - 821

Turbidity (NTU)	185 - 458
DO (mg/L)	1.09 - 2.74

Note. BOD_5 = Biochemical Oxygen Demand over 5 days, COD = Chemical Oxygen Demand, TSS = Total Suspended Solids, TDS = Total Dissolved Solids, DO = Dissolved Oxygen.

2.5 Contaminating Effects of Coffee Honey Water on Surface water

During peak periods of wet coffee processing or heavy rains, the disposal pits (lagoons) become filled with raw coffee processing honey water, causing overflow into surface waters and resulting in significant contamination. This contamination negatively impacts the socioeconomic activities of downstream communities who rely on water for various purposes such as washing clothes, bathing, irrigating, swimming, and drinking. The presence of contaminated surface water increases the risk of water-borne diseases such as cholera, typhoid, and dysentery, thereby compromising human health and affecting the socioeconomic livelihoods of the community while also contributing to biodiversity loss. Moreover, contaminated surface water releases nitrates and ammonium compounds into the atmosphere, leading to the emission of global warming gases like nitrogenous oxide (N_2O), methane (CH_4), and carbon (IV) oxide (CO_2), thereby exacerbating climate change. Additionally, the discharge of nitrogenous and phosphoric compounds from contaminated surface water could result in eutrophication, negatively impacting aquatic ecosystems due to increased oxygen demand. The presence of high levels of nitrates in contaminated surface water can lead to blue baby syndrome (methemoglobinemia), a potentially fatal illness in infants. Dejen et al. (2015) confirmed that the unwise discharge of raw coffee processing honey water into surface water leads to the deterioration of water quality, which, in turn, affects the quality of coffee processed using such contaminated water. Furthermore, contaminated surface water emits unpleasant odors into the surrounding areas. The proximity and use of contaminated surface water pose numerous severe health issues among the inhabitants of nearby areas, including dizziness, eye, ear, and skin irritation, stomach pain, nausea, and respiratory problems (Tonui, 2018).

2.6 Measures to Reduce Further Contaminating Effects on Surface Water

Numerous agencies, including governments and regulatory bodies, have made concerted efforts to mitigate the contaminating effects of surface water caused by various industrial effluents. Mandates have been established requiring all industrial effluents, whether of organic or inorganic origin, to undergo treatment processes as stipulated by water policies and statutes. Through the enactment of laws and regulations, governments aim to effectively reduce the contamination of surface water. To address the issue, policies have been formulated at both national and international levels, incorporating surface water quality objectives. United Nations (UN) forums, summits, conferences, and non-governmental organizations have actively engaged in efforts to curb surface water contamination by providing capacity training and financial support for control measures. However, many developing countries still lack effective industrial effluent management frameworks and well-aligned control policies.

Routine monitoring and strict implementation of policy guidelines by governments are crucial for effective industrial effluent management. Continuous monitoring and data collection enable the tracking of surface water contamination extremes caused by coffee processing honey water. In cases where toxic contaminant levels exceed statutory requirements, appropriate mitigation measures for treating coffee processing honey water become necessary. Recycling coffee processing honey water is one potential strategy to mitigate surface water contamination. Furthermore, eco-friendly measures for controlling surface water contamination require incentives from governments, such as grants, loans, carbon credits, value-added tax regulations, and tax reductions. Legislation should impose significant penalties on entities discharging raw coffee processing honey water into surface waters, similar to penalties for non-biodegradable polythene bags. The "polluter pays principle," advocates for those contaminating surface water to bear the costs of reducing contamination effects, potentially through levies and other charges. Public awareness campaigns on controlling surface water contamination by coffee processing honey water are essential. For instance, the contamination of Nairobi River in Kenya in 2019 led to severe health problems among residents living along the riverbanks. Consequently, they protested and petitioned the government, prompting immediate action to enforce policies and regulations aimed at reducing surface water contamination. Policies and penalties should deter any company or organization from discharging untreated industrial effluents, as this jeopardizes the health and safety of humanity and the environment.

2.6.1 Government Responsibility in the Control of Surface Water Contamination

Tonui (2018) emphasized that the government bears the responsibility of setting rigorous standards and conducting inspections on industries through its lead agencies tasked with regulating effluent discharge into surface waters. This regulatory framework is particularly vital in Kenya, where the management of coffee processing honey water has become a critical topic in discussions concerning the availability and competitiveness of Kenyan coffee in international markets.

In Kenya, the Environmental Management and Coordination Act (EMCA) provides the legal foundation for regulating effluent discharge, establishing guidelines that industries must follow to minimize environmental harm. Agencies such as the National Environment Management Authority (NEMA) are responsible for enforcing these regulations, conducting regular inspections, and ensuring that industries comply with set standards. These inspections are essential for identifying violations and promoting accountability within the coffee processing sector, where untreated effluents can have devastating effects on local ecosystems and communities.

As international consumers become increasingly aware of the environmental impact of their purchases, certification schemes such as Rainforest Alliance, Solidaridad, and Fairtrade have emerged as crucial mechanisms for promoting sustainable practices in coffee production. These organizations require coffee producers to adhere to strict environmental standards, which now include the management of coffee processing honey water. By integrating contaminant management into their certification criteria, these schemes encourage producers to adopt sustainable wastewater treatment practices and prioritize environmental stewardship alongside economic viability (Bisekwa et al., 2021).

The necessity for adherence to these certification standards underscores the economic implications of effective coffee processing honey water management. Producers who fail to comply risk losing access to lucrative international markets, where consumers increasingly demand transparency regarding environmental practices. This pressure creates an incentive for coffee farmers and processors to invest in better management practices, thereby enhancing their competitiveness while simultaneously contributing to environmental protection.

Moreover, community engagement plays a crucial role in this context. Educating local farmers and processors about the importance of managing coffee processing honey water can foster a culture of sustainability within the coffee sector. Training programs focused on best management practices not only help to improve water quality but also empower communities by equipping them with the knowledge and tools needed to mitigate the negative impacts of their activities on the environment.

2. 6.2 Private Sector Awareness and Surface Water Governance

Private sector entities play a vital role in raising awareness about environmental issues, particularly the contaminating effects of industrial activities like coffee processing on surface water. A key focus is on understanding how coffee honey water affects surface water quality, which has become an integral part of sustainable business practices. Through targeted awareness programs, the private sector collaborates with stakeholders, including industries, local communities, and authorities, to address the challenges of water contamination effectively. The private sector helps promote education and training on the risks of effluent discharge, empowering individuals and social groups to recognize the importance of water conservation and pollution prevention. By equipping people with knowledge and skills related to sustainable water management, including the proper use of water resources and wastewater treatment, industries and communities can work together to adopt cleaner and more efficient practices. This, in turn, helps to reduce water pollution, enhance water quality, and protect ecosystems from further degradation.

Additionally, private sector awareness efforts drive innovation in managing industrial effluents, promoting the adoption of cleaner technologies and sustainable production processes. These initiatives align with corporate social responsibility goals by encouraging industries to comply with both national regulations, such as Kenya's Water Act of 2016, and international certifications like Rainforest Alliance and Fairtrade, which emphasize the responsible management of water resources. Tonui (2018) underscores that private sector initiatives focus not only on reducing pollution but also on striking a balance between sustainable industrial growth and environmental protection. By fostering a culture of environmental responsibility, private sector stakeholders ensure that industrial activities, such as coffee processing, contribute to economic development without compromising the health of water ecosystems. This balance is crucial for maintaining clean and safe surface water availability for both current and future generations.

This is In line with the specific objectives of the study: Determining the level of contaminants in coffee honey water: Private sector initiatives help assess the extent of pollution from coffee processing, crucial for understanding the type and quantity of contaminants being released into water bodies: Evaluating the impact of coffee honey water on surface water quality: Through collaborative efforts, the private sector helps monitor and analyze how effluents affect water chemistry, biodiversity, and the overall health of surface water ecosystems. Examining the socioeconomic effects on downstream populations. Awareness programs empower affected communities to understand how water contamination influences their access to clean water, livelihoods, and health, fostering better advocacy for their rights and sustainable practices: Identifying and proposing effective measures to reduce contaminating effects: Private sector stakeholders contribute to designing and implementing solutions that mitigate the impact of coffee honey water, ensuring compliance with regulations and promoting sustainable water management practices. Through ongoing collaboration, innovation, and education, the private sector plays an essential role in addressing water contamination challenges while contributing to the sustainable management of water resources in coffee-producing regions.

2.7 Existing Surface Water and Coffee Effluent Management Policy Framework

Kenya's Water Act of 2016 was enacted to provide a comprehensive framework for the sustainable management of surface water, regulate its usage, and ensure the provision of proper wastewater services. The legislation emphasizes both the conservation of water resources and the secure disposal of industrial effluents, including those from coffee processing, such as honey water. A central feature of the Act is the establishment of the Water Resources Management Authority (WARMA), a regulatory body tasked with: Establishing and enforcing water resource management guidelines: WARMA creates methods and controls for the proper utilization of water resources, including flood risk management. Regulating water usage and management: The authority oversees the responsible use of water resources to ensure industries adopt sustainable practices. Processing water permit applications: WARMA evaluates applications for water permits, makes decisions on their issuance, modification, and enforcement, ensuring compliance with regulatory conditions.

Section 72 of the Water Act imposes strict penalties for industries discharging untreated effluents, including coffee honey water, into surface water bodies. Non-compliance with surface water contamination standards is considered an offense, punishable by fines of up to one million shillings, imprisonment of up to two years, or both. Additionally, offenders are responsible for covering the costs associated with the cleanup, restoration, and compensation for damages caused to the water ecosystem and affected communities. This was inline with the study's objectives, which include: Determining the level of contaminants in coffee processing honey water: This is crucial for quantifying the pollution levels in effluents, particularly in areas where coffee processing is widespread.

Evaluating the impact of coffee honey water on surface water quality: It is essential to assess how the discharge of honey water affects water chemistry, biodiversity, and overall environmental health. Examining the socioeconomic effects on downstream populations: Understanding how untreated honey water affects communities, especially in terms of access to clean water and impacts on livelihoods, was a key focus. Proposing effective measures to reduce contaminating effects: This involves recommending strategies to mitigate the environmental and social impacts of coffee honey water, ensuring compliance with the Water Act and safeguarding surface water resources. By addressing these objectives, the study sought to contribute to sustainable water management in coffee-producing regions, aligning with both local regulations and international certification standards.

2.8 Empirical Literature and Research Gaps

The impact of pollution from various industries on both natural and social environments has been a growing concern in environmental research. Industrial activities produce a significant volume of waste, often leading to detrimental consequences for surrounding ecosystems and communities. While several studies have delved into pollution loads and environmental contamination, the specific effects of pollutants from coffee processing, particularly coffee effluent, remain under-explored. This is particularly critical in regions where coffee production plays a central role in both the local economy and ecological systems. Coffee processing generates a variety of waste products, including coffee honey water, which is rich in organic matter and known to have harmful effects on water bodies. Despite its significant pollution potential, few studies have comprehensively examined the environmental and socioeconomic impacts of coffee honey water, highlighting the need for further research in this area, especially in Kenya and other coffee-producing countries.

Tsigereda et al. (2013) explored the effectiveness of advanced versus conventional wet coffee processing technologies on wastewater quality. Their findings revealed that the wastewater did not meet the Burundi coffee discharge benchmarks, indicating the potential for serious environmental harm if proper wastewater treatment systems are not implemented. The failure to adhere to water quality standards poses a direct risk to local water resources and aquatic life. However, this study, conducted outside of Kenya, does not directly address the specific contaminants present in coffee honey water, a significant byproduct of coffee processing. Coffee honey water, known for its high organic load, is a major source of water pollution that could have severe environmental consequences. Its exclusion from this study represents a notable gap in the literature, particularly for Kenyan coffee-producing regions, where coffee production is a key economic activity.

Kosgey (2013) conducted a study on heavy metal contamination in the sediment-water systems of the Athi River Basin in Kenya, identifying exceptionally high concentrations of heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), and nickel (Ni) in both water and sediment samples. These levels far exceeded Kenya's industrial waste discharge standards, indicating severe water pollution that could harm both human health and aquatic ecosystems. However, Kosgey's study did not focus on coffee processing effluent, nor did it address the potential contaminants present in coffee honey water. Given the extent to which untreated coffee waste may introduce additional pollutants into rivers and surface water systems, this represents a critical gap in our understanding of how coffee processing waste affects Kenyan rivers, particularly in coffee-producing areas where water bodies are directly exposed to untreated effluents.

Mburu (2014) examined the use of lime and Moringa oleifera as natural agents for removing suspended solids from coffee processing effluent. The study showed that Moringa oleifera oil press cake was effective in reducing suspended solids, improving wastewater quality. While this approach presents a potential low-cost solution for treating coffee effluent, the study did not explore the broader environmental impacts of untreated coffee honey water on surface water systems. Additionally, it did not address the design of waste stabilization pits, which are critical for ensuring long-term treatment of coffee effluent and mitigating surface water pollution. This omission highlights the need for further research on the broader ecological risks posed by coffee honey water, as well as the need to assess the effectiveness of low-cost treatment solutions.

In a study conducted in the Jimma Zone of Ethiopia, Dejen et al. (2015) investigated the effects of coffee processing plant effluent on the physicochemical properties of receiving water bodies. The findings revealed that untreated coffee effluent was discharged into nearby pits, which often overflowed into rivers, leading to significant water quality degradation. The discharge of untreated effluent can lead to conditions that result in eutrophication, oxygen depletion, and loss of biodiversity in aquatic systems. However, this study did not specifically address the contaminating effects of coffee honey water, despite its known pollution potential. Targeted research is therefore needed to determine the specific environmental impacts of coffee honey water on surface water and downstream communities.

Ejeta et al. (2016) studied the impact of coffee refinery effluent discharge on river water quality in Southwestern Ethiopia. The findings revealed that unsafe levels of physicochemical parameters rendered the water unsuitable for human consumption and damaged aquatic life. Although this study provided critical data on water contamination caused by coffee effluent, it failed to propose specific strategies for mitigating the pollution, and did not address the specific role of coffee honey water in contaminating surface water systems. Given the importance of sustainable wastewater treatment in coffee-producing regions, future research should focus on affordable and effective solutions for treating coffee honey water.

Kanyiri et al. (2017) focused on the potential economic benefits of utilizing biomass waste from small and medium-sized coffee processing factories in Kiambu County, Kenya. The study demonstrated how coffee by-products could be repurposed to generate economic value. However, the study did not explore the environmental risks associated with untreated coffee effluent, nor did it examine how coffee honey water might impact surface water quality. This represents a gap in the understanding of the environmental threats posed by coffee waste in Kenyan coffee-producing regions. Given the economic significance of coffee production in Kenya, understanding the environmental risks posed by coffee waste is essential for developing sustainable management solutions.

Workinesh (2017) examined the effects of coffee processing waste on water quality in the Gidabo watershed in southern Ethiopia. The research revealed that untreated coffee effluents posed significant risks to surface water and aquatic ecosystems, as they failed to meet national discharge standards. Although the study emphasized the need for improved waste management practices in the coffee industry, it did not explore the specific pollutants present in coffee honey water. This gap in the research highlights the importance of further studies focusing on the environmental and socio-economic impacts of coffee honey water in coffee-producing regions.

Tesfalem et al. (2017) investigated wastewater effluents from industrial areas in Ethiopia, analyzing key physicochemical parameters such as pH, electrical conductivity (EC), and total dissolved solids (TDS). The findings revealed that effluents often exceeded World Health Organization (WHO) standards, posing significant risks to both human health and the environment. However, this study was not conducted in Kenya and did not assess the socio-economic impacts of contaminated water on local communities. The lack of localized studies focusing on Kenyan coffee regions underlines the need for research that considers both environmental and socio-economic factors related to coffee processing waste.

Dessalegn et al. (2017) highlighted the effects of wet coffee processing wastewater on downstream water quality, revealing that untreated coffee effluent overflowed into natural watercourses, posing significant risks to surface water and aquatic life. However, the study did not address the specific contaminating effects of coffee honey water, an issue that remains under-researched. Given the potential for untreated coffee honey water to cause surface water pollution, further research is needed to develop targeted mitigation strategies aimed at protecting both human health and ecosystems.

Minuta et al. (2017) studied the impact of wet coffee processing plants on the Walleme River in southern Ethiopia, revealing that untreated coffee effluent caused heavy contamination of the river. The study focused primarily on the environmental effects of water contamination, but did not examine the socio-economic impacts of polluted water on surrounding communities. This gap underscores the need for research that examines both the environmental and socio-economic consequences of water pollution in coffee-producing regions, particularly in areas where local livelihoods depend heavily on access to clean water.

Dori (2017) explored the environmental and economic impact of wet coffee processing industries in the Gedeo Zone of southern Ethiopia, finding that untreated effluent discharge negatively impacted downstream water quality and ecosystems. However, the study did not explore the socio-economic effects of contaminated water on agricultural activities downstream, nor did it propose strategies for mitigating these impacts. Future research should address these gaps by exploring the environmental and socio-economic effects of untreated coffee effluent, especially coffee honey water, and proposing affordable waste management solutions.

Tonui (2018) investigated the effects of tea effluent discharge into the Kipsonoi River in Bomet County, Kenya, revealing significant environmental damage to surface waters and aquatic life. Although this study focused on tea effluent, its findings offer valuable insights into industrial waste pollution in Kenyan water systems. Given that both tea and coffee are major exports in Kenya, a similar study focusing on the environmental and socio-economic implications of coffee processing effluent is warranted.

Ijanu et al. (2019) studied wastewater treatment methods for coffee processing in Malaysia, noting that while advanced treatment methods were effective, they would be prohibitively expensive for most Kenyan coffee producers. This highlights the need for cost-effective, sustainable wastewater treatment strategies that can be adapted for local conditions in Kenya, where financial constraints often limit the ability to implement expensive technologies.

While several studies have investigated the environmental effects of industrial effluent on water quality, there remains a significant gap in the research concerning the impact of coffee honey water on surface water systems and downstream communities. This research gap is critical to addressing the environmental and socioeconomic challenges posed by coffee processing in coffee-producing regions like Kenya. Future studies should focus on both the environmental and socioeconomic impacts of untreated coffee honey water and identify affordable, sustainable strategies for mitigating its harmful effects. Addressing this gap will be essential for developing effective waste management solutions that protect ecosystems and support the livelihoods of communities in coffee-growing regions.

2.9 Conceptual Model

A conceptual model is essential in illustrating the relationships between the variables under study, providing a clear framework for understanding how these variables interact. In this case, Industrial Coffee Effluent acts as the independent variable, while surface water contamination is the dependent variable. The poor coffee effluent management system serves as the intervening variable, influencing the relationship between the industrial effluents and water contamination.

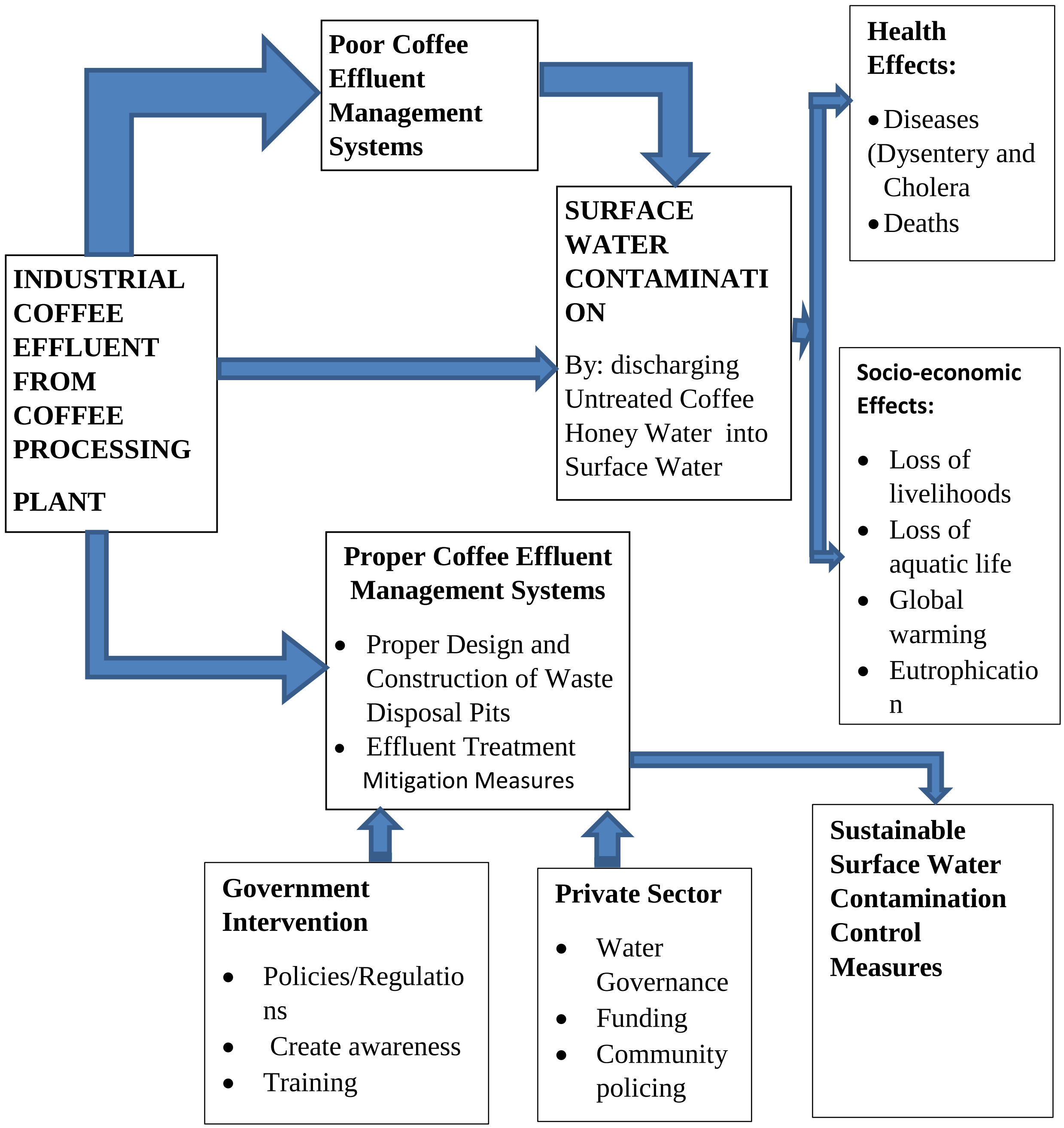
Surface water contamination is directly influenced by the presence of untreated industrial coffee effluents. When these effluents, which typically contain harmful substances such as organic waste, chemicals, and suspended solids, are discharged into water sources without adequate treatment, they lead to significant contamination. This contamination can degrade water quality, harm aquatic life, and pose health risks to communities dependent on these water sources. The discharge of untreated coffee effluents results from several factors, including poor waste management practices and the absence of proper treatment facilities.

The effluent management system plays a critical role as an intervening variable, which can either mitigate or exacerbate the impact of industrial coffee effluents on water quality. A poor or inadequate management system contributes directly to increased surface water contamination. Ineffective systems often lack proper mechanisms for treating and disposing of effluents, leading to the unchecked release of pollutants into rivers, lakes, and other surface water bodies. This poor management may result from weak regulatory frameworks, insufficient infrastructure, or a lack of awareness regarding best practices for waste treatment. On the other hand, a well-implemented industrial effluent management system could effectively intervene and reduce surface water contamination. Such systems would include advanced treatment technologies, proper disposal methods, and regular monitoring to ensure that effluents are adequately treated before being discharged into the environment. Government intervention through policies and regulations, such as the enforcement of environmental standards and the provision of incentives for adopting cleaner technologies, plays a pivotal role in ensuring compliance and improving waste management practices. Additionally, the private sector's involvement is crucial in funding and managing effluent treatment infrastructure, introducing sustainable practices, and fostering innovation in waste management.

While industrial coffee effluents are a key factor in surface water contamination, the degree of contamination is heavily influenced by the effectiveness of effluent management systems. Poor management exacerbates the problem, while proper systems, supported by government regulations and private sector engagement, can significantly mitigate the negative impacts. Figure 2.1 illustrates these relationships, depicting how the independent variable (industrial coffee effluent) impacts the dependent variable (surface water contamination), with the intervening variable (effluent management systems) playing a pivotal role in either preventing or worsening the contamination.

Figure 2.1

Conceptual Model



Independent Variable Intervening Variables Dependent Variable

CHAPTER THREE

RESEARCH METHODOLOGY

The chapter starts by recognizing and depicting the inquiry about considered zone. It gives the inquiry about plan to apply, portrays the considered populace and its measure and the testing methods. The chapter points out how the collected information should be analyzed and displayed.

3.1 Description of the Study Area

Geographically, Othaya Farmers Co-operative Society Limited is situated about 150km north of Kenya's capital, Nairobi in Othaya Town, Nyeri County. Othaya Sub-County has a population of 91,081(KNBS, 2019). It is sandwiched between two water towers of Mt. Kenya and the Aberdare Ranges, at an altitude of 1,828 meters (approximately 6,000 feet) above sea level. It receives an annual rainfall ranging between 500mm and 1,600 mm (Nyeri County Integrated Development plan [CIDP], 2023-2027). The climate is temperate, with average temperatures ranging between 14°C and 26°C (57°F to 79°F). Othaya's soils are primarily composed of red, well-drained volcanic soils (nitisols). These are highly fertile and rich in organic matter, making them ideal for coffee cultivation.

The Society is located in Othaya Sub-County in Nyeri County and was established in 1956 as a coffee marketing society with an initial membership of 250. The cooperative has grown in leaps and bounds over the years. Currently , the society has 16 active factories and a total membership of 15,000 with an average annual processing of four million kilograms of cherry. This is where the world-famous Arabica coffee is grown, mostly SL28 and SL34 varieties along with some Ruiru 11 and Batian. The area has red volcanic soils that are rich in phosphorus and are well drained which is perfect for growing the characteristic Kenyan coffee.

The Society was chosen because of the numerous washing stations, a dry mill, and a nursery that rely on significant amounts of water from River Tana for production and processing. The sixteen active washing stations include Thuti, Chiga, Mahiga, Kagere, Gatuyaini, Ichamama, Kiaguthu, Kiruga, Gichichi, Iriaini, Gitugi, Rukira, Kiaga, Gura, Kagonye, and Gitundu. Due to the researcher's current employment, there was easy access to all the mentioned society's facilities. Therefore, the researcher believed that the study area could provide all the necessary information about the contaminating effects of coffee honey water on surface water.

Figure 3.1

Map of the Othaya Sub-County and Study Area

3.2 Research Design

The researcher used a mixed research design. The research design was appropriate because the researcher needed to mix a qualitative component within quantitative component as a case of experimental design. a mixed research design is often chosen to leverage the strengths and mitigate the weaknesses of both qualitative and quantitative approaches. It is particularly suited for complex research questions that require both detailed understanding and generalized findings. By integrating diverse types of data, the researcher aimed to achieve a more comprehensive and nuanced understanding of the phenomena under study. Therefore, the design helped the researcher to achieve the main objective of the study. Since the sixteen washing stations were situated in different locations within the Othaya catchment area, the researcher used global positioning system software (GPS) and geographic information system software installed in the smartphone to map them into four blocking units for easy traceability of the washing stations. The researcher grouped blocking units (sixteen active washing stations) into four blocks (I-IV) and assigned three treatments (K-M) to every block with three sub-samples (1-3) as shown in table 3.1. The researcher collected samples from both surface water and coffee processing honey water. To minimize the variation of the surface water and coffee processing honey water samples collected from the same sample sites, randomized complete block design (CRBD) with four composite replicates guided in developing analysis of variance table (Table 3.2). The design was used because it is the standard design in the field of outdoor agricultural experiments where environmental factors (temperature, turbidity and pH) are heterogeneous. The researcher tabulated an Analysis of Variance (ANOVA) results at a 95% Confidence level.

Table 3.1

Sample Plot Layout

BLOCK I			**BLOCK II**			**BLOCK III**			**BLOCK IV**		
K1	K3	K2	L3	L2	L1	M1	M2	M3	K2	K1	K3
L3	L2	L1	K1	K2	K3	L3	L1	L2	M3	M2	M1
M1	M2	M3	M2	M1	M3	K3	K2	K1	L1	L3	L2

Table Legend

I-IV-Blocks; K-M-Treatments for upper, mid and downstream; 1-3-Sub-Samples

3.2.1 Analysis of Variance (ANOVA)

The application of Analysis of Variance (ANOVA) led to the strategic grouping of experimental units into blocks, thereby simplifying the analysis of sample data. This method effectively mitigated the variability among experimental units, as evidenced by the data presented in Table 3.2. By organizing similar units into blocks, the researcher was able to control for extraneous factors that could otherwise obscure treatment effects. Consequently, blocking not only enhanced the precision of the results but also increased the reliability of the conclusions drawn from the experimental outcomes.

Table 3.2

Analysis of Variance

SoV	df	SS	MS	F	Sig.
Blocks (B)	3	64.32	21.44	3.54	0.061
Treatments (Tr)	2	201.86	100.93	16.68	0.000
B*Tr	6	59.53	9.92	**1.64**	
Error (S)	24	145.18	6.05		
Total (Tot)	35	470.89			

F test with 3,6 Degrees of freedom at $p < 0.05$ is 4.76

F test with 2,6 Degrees of freedom at $p < 0.05$ is 5.14

F test with 6,24 Degrees of freedom at $p < 0.05$ is 2.51

The results in F calculated (1.64) were lower than F test (2.51), hence it was evident that blocking reduced the variability (variations) of experimental units.

Legend: SoV-Source of Variation, df-Degrees of Freedom,SS-Sum of Squares, MS-Mean Squares, F-Frequency and Sig.-Significance

3.3 Surface Water and Coffee Processing Honey Water Sampling Procedures

Othaya Coffee Society processes its coffee during two peak seasons: from October to December and from March to May each year. For the purpose of this study, the researcher selected three sampling sites within each of the four blocks, corresponding to sixteen active washing stations located along the Tana River near these processing facilities. A total of twelve (12) surface water samples were collected from three key sampling sites: Upstream (control sites) – These sites were unaffected by coffee effluent, serving as the baseline for comparison. Midstream – Areas where surface water was heavily contaminated by coffee effluent, allowing for the assessment of pollution levels. Downstream locations were selected to evaluate the potential recovery of surface water, spaced 100 meters apart from the midstream locations.

In addition, four (4) untreated coffee effluent samples were collected from effluent pits adjacent to the coffee washing stations. This brought the total number of samples for physicochemical analysis to sixteen (16), all collected during peak processing season, ensuring consistency in the data collection process. Standardized methods and protocols, as outlined in the APHA Operating Manual (2017), were meticulously followed during sample collection. Samples were taken using 500 ml plastic vessels, which were pre-sterilized with 10% nitric acid (v/v) and thoroughly rinsed with purified water. The researcher wore protective gloves to avoid contamination during the sampling process. Once collected, the sample bottles were sealed, stored in a freezer, and maintained at a temperature below 3°C to preserve their physicochemical integrity before being promptly transported to the laboratory for further analysis.

At the sampling sites, key parameters such as pH levels, temperature, total dissolved solids (TDS), and conductivity were measured on-site using a pH meter, TDS meter, and conductivity meter, respectively. In the laboratory, advanced spectrometry techniques were used to measure chemical oxygen demand (COD), total nitrates (NO_3), and phosphates ($PO4^{3-}$). Additional water quality parameters, including turbidity, dissolved oxygen (DO), and biological oxygen demand over five days (BOD_5), were analyzed following standard

APHA methods. The concentration of total suspended solids (TSS) was determined using a photometer.

3.4 Study Population

Mugenda et al. (2003) defines population as the complete set of objects, cases, or individuals that share common characteristics, serving as the foundation for statistical analysis and research. In the context of this study, the population under examination included three distinct groups: the management committee of the Othaya Coffee Society, the employees who worked within the organization, and the households in the surrounding community.

The management committee, consisting of key decision-makers, played a crucial role in shaping the policies and direction of the society, thereby influencing both its operations and its impact on the local economy. The employees, who were integral to the daily functioning of the coffee society, contribute their skills and labor, impacting productivity and the overall work environment.

Additionally, the surrounding households represent the broader community affected by the coffee society's activities. Their interactions with the society—whether through employment opportunities, economic exchanges, or social services—offer valuable insights into the socioeconomic dynamics at play. Understanding this population is essential for addressing the challenges faced by the coffee society and for enhancing the well-being of both its members and the wider community.

3.4.1 Target Population for Othaya Coffee Society

Currently, there are about 15,000 registered members in Othaya Society (Nyeri County Integrated Development Plan [CIDP], 2023-2027). The heterogeneity of population size allowed the researcher to target 100 members within the active sixteen washing stations at Othaya Society. The researcher sampled each category to establish the representative respondents as shown in table 3.3.

Table 3.3

Target Population

Categories of Population	**Frequency**
Othaya Society Management Committee	10
Othaya Coffee Society Managers	16
Othaya Coffee Society Farmers	74
Total	**100**

3.4.2 Targeted Sample Size for Othaya Coffee Society

The researcher used both stratified random sampling to pick heterogeneous target populace and simple random sampling that gave each respondent an equal opportunity to participate. Where the cruel and the standard deviation were obscure as bolstered by Cooper, et al. (2011) the extents approach of computing test estimate were applied as expounded;

For a populace comprising a figure over 10,000, the equation might apply;

$n = p \times q \times (z/e)^2$

Thus;

n = Least test size

p = Extent having a place to an indicated category

q = Extent not having a place to an indicated category

z = Esteem comparing to indicated level of certainty e.g. 95%, z = 1.96

e = Edge error

Further the presumptions for such a populace is that;

P = 50% or 0.5

q = 50% or 0.5

z = 1.96 (95%)

e = + 5% or 0.05

Hence;

$n = 0.5 \times 0.5 \times (1.96 / 0.05)^2 = 384$

When the populace figure is less than 10,000, alterations could be made as follows;

$n' = n / 1 + (n / N)$

Thus;

n' =Balanced test size

n = Calculated least test size

N = Add up to Populace = 100

$n' = 384 / 1 + (384 / 100) = 79$

n' = 79 as the Test Size

Table 3.4

Sample Frame

Strata of Respondents	**Proportions**	**Test Measure of Respondents**
Committee Management	10 /100 x 79	8
Othaya Society Managers	16 /100 x 79	13
Othaya Society Farmers	74 /100 x 79	58
Total 100		**79**

3.4.3 Targeted Sample Size for Households

The researcher targeted households within the Othaya Coffee Society's catchment area to gain insights into community perspectives on coffee production processes. A radius of 150 meters was established around the society's operations to encompass a diverse range of households potentially affected by the contamination of surface water from untreated coffee honey water.

A descriptive survey design, coupled with an exploratory approach, facilitated the collection of both qualitative and quantitative data through open-ended and closed-ended questionnaires. The method aimed to capture community members' perceptions, attitudes, habits, and opinions regarding the environmental impacts of untreated wastewater on local water quality, agriculture, and public health. By assessing residents' awareness of these issues, the study sought to uncover their knowledge of the environmental risks posed by raw coffee effluents and identify any coping mechanisms they employed in response to these challenges.

3.5 Validity and Reliability

3.5.1 Content Validity

Kothari (2004) defines content validity as the degree to which test items accurately represent the subject matter they are intended to measure. The concept was crucial in evaluating whether the data collected truly reflects the intended measurement of a specific construct. In the context of this research, the researcher prioritized content validity to ensure that the instrument used for data collection effectively captures the full spectrum of the concept under investigation.

To confirm the instrument's content validity, the researcher engaged in a systematic process that involved seeking feedback from a diverse range of stakeholders, including scholars, industry experts, and managers with practical experience in the relevant field. This collaboration provided multiple perspectives, enhancing the robustness of the instrument. The input from these experts helped identify any potential gaps or ambiguities in the test items, ensuring that each item was relevant and aligned with the intended measurement goals. Additionally, the researcher conducted a pilot study to further evaluate the instrument's effectiveness in capturing the desired data. This preliminary testing allowed for the refinement of questions based on participants' feedback and responses, leading to a more reliable and valid instrument.

3.5.2 Reliability

Reliability refers to the consistency and stability of a test in measuring what it is intended to measure (Mugenda et al., 2003; 2006). To assess reliability, the same test should be administered twice to the same respondents with a short time interval between the tests. The Pearson product-moment correlation coefficient (r) is used to calculate the relationship between the two sets of responses, indicating the reliability of the questionnaire. The Pearson coefficient ranges from +1 to -1, where +1 indicates a positive relationship, -1 a negative relationship, and 0 no relationship. This coefficient measures the strength, direction, and probability of a linear association between two interval or ratio variables.

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}}$$

Thus;

r = Pearson's relationship coefficient

n = Number of matched scores

$\sum$ = Whole of

x = Score of the primary variable

y = Score of the moment variable

x^2 = Squared score of the primary variable

y^2 = Squared score of the moment variable

xy = The difference of the two combined scores

In this study, a correlation coefficient between the two sets of results were calculated and a reliability coefficient of **0.78** was achieved.

3.6 Data Collection Methods and Instruments

Primary data was collected from field visits and laboratory findings while secondary data was collected from various sources such as reports of previous research findings, published and unpublished materials, books and magazines on matters related to the study. The data collection instruments used in the study included; interviews, questionnaires and documented observations.

3.6.1 Administration of Questionnaires

Oliver (2010) characterizes a questionnaire as an instrument that could assemble information over a huge test and points to decipher the most objective into particular questions and to evoke the answers for each of the enquiry about questions. The study used both closed and open-ended questionnaires as the essential information collection instrument. Respondents utilized their possessing words in their answers in an open-ended questionnaire. The study used an open-ended questionnaire to gather information from the Othaya Coffee Society staff (Appendix II). The study also used a closed-ended survey isolated into three areas to gather information from the households (Appendix III).

Section A gathered the general respondents' information. Section B gathered information on the contaminating effects of coffee processing honey water on surface water and section C discussed the contaminating effects of coffee honey water to the health of the population that use the nearby contaminated surface water sources. Reactions were captured within the Likert scale extending from 1-5 (from unequivocally oppose this idea to emphatically concur).

3.6.2 Interviews

An interview is a widely used method for collecting information through direct interaction, typically involving a one-on-one conversation between two or more individuals. It allows the researcher to gather in-depth insights, clarifications, and personal perspectives on the subject matter. In Mburu's (2014) study questionnaires were the primary tool for data collection. However, to enhance the richness and depth of the data, these questionnaires were supplemented with interviews and observations, allowing for a more comprehensive understanding of the research topic (Appendix III).

The interviews provided an opportunity for participants to elaborate on their responses and for the researcher to explore areas that may not have been fully covered in the questionnaires. To ensure the relevance of the data collected, the researcher employed a purposive sampling strategy, which targeted respondents who were particularly knowledgeable or involved in the subject under investigation. This method, as suggested by Mugenda et al. (2006) ensures that the most pertinent respondents are selected, thus increasing the quality and relevance of the data gathered.

3.6.3 Observation

To check the status of the coffee washing station foundation and coffee emanating treatment measures utilized by the coffee washing station, the researcher employed the use of a participant observation checklist (Appendix III). In addition, the researcher employed direct observations where there are observable products and outcomes of contaminating effects of coffee honey water on surface water (Mburu, 2014).

3.7 Data Analysis and Presentation

The samples of both surface water and coffee processing honey water were analyzed to induce their quantitative physicochemical characteristics. The examination included suspended solids (TSS), biological Oxygen demand (BOD_5), chemical oxygen demand (COD), Nitrates and Phosphates within the laboratory of KALRO-CRI concurring to the strategies endorsed within the American Public Health Association (APHA) operating manual. The outcomes of the analyzed tests were compared with the World Health Organization (WHO) and American Public Health Association (APHA) operating manuals for the reasonable limits of crude coffee handling nectar water worthy for release into surface water as appearing in Table 3.5.

Table 3.5

World Health Organization (WHO) Allowable Limits of Raw Coffee Processing Honey Water for Control of Surface Water Contamination

Number	Parameters	WHO Allowable Limits
1	Temperature (0C)	25
2	pH	6.5-8.5
3	BOD_5 (mg/l) (5days at 200C)	100
4	COD (mg/l)	300
5	Total suspended solids (mg/l)	200
6	Phosphate (mg/l)	5
7	Nitrate (mg/l	5

Qualitative data collected through descriptive survey with an exploratory approach on the questionnaires was analyzed. The researcher filed the completed questionnaires for coding and analysis. Predictive Analytic Software (PASW), and spreadsheet software were used to analyze the coded information. The results were displayed using descriptive statistics (such as frequency tables, pie-charts and graphs). The researcher analyzed the findings, compared them with available literature reviews, drew conclusions and recommendations.

3.8 Issuance of Research Permit and Ethical integrity

Issuance of the research permit and adherence to ethical standards were foundational to the integrity and legality of this study. A formal research permit was granted by the National Commission for Science, Technology & Innovation (NACOSTI), which provided the legal framework required for data collection and established the boundaries within which the research could ethically operate. This permit allowed the researcher to access various stakeholders and ensure compliance with national regulations governing scientific research.

The researcher prioritized ethical principles throughout the entire research process, ensuring the study adhered to the highest standards of academic and professional conduct. Central to this was informed consent. Before any data collection, participants were thoroughly briefed about the objectives, scope, and potential implications of the study. They were informed of their roles, responsibilities, and the nature of their involvement in clear, understandable language, avoiding technical jargon that could cause confusion. Participants were made aware that their participation was entirely voluntary and that they had the right to withdraw at any time, without facing any penalties or consequences. To formalize consent, each participant signed an introductory letter that indicated their understanding and willingness to engage in the study.

The researcher also placed a strong emphasis on protecting the rights, privacy, and well-being of the participants. Strict measures were implemented to ensure confidentiality and anonymity. No personal identifying information, such as names, addresses, or other sensitive data, was collected, ensuring participants' identities remained completely anonymous. This was particularly important in safeguarding the participants from potential risks that could arise from their association with the study. All collected data was securely stored and treated as highly confidential, with access restricted to the researcher, a research assistant, and the university supervisors overseeing the study. The researcher made clear that the data would be used exclusively for academic purposes related to this study and that no unauthorized individuals or entities would gain access to the information.

To maintain the highest level of ethical rigor, the researcher also followed strict guidelines for data handling, analysis, and reporting. This included safeguarding the accuracy and authenticity of the data, ensuring that findings were not manipulated or misrepresented. Transparency was key to the research process: data was interpreted honestly, and all results—whether positive, negative, or neutral—were reported with complete transparency. This approach upheld the integrity of the research, ensuring that no selective reporting or alteration of findings occurred.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of both experimental and qualitative data after analysis. In addition to desk checks for secondary data, two sets of questionnaires were used to collect primary data from the target participants. The first questionnaire was addressed to Othaya Society staff and provided key information on honey water production from coffee processing, management, effects of coffee honey water on surface waters, and proposed interventions. A second questionnaire targeted households living around coffee washing stations in Othaya to capture demographic and socioeconomic characteristics. This was important to assess how potential contamination by coffee processing honey water affected their lives. Qualitative data were analyzed using predictive analytic software (PASW). Descriptive statistics and results were presented in tables, pie-charts and graphs. The samples of both surface water and coffee processing honey water were analyzed to know their quantitative physicochemical characteristics.

4.2 Bio Data of the Household Respondents

A total of 30 respondents were interviewed from households living near Othaya Society washing stations. All completed questionnaires were well coded and analyzed.

4.2.1 Gender of the Household Respondents

Of the 30 completed questionnaires, 20 women (66.6%) responded and 10 men (33.4%) responded. This is in the Table 4.1.

Table 4.1

Gender of the Household Respondents

Gender of Respondents	Frequency	Percentage (%)

Female	20	66.6
Male	10	33.4
Total	**30**	**100**

4.2.2 Age and Profile of the Household Respondents

As shown in table 4.2, the 30 respondents interviewed belonged to the most productive age groups and were well represented in the study. Most of the respondents are from the local area and have been using River Tana water for more than 10 years. From the 30 respondents,the results showed that 20% of men and 25% of women were between the ages of 20 and 30 (23.4% combined) and 40% of men and 30% of women were between the ages of 31 and 40 (33.3% combined). The results further showed that, 30% of men and 35% of women were between the ages of 41 and 50 (33.3% combined), and 10% of men and 20% of women were over the age of 51 (10% combined).

Table 4.2

Age and Gender Profile of the Household Respondents

Age (Years)	Gender of Respondents

	Male		Female		Total	
	F	Percentage	F	Percentage	F	Percentage
20-30	2	20	5	25	7	23.4
31-40	4	40	6	30	10	33.3
41-50	3	30	7	35	10	33.3
51 and Above	1	10	2	20	3	10
Total	**10**	**100**	**20**	**100**	**30**	**100**

F-Frequency

4.2.3 Use of Water from River Tana

The findings presented in Table 4.3 provide insightful data regarding the usage of River Tana water among different age groups and genders. Specifically, it reveals that among individuals aged 1-5 years, 10% of both males and females have utilized River Tana water, resulting in an overall total of 10% for this age group. When examining the older population, we find that 30% of males and 35% of females have reported using the river water, leading to a combined usage rate of 33.3% for those aged 6-14 years.

Furthermore a significant portion of the respondents indicates prolonged use of River Tana water; 60% of men and 55% of women have been using this water source for more than a decade. This contributes to a noteworthy total of 56.4% of the entire sample, suggesting that a substantial number of individuals have relied on River Tana water for extended periods. These statistics underscore the importance of this water source in the lives of the local population and highlight the potential implications for water quality and health in the community.

Table 4.3

Response on Use of Water from River Tana

Length of water use (Years)	**Respondents on Use of Water From River Tana**					
	Male		**Female**		**Total**	
	F	**Percentage**	**F**	**Percentage**	**F**	**Percentage**
Less than one Year	0	0	0	0	0	0
1-5 Years	1	10	2	10	3	10
6-9 Years	3	30	7	35	10	33.3
10 Years and Above	6	60	11	55	17	56.7
Total	**10**	**100**	**20**	**100**	**30**	**100**

Key

F-Frequency

4.3 Household's Socioeconomic Benefits

Research results show that there are several potential socioeconomic benefits that households could derive from the surface water of the Othaya Coffee Society and the River Tana. The results showed that:

4.3.1 Othaya Coffee Society Contribution to Employment and Income Generation

The study results indicate that the Othaya Coffee Society significantly supports surrounding households by providing employment and income generation. Using a Likert scale to gauge community perceptions, the findings show strong positive sentiments toward the society's impact.

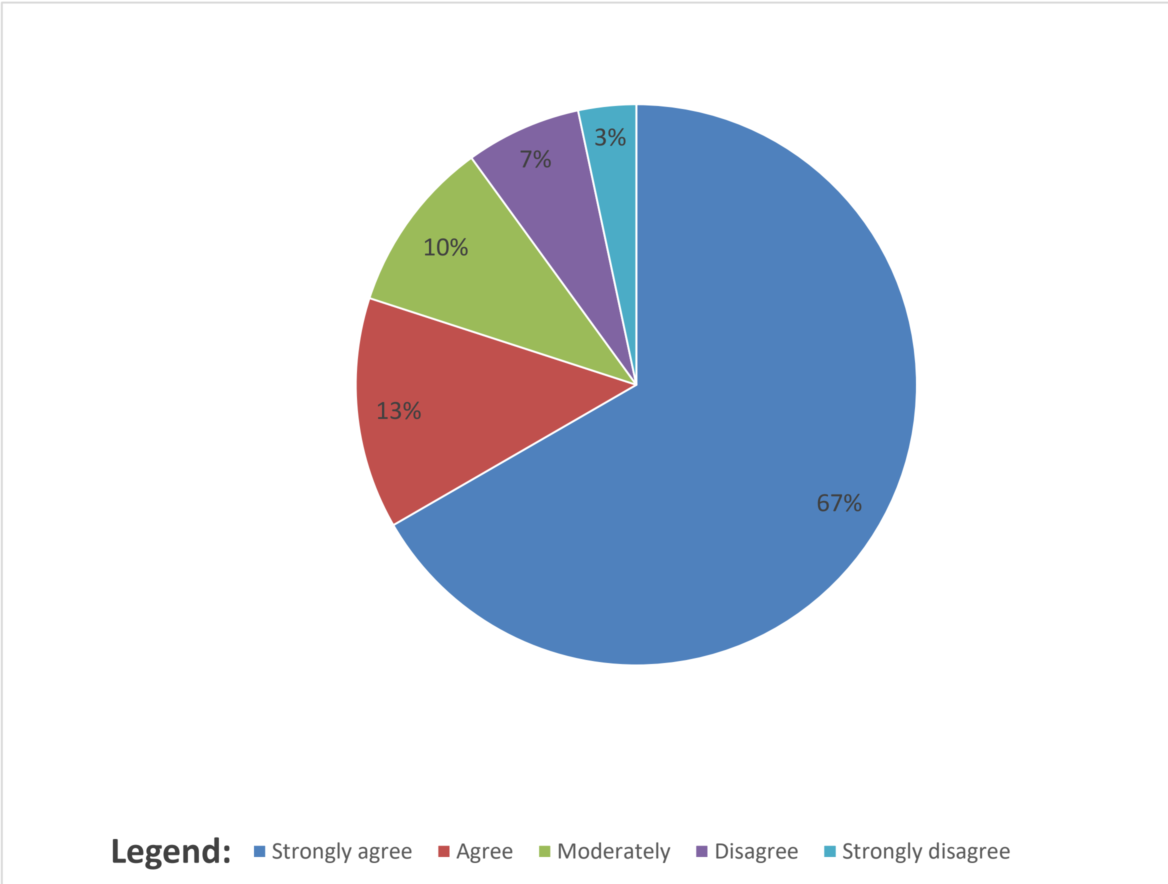
Out of 30 respondents, 22 completely agreed that the Othaya Coffee Society positively contributes to their livelihoods, while four agreed, highlighting the society's benefits to the community. Three respondents held a moderate view, acknowledging some positive effects but expressing potential concerns about certain aspects of the society's operations.

In contrast, only two respondents opposed the claim, and just one strongly disagreed, as shown in Figure 4.1. This distribution emphasizes the community's recognition of the coffee society's essential role in enhancing economic opportunities and overall well-being.

The findings highlight the importance of the Othaya Coffee Society in fostering economic development, suggesting that continued support for its initiatives could further strengthen community resilience and prosperity.

Figure 4.1

Response on Employment and Income Generation



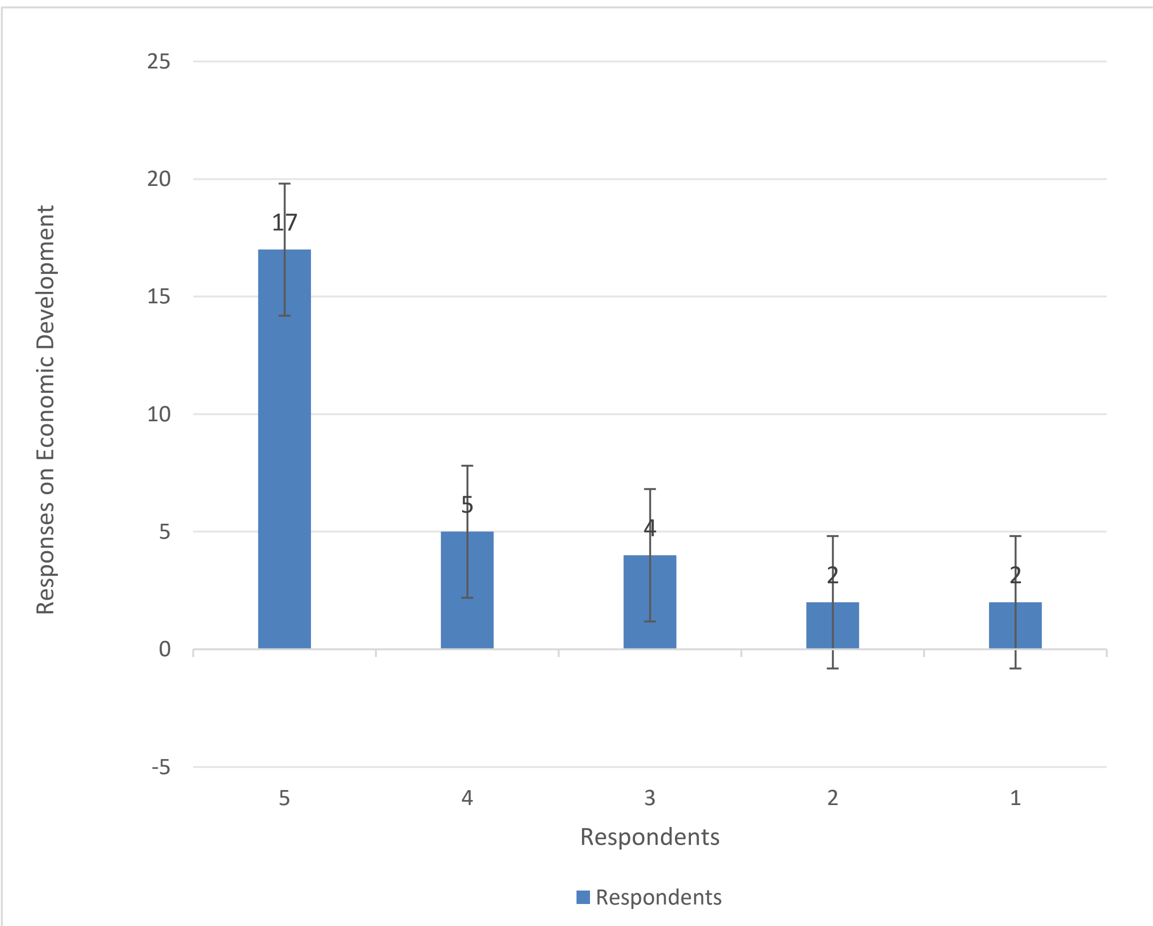
4.3.2 Contribution of Othaya Society to Economic Development

The study results indicate that the Othaya Coffee Society significantly contributes to the economic development of Nyeri County. A Likert scale was used to assess community perceptions, revealing a predominantly positive sentiment. Out of 30 respondents, 17 completely agreed that the society plays a crucial role in regional economic growth, while five expressed agreement, supporting the notion that the society benefits the county's economy. Four respondents took a moderate stance, acknowledging some positive impacts but expressing reservations about the society's broader effects. Conversely, two disagreed, and two completely disagreed with the assertion that the society contributes to economic development, as shown in Figure 4.2.

The findings underscore the society's importance in supporting local economic initiatives and suggest that continued investment in its programs could further enhance the region's economic well-being.

Figure 4.2

Response on Economic Development



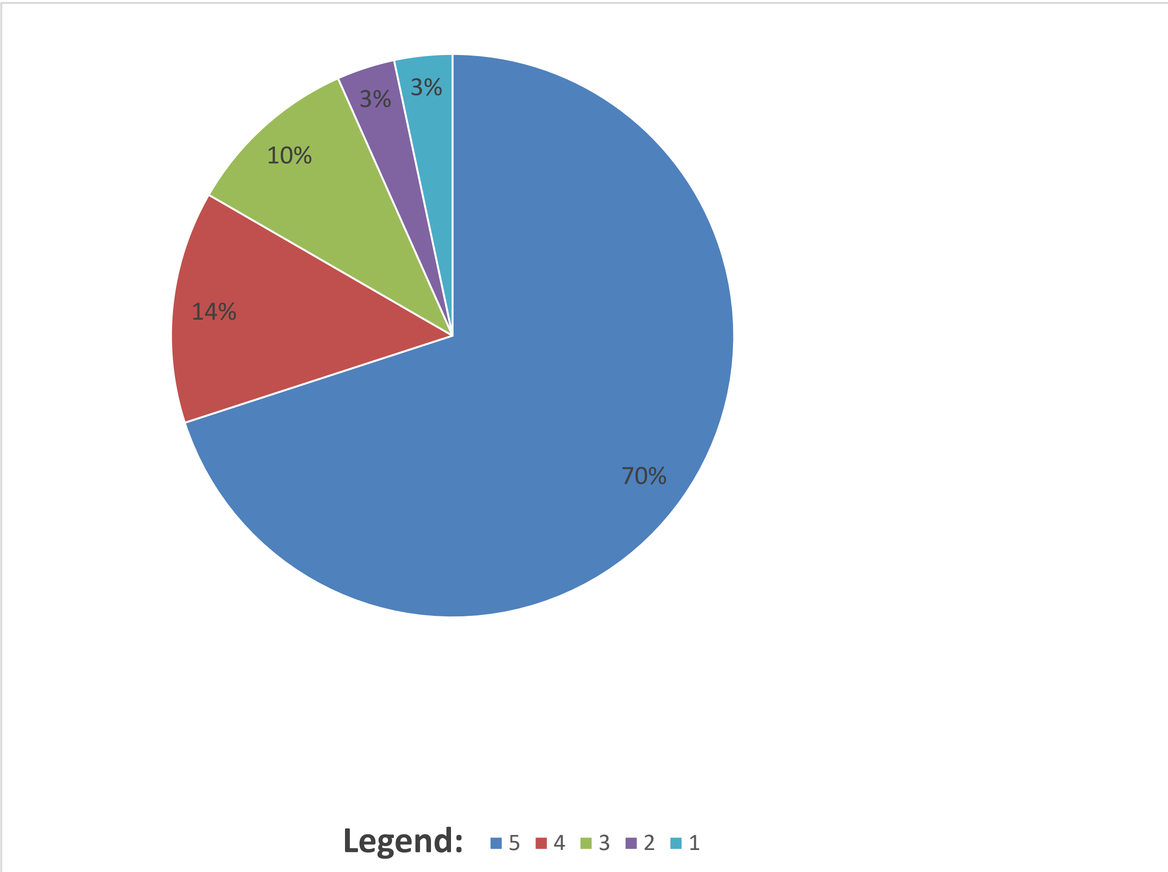
4.3.3 Household's Dependence on Surface Water

The study results indicate that most surrounding households depend on the River Tana for essential needs like personal consumption, aquaculture, and irrigation, highlighting its importance for local livelihoods. A Likert scale assessment shows strong community consensus: 21 out of 30 respondents completely agreed that they rely on the river, while four agreed. Three respondents held moderate views, recognizing the river's significance but expressing concerns about water quality or accessibility.

Conversely, one respondent objected, and another completely disagreed, as shown in Figure 4.3. This distribution underscores the community's acknowledgment of the River Tana as a vital resource. The findings emphasize the need for sustainable water management to ensure the river's availability and quality for consumption and local economic activities. Investing in water conservation and pollution prevention is crucial for safeguarding the river for future generations.

Figure 4.3

Response of Household's Dependence on Surface Water



4.3.4 Livelihood's Support from Coffee Processing Honey Water

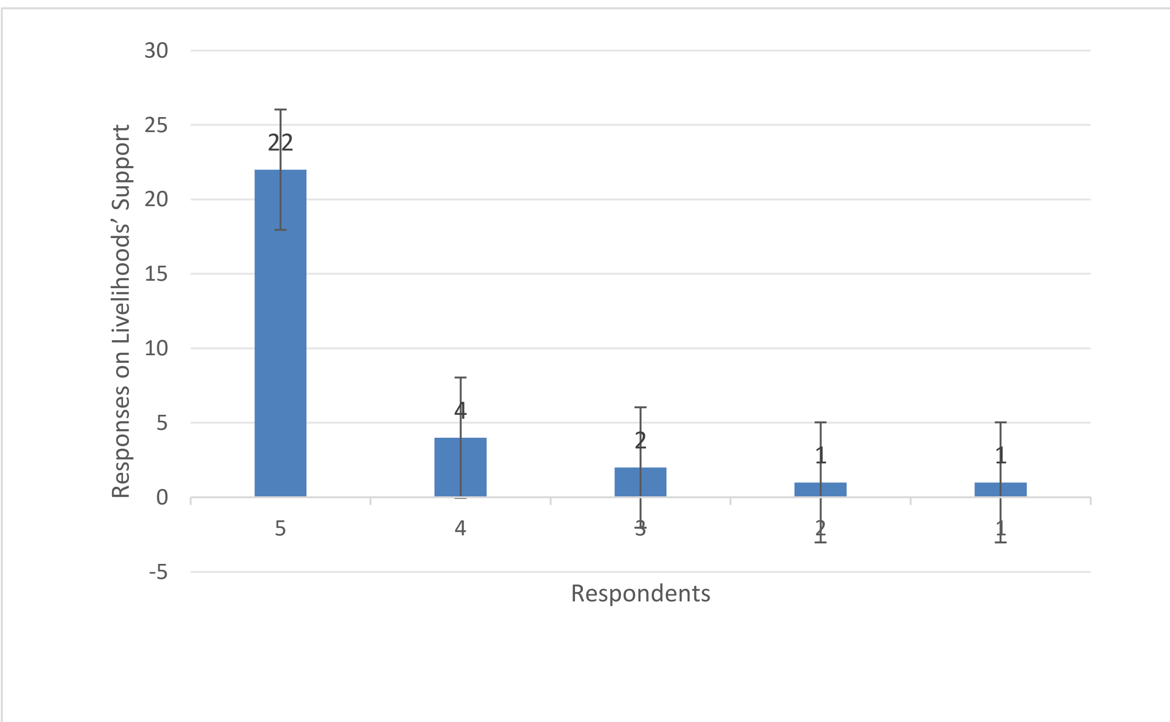
The study's results indicate that the Othaya Coffee Society significantly contributes to the local economy by producing honey water as a by-product of coffee processing. This innovative practice not only adds value to coffee production but also supports the livelihoods of surrounding households. Honey water, derived from processed coffee beans, serves as a unique marketable product, enhancing the community's economic well-being.

Additionally, pulp, another by-product of coffee processing, offers further opportunities for community benefit. This diversification reflects the Othaya Coffee Society's commitment to resource maximization and sustainable agricultural practices.

To gauge community perceptions of these by-products, a Likert scale survey was conducted with 30 respondents. The feedback was largely positive, with 22 respondents expressing complete agreement on the benefits, while four agreed. Only two took a moderate stance, and just one person objected entirely. These findings, illustrated in Figure 4.4, demonstrate strong community support for the Othaya Coffee Society and emphasize the positive impact of these by-products on local livelihoods and sustainability in the region.

Figure 4.4

Response on Livelihood's Support from Coffee Processing Honey Water



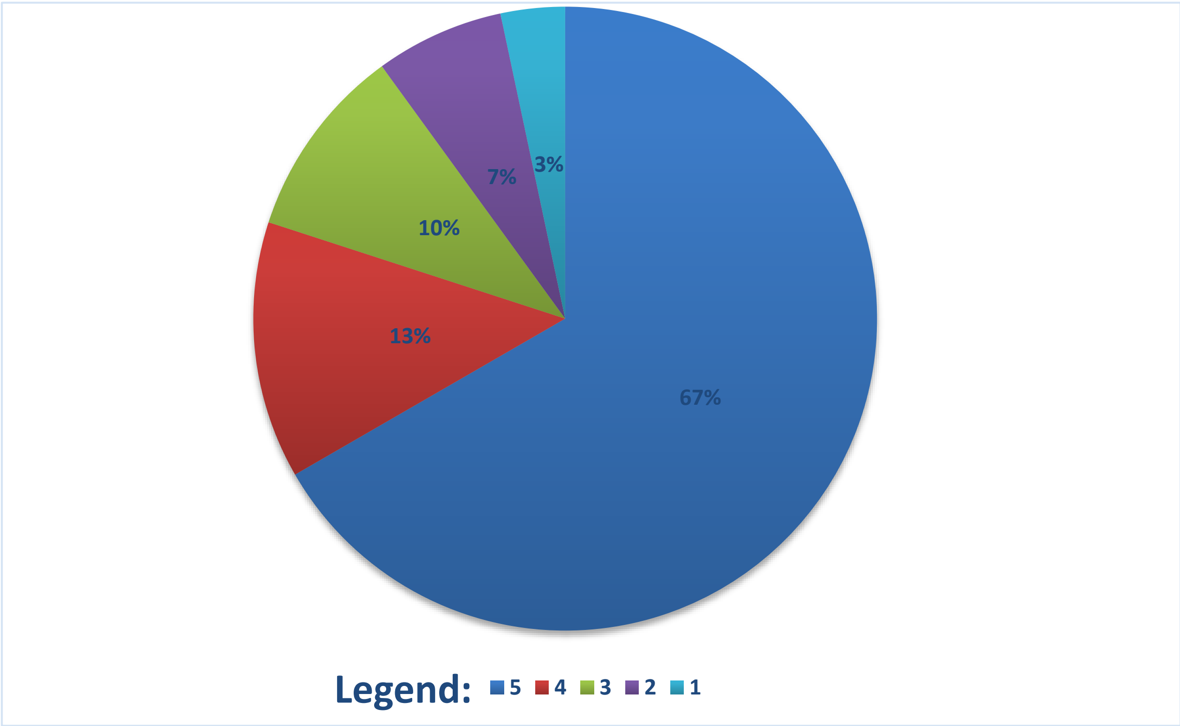
4.4 Contaminating Effects of Coffee Processing Honey Water on Households' Health

4.4.1 Othaya Society has impacted the Surrounding Community Negatively through Surface Water Contamination with Coffee Effluent

The study reveals that coffee farming practices in the Othaya community significantly contribute to the pollution of surrounding surface waters. Runoff from these farms, containing agrochemicals and organic matter, adversely affects the water quality of nearby streams and rivers. Survey results show a strong consensus among respondents: 20 completely agreed that coffee runoff negatively impacts the community, four agreed, and three expressed moderate concern. Only two disagreed with this assessment, and just one completely disagreed, indicating widespread recognition of the environmental challenges posed by coffee cultivation. The findings emphasize the need for sustainable farming practices to minimize runoff and protect water resources. These include adopting better land management techniques, using less harmful agricultural inputs, and exploring agroecological approaches to enhance both environmental health and agricultural productivity.

Figure 4.5

Response on Effects of Othaya Society through Coffee Effluent



4.4.2 Contaminated Surface Water Leads to Global Warming

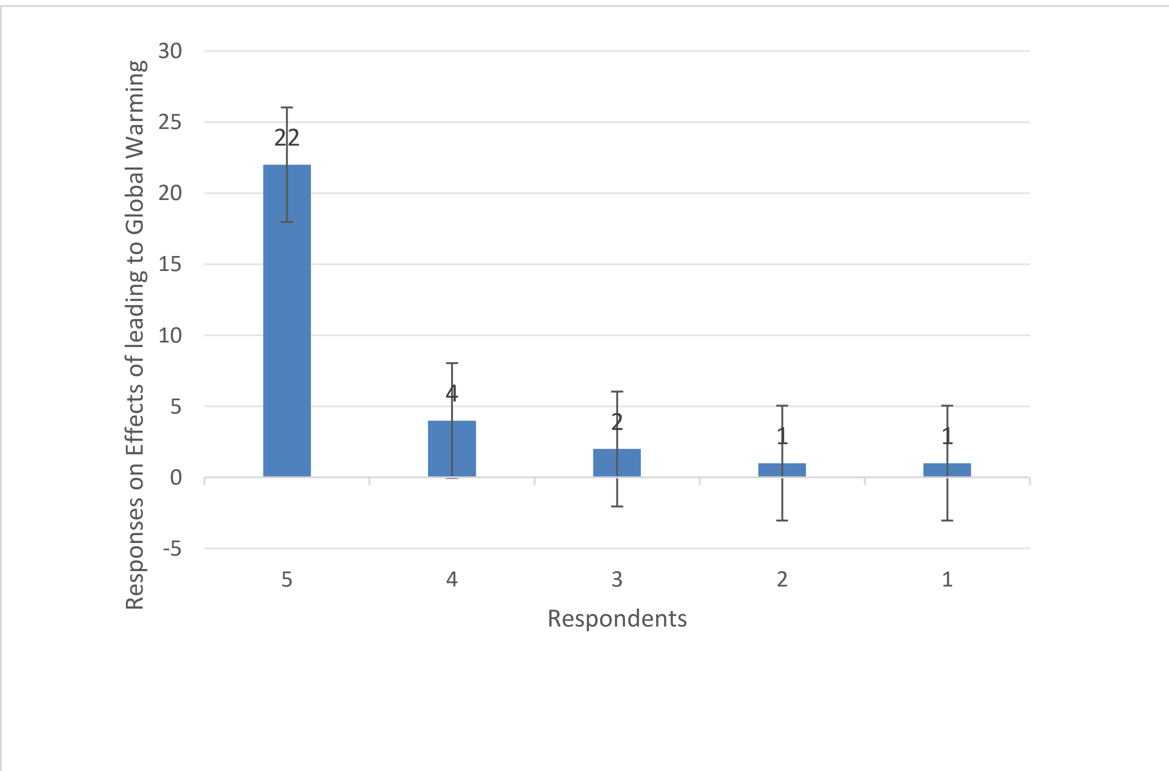
The study's findings indicate that polluted surface water significantly releases nitrates and ammonium compounds, which contribute to greenhouse gases and drive global warming. This connection emphasizes the urgent need to address water quality issues, impacting both local ecosystems and global climate stability. To assess community awareness, a Likert scale survey was conducted with 30 respondents. The results showed that 17 participants completely agreed that polluted surface water contributes to greenhouse gas emissions, while five agreed, reflecting a general understanding of the issue.

In contrast, four respondents took a moderate stance, recognizing the issue but not fully grasping its impact. Two individuals disagreed, and another two completely disagreed, highlighting a lack of consensus on the link between polluted water and greenhouse gas emissions.

These results, shown in Figure 4.6, demonstrate varying levels of awareness among community members regarding environmental pollution and its role in global warming. The strong agreement suggests a growing recognition of the need for environmental action, while the dissent points to the necessity for further education on this critical issue.

Figure 4.6

Effects of Contaminated Surface Water Leading to Global Warming



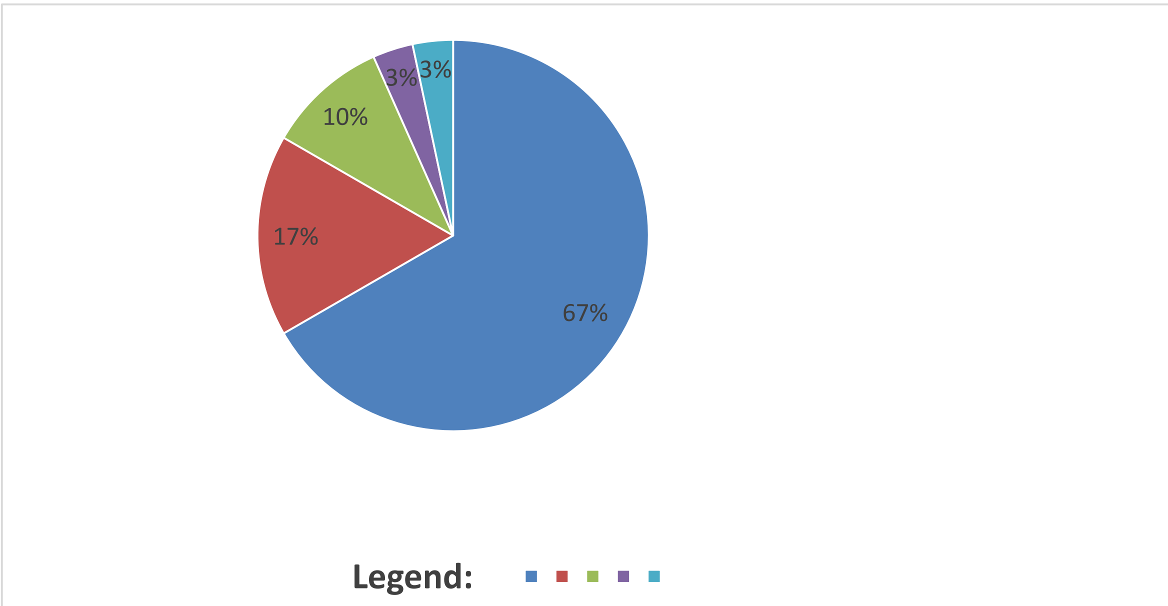
4.4.3 Contaminated Surface Water Affects Aquatic Population

The study revealed that contaminated surface water releases nitrogen- and phosphorus-containing compounds, leading to eutrophication. This process causes excessive nutrient enrichment, resulting in rapid algal growth. As algae proliferate, they compete for dissolved oxygen, creating hypoxic conditions that harm fish and other aquatic life, ultimately reducing their populations. Eutrophication can disrupt entire ecosystems and degrade water quality. To gauge community awareness, a Likert scale survey was conducted with 30 respondents. Results showed that 20 participants completely agreed that contaminated surface water contributes to eutrophication and its harmful effects, while five agreed, indicating a general understanding of the issue.

However, opinions varied: three respondents took a moderate stance, one disagreed, and another completely disagreed, reflecting a lack of consensus about the link between surface water contamination and eutrophication. These findings, illustrated in Figure 4.7, highlight varying levels of awareness within the community regarding the impacts of contaminated water. The strong agreement suggests increasing recognition of the need for action, while the dissent points to the necessity for further education on this critical ecological issue.

Figure 4.7

Response on Contaminated Surface Water Affects Aquatic Population



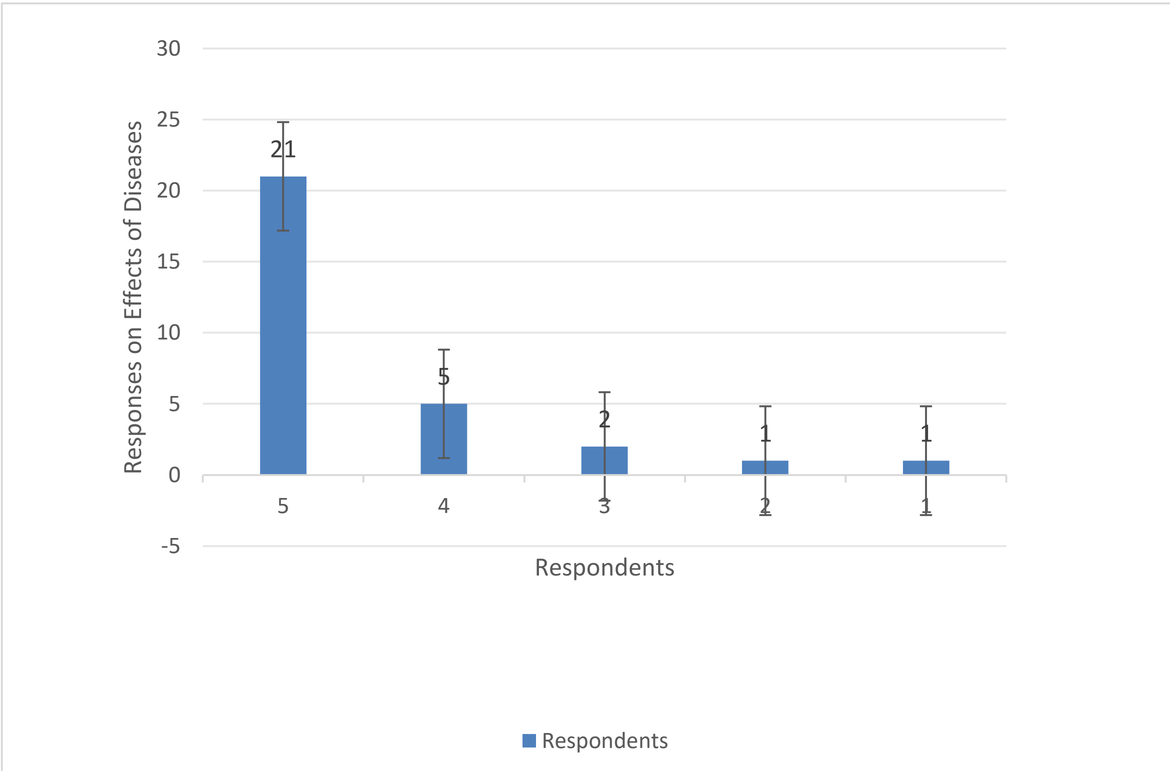
4.4.4 Contaminated Water Causes Waterborne Disease and Body Irritations

The study highlighted significant public health concerns related to contaminated water, particularly in connection with waterborne diseases such as Bilharzia, typhoid fever, cholera, diarrhea, and dysentery. Contaminated water carries harmful pathogens and can cause inflammatory responses, eye irritation, dizziness, gastrointestinal issues, and respiratory problems.

To assess public perceptions of these risks, a Likert scale survey was conducted with 30 participants. Results showed that 21 respondents (70%) completely agreed that contaminated water poses a serious health risk, five (16.7%) agreed, two (6.7%) were neutral, and one (3.3%) disagreed. This distribution, illustrated in Figure 4.8, indicates strong consensus on the dangers of contaminated water.

Figure 4.8

Effects of Contaminated Water Causing Waterborne Disease and Body Irritations



4.4.5 Nitrates in the Contaminated Water Cause Blue Baby Syndrome

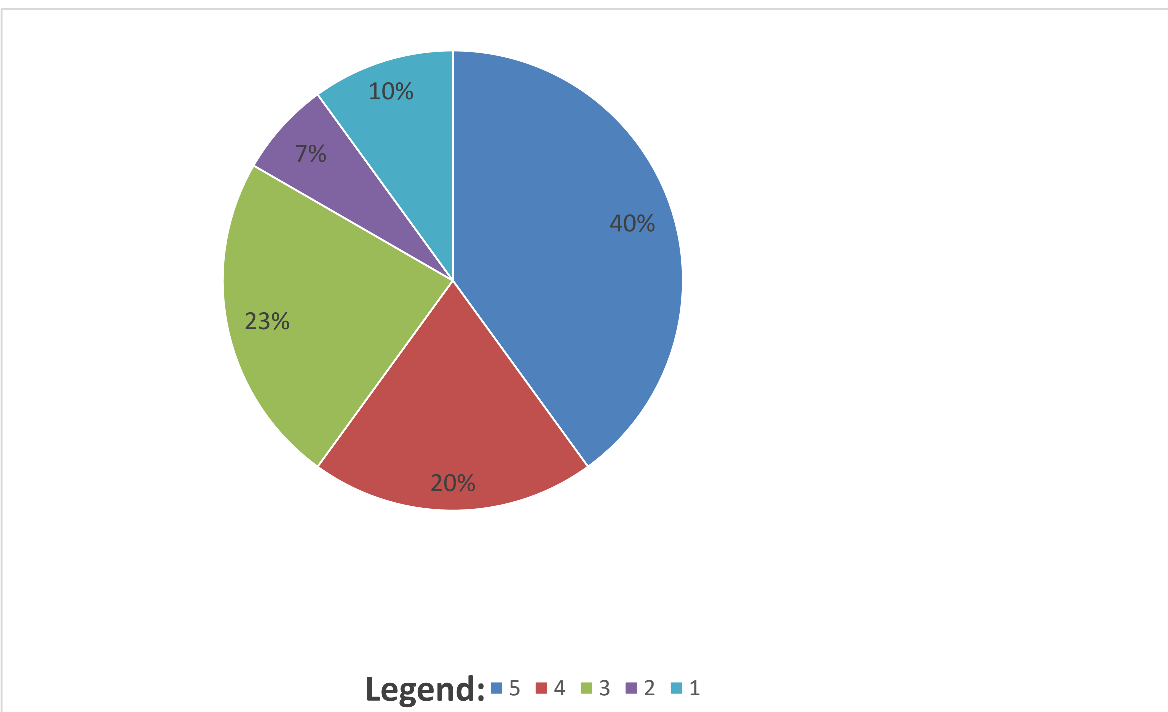
The study reveals a troubling link between ingesting nitrates in contaminated water and blue baby syndrome, or methemoglobinemia, which reduces oxygen transport in infants. To evaluate community awareness of this issue, a Likert scale survey was conducted with 30 respondents.

Results showed that 12 participants completely agreed that nitrates in contaminated water could cause blue baby syndrome, reflecting strong awareness of the health risks. Six respondents also agreed, indicating a general understanding of the issue. However, opinions varied: seven took a moderate stance, acknowledging potential risks without fully grasping their severity. Meanwhile, two disagreed, and three completely disagreed, highlighting a lack of consensus on the connection between nitrates in water and blue baby syndrome.

These findings, illustrated in Figure 4.9, show varying levels of awareness about the health implications of contaminated water. While the majority recognizes the need for action, the dissenting views indicate a need for further education on this critical health issue.

Figure 4.9

Effects of Nitrates from Contaminated Surface Water



4.5 Othaya Society Staff and Coffee Effluent Management Systems

A total of 79 questionnaires were created and distributed to company employees. At the end of the study, 48 questionnaires were returned, coded and analyzed. This corresponded to a response rate of 61%. This was due to the short time given to respondents to submit their contributions and the fear of information leakage from the Othaya Association. The remaining 31 questionnaires were not returned.

4.5.1 Awareness on Contaminating Effects of the River Tana by Othaya Society

A total of 48 employees participated in the survey on environmental awareness related to the company's operations. The results showed that 36 employees (75%) were aware of river surface water pollution caused by coffee runoff from the company's washing stations, indicating a solid understanding of the environmental impact among the workforce. In contrast, 12 employees (25%) were unaware of the pollution resulting from coffee wastewater. This gap presents an opportunity for the company to improve education and awareness regarding environmental issues among its staff.

4.5.2 Coffee Effluent Management Systems in Place

Of the 48 respondents, 38 (80%) of the Othaya Society employees surveyed felt that there was no adequate coffee wastewater management mechanism enforced by the Othaya Society management. while the remaining 10 employees (20%) indicated that society had good, designed drainage basin. The study also found that honey water from coffee processing usually finds its way into water bodies, causing a contaminating effects. The study also found that policies and regulations on the effects of coffee honey water on surface water pollution were not being effectively implemented.

4.5.3 Contaminating Effects of Surface Water on the Downstream Population

In the survey, out of 48 respondents, 30 employees (62%) reported severe surface water pollution along the River Tana, while the remaining 18 employees (38%) reported severe surface water pollution along the River Tana. The results indicated that contamination of surface water by coffee sewage had adversely affected the livelihoods of people downstream.

4.6 Surface Water and Coffee Processing Honey Water collection procedures

A total of twelve (12) surface water samples and four (4) coffee wastewater samples were systematically collected from three designated sampling points within each of the four operational blocks, which consist of 16 active washing stations along the River Tana. This comprehensive sampling strategy aimed to capture a holistic view of water quality and contamination levels in the area.The selected sampling points included an upstream control site (UPS), located 100 meters away from potential contamination sources, which served as a baseline for evaluating the natural water quality of the river. This control post was crucial for assessing the impact of the washing stations on river health, providing a point of comparison for the other samples. The entry point (ENP) was strategically chosen to represent areas of severe contamination, where wastewater from the coffee processing operations is likely to enter the river system.

By analyzing samples from this site, the researcher aimed to quantify the extent of pollution and its immediate effects on the aquatic environment. Additionally, a downstream sampling point was included to evaluate the river's ability to recover from contamination. This location provided insights into the natural remediation processes that might occur as water flows away from the pollution source, shedding light on the resilience of the ecosystem and the effectiveness of any mitigating factors present. Each sample was carefully collected and stored following standardized protocols to ensure accuracy and reliability in subsequent analyses. The study aimed not only to quantify contaminants but also to assess the broader ecological impacts on the river's health and its surrounding communities. By employing this multi-point sampling approach, the research could provide a comprehensive understanding of water quality dynamics in relation to coffee processing activities, informing both environmental management strategies and community awareness initiatives.

4.6.1 Physicochemical Analysis

The samples were collected from four blocks using 500 ml plastic vessels sterilized with 10% v/v nitric acid and washed with purified water. Protective gloves were worn during collection. Sealed sample bottles were stored in a freezer below 3°C at room temperature to maintain physicochemical properties and promptly sent to the laboratory for analysis. pH, temperature, total dissolved solids, and conductivity were measured onsite using respective meters. In the laboratory, COD, total nitrate ($N0_3^-$), and phosphate (PO_4^{3-}) were analyzed with a spectrometer (DR/2010 HACH, Loveland, USA) following HACH instructions. Turbidity, dissolved oxygen (DO), and biological oxygen demand (BOD_5) were assessed using standard APHA methods, while total suspended solids (TSS) were determined using a photometer. Details are presented in Table 4.4.

Table 4.4

Physicochemical Analysis of Variables

(a)Physical Variables mean averages						
Block/ Factory	**SS**	**pH**	**T(0^C)**	**EC(µS/cm)**	**TDS(mg/l)**	**T(mg/l)**
Block 1/ Chinga	Upstream	6.52	21.81	106	158	200
	Raw Effluent	4.15	21.00	742	1857	322
	Entry Point	4.25	20.62	690	1420	720
	Downstream	6.91	19.54	650	1360	660
Block 2/ Ichamama	Upstream	6.33	20.53	110	170	195
	Raw Effluent	4.14	22.00	743	1856	321
	Entry Point	4.52	19.22	730	1370	700
	Downstream	6.61	19.81	675	1340	650
Block 3/Iriaini	Upstream	6.43	20.53	109	145	210
	Raw Effluent	4.16	23.00	741	1855	320
	Entry Point	4.32	20.92	665	1480	730
	Downstream	6.31	19.54	674	1240	640
Block 4/ Rukira	Upstream	6.82	19.43	105	180	220
	Raw Effluent	4.17	24.00	744	1858	324
	Entry Point	3.81	18.82	720	1460	750
	Downstream	6.43	19.73	672	1320	670

Legend:SS-Sampling Site,EC-Electrical Conductivity,TDS-Total Dissolved Solids, T-Turbidity, DO-Dissolved Oxygen, P-Phosphate

Table 4.4

Physicochemical Analysis of Variables

(b) **Chemical Variables mean averages**						
Block/Factory	**SS**	**N(mg/l)**	**P (mg/l)**	**BOD_5(mg/l)**	**DO (mg/l)**	**COD(mg/l)**
Block 1/Chinga	Upstream	3.06	3.76	58	6.95	65
	Raw Effluent	4.86	3.08	1674	1.89	5795
	Entry Point	4.35	4.45	294	6.10	365
	Downstream	3.24	3.64	80	5.50	85
Block 2/Ichamama	Upstream	3.16	3.47	70	6.90	90
	Raw Effluent	4.91	3.07	1672	1.87	5796
	Entry Point	4.50	4.52	850	6.05	6150
	Downstream	3.29	3.85	120	5.60	125
Block 3/Iriaini	Upstream	3.40	3.96	60	6.92	155
	Raw Effluent	4.76	3.10	1670	1.92	5791
	Entry Point	4.30	4.65	750	6.15	7085
	Downstream	3.26	3.78	102	5.80	154
Block 4/Rukira	Upstream	3.35	3.90	90	6.94	105
	Raw Effluent	4.92	3.12	1676	1.89	5789
	Entry Point	4.45	4.62	830	6.12	7140
	Downstream	3.44	3.72	502	5.30	625

Legend: COD-Chemical Oxygen Demand, BOD-Biological Oxygen Demand, N-Nitrate

4.6.2 Discussion of Results

The study provides a detailed analysis of the impact of coffee processing honey water on surface water quality and its socioeconomic implications. In relation to the study's specific objectives, the findings could be interpreted as follows:

To determine the level of contaminants contained in coffee honey water: The study found that the inlet pH levels in all four blocks were less than 5 (acidic), below the WHO tolerance limit of 6.5 to 8.5 for treated coffee waste discharge. This acidity, caused by organic matter decomposition and carbonic acid formation, is toxic to aquatic ecosystems and downstream users. Downstream pH values were higher, indicating some recovery. These findings align with previous studies (Bisekwa et al., 2021; Tsigereda et al., 2013). Inlet temperatures were below the WHO limit of 25°C, but higher than downstream locations due to microbial degradation of organic matter. Downstream temperatures were lower due to the water's self-healing ability. Electrical conductivity (EC) at all entry points was higher than upstream and downstream, indicating untreated coffee wastewater with high ion concentrations, potentially leading to eutrophication. This is inconsistent with findings by Workinesh (2017). Total dissolved solids (TDS) levels at the entry points ranged from 1,370 to 1,480 mg/l, far exceeding the WHO limit of 200 mg/l. High TDS and EC values increased water salinity, reducing its suitability for drinking and irrigation. High turbidity values (700-750 mg/l) were observed due to dissolved solids, affecting light transmission and photosynthesis, and potentially altering community structure. Dissolved oxygen (DO) values were low downstream, indicating heavy contamination by coffee waste and reduced self-cleaning capacity of rivers. Entry point chemical oxygen demand (COD) values ranged from 365-7140 mg/l, much higher than the WHO limit of 300 mg/l, indicating significant organic pollution. Biological oxygen demand (BOD_5) values also exceeded the World Health Organization's limit of 100 mg/l. This aligns with studies by Kosgey (2013) and Workinesh (2017), showing slow degradation of organic matter by microbes, leading to oxygen depletion and potential anoxia, which can kill aquatic life (Tsigereda et al., 2013; Kanyiri et al., 2017). Nitrogen concentrations at the inflow points (4.35–4.45 mg/L) were higher than upstream (3.06– 3.40 mg/L), indicating contamination. Excess nitrates can cause health issues such as Blue Baby Syndrome. This is supported by Dejen et al. (2015) who found that contaminated water releases greenhouse gases. Phosphorus concentrations at the inlets (4.45–4.65 mg/l) were higher than upstream (3.47–3.90 mg/l) but below the WHO limit of 5.00 mg/l. Excess nitrogen and phosphorus can cause eutrophication and harmful algal blooms, releasing toxins that affect aquatic life and socioeconomic livelihoods.

To evaluate the impact of coffee honey water on the quality of surface water: The study showed that coffee honey water severely impacts surface water quality, particularly at the entry points of the wastewater into water bodies. Elevated levels of Electrical Conductivity, Total Dissolved Solids, Chemical Oxygen Demand, and Biological Oxygen Demand contributed to the decline in water quality, disrupting aquatic ecosystems by decreasing oxygen levels and increasing salinity, thus harming aquatic life and the river's self-healing ability. The downstream recovery of pH and temperature values indicated some natural recuperation, though the contamination was still severe enough to affect downstream water users and aquatic organisms.This aligned with studies by Kosgey (2013) and Workinesh (2017).

To examine the socioeconomic effects on the downstream population from the discharge of raw coffee honey water: The elevated levels of Total Dissolved Solids, Electrical Conductivity, and nitrogen/phosphorus concentrations reduce water's suitability for drinking and irrigation, impacting the livelihoods of downstream populations who rely on these water sources. The potential for eutrophication and algal blooms from excess nitrogen and phosphorus further threatened aquatic ecosystems, which could lead to long-term harm to fisheries, agriculture, and human health. This aligned with findings by Workinesh (2017). The contamination also presented health risks, such as Blue Baby Syndrome due to high nitrate levels, as supported by Dejen et al. (2015).

To identify and propose effective measures to reduce the contaminating effects of coffee honey water: The study implies that better treatment of coffee wastewater is essential to prevent environmental damage. Potential measures include: Implementation of proper wastewater treatment systems to reduce the levels of organic matter and toxic substances before the water is discharged. Aeration and filtration systems to lower BOD, COD, and improve DO levels in the water, thereby promoting a healthier ecosystem. Monitoring programs to regulate the discharge levels in accordance with WHO standards, ensuring long-term sustainability for both the environment and local communities. Promotion of sustainable agricultural practices, reducing the overall environmental impact of coffee production on surface waters.

4.7 Measures To Reduce Further Contaminating Effects On Surface Water

Efforts to mitigate the polluting effects of industrial effluents, including coffee honey water, on surface waters have been made by various regulatory authorities. However, the study identified several critical gaps in the enforcement and implementation of policies aimed at reducing water Contamination. Specifically, the findings indicated that while laws and regulations exist, their execution, particularly in the context of the Othaya Coffee Society, has been inadequate. The lack of proper coordination and clear management policies for industrial wastewater, as well as the absence of consistent monitoring and enforcement, have exacerbated the contamination of surface waters by untreated coffee effluents.

The study's primary objectives included determining the level of contaminants in coffee processing honey water, evaluating the impact of this effluent on surface water quality, examining the socioeconomic effects on downstream populations, and proposing measures to mitigate these effects. Determining the level of contaminants in coffee processing honey water revealed significant levels of pollutants, including nitrates, phosphates, suspended solids, and organic matter, all of which contributed to the deterioration of water quality in the River Tana. These contaminants have been linked to severe environmental issues such as eutrophication, which promotes excessive algal growth, reducing oxygen levels and threatening aquatic ecosystems.

Evaluating the impact of coffee honey water on surface water quality demonstrated the harmful effects of untreated effluents on water sources. The study found that the coffee processing industry contributed to elevated chemical oxygen demand (COD), biological oxygen demand (BOD_5), and increased turbidity in downstream water bodies. This degradation not only affected water quality but also had a direct impact on local communities that rely on these waters for domestic use and agricultural activities. Examining the socioeconomic effects on downstream populations revealed that the contamination of surface waters from untreated coffee effluent significantly impacted livelihoods. Communities relying on fishing, farming, and clean water for household use were particularly vulnerable, experiencing reduced income, compromised health, and increased financial burdens as a result of deteriorating water quality.

Identifying and proposing effective measures to reduce the contaminating effects of coffee honey water focused on several key areas:

Strengthening wastewater management policies: The study highlighted deficiencies in the Othaya Coffee Society's wastewater management framework, including a lack of coordinated policies and regular monitoring of effluent discharge. It recommended that government agencies work closely with coffee processing industries to develop and enforce robust wastewater treatment protocols.

Improving enforcement of regulations: There is an urgent need for stricter enforcement of government guidelines on industrial wastewater management. Regulatory bodies such as the National Environmental Management Authority (NEMA) must conduct frequent inspections and impose penalties on companies that fail to treat their wastewater before discharging it into surface waters.

Investing in wastewater treatment technologies: The study recommended that the Othaya Coffee Society and other coffee industries invest in modern wastewater treatment facilities to ensure that effluent is adequately treated before being discharged into local water bodies. Implementing cost-effective technologies such as constructed wetlands, biofilters, and anaerobic digesters could significantly reduce the concentration of pollutants in coffee honey water.

Private sector involvement and community education: The study identified a notable absence of private sector involvement in raising awareness about sustainable water management practices. Collaborating with private entities to educate communities on the importance of water conservation and pollution prevention can bridge the gap between industrial growth and environmental protection. Public-private partnerships could facilitate the development of community-led water management initiatives that benefit both the local population and the environment.

Encouraging sustainable coffee production practices: Promoting eco-friendly processing methods, such as the use of mechanical drying to reduce the reliance on water-intensive processes, could also play a significant role in reducing the volume of effluent generated. Adopting sustainable practices could ensure a balance between economic growth and environmental conservation in the coffee sector.

4.8 Summary

In summary, the analysis of wet coffee processing plants revealed significant contamination of surface waters due to the discharge of untreated coffee honey water. The effluent was found to contain high levels of acidity, organic loading, including elevated biological oxygen demand (BOD_5) and chemical oxygen demand (COD), as well as nutrients like nitrates and phosphates, and suspended solids. These contaminants exceeded acceptable thresholds and contributed to the degradation of water quality in the region.

By comparing upstream and downstream sites, the study demonstrated a clear deterioration in the water quality of the river, with downstream areas showing significantly higher levels of pollution. The river had effectively become a repository for untreated wastewater from the coffee processing industry, directly impacting the livelihoods of communities in Othaya and beyond. This pollution disrupted not only local economic activities, such as fishing and agriculture, but also posed health risks to the broader population relying on the river for water consumption and household use.

The study concluded that the wastewater from the wet coffee processing industry does not comply with the World Health Organization (WHO) standards for the discharge of treated wastewater into surface waters. This underscores the urgent need for cost-effective and adaptable wastewater treatment technologies to mitigate the negative environmental impacts. Implementing such technologies is essential to ensuring compliance with existing water policies and regulations and safeguarding the well-being of both the environment and local communities.

In line with the study’s objectives: Determining the level of contaminants confirmed that untreated coffee honey water contained hazardous levels of organic matter, nutrients, and solids, which contributed to severe water pollution. Evaluating the impact of coffee honey water on surface water quality demonstrated that water quality declined significantly downstream due to the release of untreated effluent. Examining the socio-economic effects revealed that the contamination of surface waters compromised the livelihoods of downstream communities, who rely on clean water for agriculture, fishing, and domestic use, thereby affecting the local economy and public health.

Identifying effective measures to reduce contamination highlighted the need for adopting modern, sustainable wastewater treatment solutions and for stronger enforcement of environmental regulations to prevent further degradation of surface water resources. Thus, the study emphasizes the importance of finding innovative and practical solutions to ensure the responsible management of coffee processing effluent and to protect the health and prosperity of affected communities.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The study examined the contaminating effects of coffee processing honey water on surface water quality, focusing on the level of contamination and its environmental and health consequences, with a particular emphasis on the Othaya Coffee Society in Nyeri County, Kenya, as a case study. The key objectives were to determine the concentration of contaminants present in coffee honey water, assess the subsequent impact of this contamination on surface water quality, evaluate the socioeconomic effects on downstream communities, and propose effective strategies to mitigate future pollution from coffee processing.

Data collection incorporated both primary and secondary sources. Primary data were collected through field visits, laboratory analyses, and firsthand observations, while secondary data were drawn from reports, publications, and relevant literature. The study employed stratified and simple random sampling techniques, coupled with descriptive surveys, interviews, questionnaires, and qualitative observational methods. Surface water and coffee honey water samples were analyzed for their physicochemical properties, and the qualitative data were coded and analyzed using PASW (Predictive Analytics Software) and spreadsheet tools. Descriptive statistics, including tables, pie charts, and graphs, were used to present the findings clearly and comprehensively.

The study's key findings revealed that households in the area benefited socioeconomically from the Othaya Coffee Society and River Tana. The coffee society provided employment opportunities and income generation for local residents, thereby contributing to Nyeri County's economic development. Many households depended on the River Tana for their water supply, as well as for activities like aquaculture and irrigation, which were critical to local food production and livelihoods. In addition to these benefits, coffee processing produced honey water and pulp, which were often used to support local agricultural activities. However, despite these socioeconomic benefits, the study also found significant negative environmental impacts. Specifically, 61% of the respondents reported that wastewater from coffee processing activities polluted the River Tana.

The contaminated wastewater was found to release nitrates and ammonium into the environment, which contributed to the emission of greenhouse gases and exacerbated global warming. Additionally, the presence of nitrogen and phosphorus in the wastewater led to the eutrophication of local water bodies. Eutrophication resulted in the excessive growth of algae, or algal blooms, which depleted oxygen levels in the water and led to the decline of aquatic life. This process not only degraded the water quality but also threatened the ecosystems and biodiversity dependent on the river.

The health impacts of consuming contaminated water were also alarming. Respondents reported various health issues, including bilharzia, typhoid, cholera, diarrhea, dysentery, body inflammation, eye irritation, dizziness, stomach problems, and respiratory issues. The presence of excess nitrates in the water was a particular concern, as it posed the risk of blue baby syndrome, a condition that affects infants who consume water with high nitrate concentrations. The study's interviews also uncovered poor wastewater management practices at the Othaya Coffee Society. Wastewater was discharged into poorly designed waste pits, with minimal pollution control measures in place to prevent the contamination of surface water bodies.

Physicochemical analyses of the water samples showed that the contaminated water was highly acidic and contained elevated levels of organic matter, as indicated by the high biological oxygen demand (BOD5) and chemical oxygen demand (COD) values. The samples also contained excessive concentrations of nutrients such as nitrates and phosphates, as well as suspended solids. Water quality downstream of the coffee processing sites was significantly worse than that of upstream sites, confirming that untreated coffee wastewater was a major source of contamination in the river. The poor water quality downstream indicated that the pollutants from the coffee processing industry were being released into the river without adequate treatment, further compromising the health of the local environment and communities.

The study also identified a significant gap in the industrial wastewater management practices of the Othaya Coffee Society. There was no effective framework for managing wastewater from the coffee processing plants, and government regulations concerning wastewater discharge were not being consistently monitored or enforced. The lack of penalties for companies that discharged untreated wastewater exacerbated the situation, placing both public health and surface waters at considerable risk. Furthermore, the study highlighted the minimal involvement of the private sector in raising awareness and educating the local community about the importance of surface water management. This lack of involvement hindered efforts to strike a balance between industrial growth and environmental sustainability.

The study emphasized the urgent need for better wastewater management practices in coffee processing regions like Nyeri County. It called for the implementation of cost-effective and environmentally sustainable wastewater treatment technologies to prevent further degradation of the River Tana and other local water bodies. The study also advocated for stricter enforcement of environmental regulations and penalties for non-compliance to protect public health and the environment. In addition, it recommended increasing awareness and education on surface water management among both coffee processing industries and the local community to ensure that industrial activities are conducted in a manner that supports both economic growth and environmental protection. Addressing these challenges is essential for the long-term sustainability of water resources and the livelihoods of the communities that depend on them.

5.2 Conclusions

Based on the study objectives that determined the level of contaminants in coffee honey water, assessed the impact of this contamination on surface water quality, evaluated the socioeconomic effects on downstream communities, and proposed measures to reduce future contamination, the following conclusions were made:

Contaminant Levels in Coffee Honey Water: The study revealed that untreated coffee wastewater, or "honey water," discharged from Othaya Coffee Society contained high levels of contaminants. These contaminants significantly exceeded World Health Organization (WHO) standards for treated wastewater, posing a substantial risk to surface water quality. The effluent altered the physical, chemical, and biological properties of nearby rivers, particularly the River Tana, underscoring the pressing need for proper treatment mechanisms before disposal.

Impact on Surface Water Quality: The discharge of untreated coffee honey water into nearby water bodies resulted in severe water contamination. The study documented significant deterioration in the water quality of the River Tana, with both workers and community members linking the contamination to increased turbidity, harmful chemical concentrations, and a reduction in biological diversity. This degradation endangers not only the aquatic ecosystem but also the health of communities reliant on the river for drinking water, agriculture, and daily needs.

Socioeconomic Effects on Downstream Communities: The downstream communities, especially those dependent on the River Tana, faced severe socioeconomic impacts due to water contamination. Residents reported waterborne illnesses, loss of access to clean water, and adverse effects on agriculture, which relies heavily on the river for irrigation. The public health risk, combined with reduced agricultural productivity, negatively impacted livelihoods, particularly for low-income households. This highlights the crucial link between environmental health and community well-being.

5.3 Recommendations on Research Findings

Based on the conclusions drawn from the study, a multifaceted approach is recommended to address the environmental and health challenges posed by coffee effluents in the Othaya region. The following measures are crucial for mitigating the adverse effects of coffee processing on surface water quality and ensuring the well-being of the local community.

Treatment of Coffee Effluents: First and foremost, it is essential that the Othaya Coffee Society Management take immediate steps to treat coffee effluents prior to their discharge into surface waters. All coffee processing industries within the study area must be equipped with efficient and appropriate wastewater treatment facilities. These facilities should be designed to handle the unique characteristics of coffee waste, ensuring that the treated wastewater meets established environmental standards before being released into receiving water bodies. Regular inspections and efficiency checks of these treatment facilities must be conducted by responsible authorities to ensure compliance and performance.

In addition to wastewater treatment facilities, the implementation of suitable disposal systems, such as designed lagoons or containment pits, is vital to manage coffee effluent seepage into nearby water bodies. These lagoons should be engineered to effectively contain and treat effluents, thereby preventing any potential leakage into the surrounding environment. By establishing such systems, the risk of contamination to local water sources can be significantly reduced.

Enforcement of Policies and Regulations: Another critical recommendation is the enforcement of existing policies and regulations governing wastewater discharge. Authorities such as the National Environmental Management Authority (NEMA) should play a proactive role in monitoring compliance with these regulations. Continuous enforcement will ensure that coffee industries adhere to guidelines related to wastewater management.

Furthermore, the Ministry of Water and Irrigation, particularly the Water Resources Management Authority, must prioritize strict adherence to water quality regulations. This includes regulating the effluent discharge standards for coffee processing facilities. The "polluter pays principle" should be vigorously enforced to hold industrial owners accountable for any environmental damage caused by their operations. This principle entails that those responsible for pollution should bear the costs of managing it and compensating affected communities. This may involve revoking the licenses of non-compliant industrial owners, thereby enhancing compliance and promoting responsible environmental stewardship.

Handling of Coffee Honey Water: Proper handling of coffee honey water, a byproduct of coffee processing, is essential in preventing health risks associated with waterborne diseases such as typhoid fever and cholera. The local community, particularly those living along the banks of the River Tana, should be educated about the potential dangers of using contaminated surface water for domestic purposes. Awareness campaigns and educational programs should be developed to inform residents about the risks associated with polluted water sources and to provide information about alternative safe water sources that can be utilized to protect their health and livelihoods.

Reinforcement of Environmental Impact Assessment and Audit: The reinforcement of Environmental Impact Assessments (EIA) prior to the establishment of industrial facilities is another crucial step. An EIA helps to identify potential environmental impacts, including water contamination, and facilitates the implementation of adequate measures to mitigate these effects. Furthermore, conducting Environmental Audits for existing industries is vital to evaluate their compliance with environmental regulations and their overall impact on the ecosystem. These audits should focus on assessing effluent management practices, treatment efficiency, and the capacity of facilities to handle waste effectively.

Measures to Reduce Future Contamination: To address the ongoing challenges of wastewater management, both workers in the coffee industry and local community members have proposed several measures. A collective call for sustainable wastewater management systems has emerged, highlighting the need for effective treatment of coffee honey water. Implementing low-cost and adaptable technologies for effluent treatment prior to discharge is essential. Such technologies should comply with World Health Organization (WHO) standards to ensure the safety and well-being of the community.

Additionally, complementary strategies such as afforestation, responsible use of agricultural chemicals, and improved farming practices are vital in preventing further contamination of local water sources. Afforestation can help restore natural ecosystems and enhance water quality by stabilizing soil and reducing runoff. Stronger government oversight of coffee processing plants and the enforcement of policies aimed at reducing pollution are critical steps that need to be prioritized. By fostering collaboration among stakeholders, including government authorities, industry leaders, and community members, a sustainable path forward can be established to safeguard public health and protect the environment.

5.4 Areas of Further Study

The study evaluated the contaminating effects of coffee honey water on surface water in the Othaya catchment area and along the River Tana, focusing on the Othaya Coffee Society in Nyeri County. Key findings and proposed areas for further research include:

City Planning Policies. Future research should examine how city planning policies influence wastewater management in Othaya. This could involve: Policy Assessment: Identifying gaps in current regulations. Stakeholder Engagement: Gathering insights from local governments, communities, and industry to improve policies. Best Practices Review: Analyzing successful wastewater management strategies from other regions.

Impact of Coffee By-Products. While the study focused on coffee honey water, other by-products like pulp and wastewater also need evaluation: Characterization: Identifying chemical properties of coffee by-products. Contamination Pathways: Studying their contributions to water pollution and effects on aquatic life. Mitigation Strategies: Exploring recycling and disposal methods to reduce environmental impact.

Extension to Other Coffee-Growing Counties. The research should extend to all thirty-three coffee-growing counties in Kenya, focusing on: Regional Variability: Analyzing how geographic and socioeconomic factors affect contamination. Comparative Analysis: Comparing coffee processing impacts across counties. Community Programs: Educating farmers and processors about sustainable practices.

End Point Contamination. Further investigation is needed on the effects of coffee effluents at endpoints like oceans and groundwater: Ecological Assessment: Evaluating the health of ecosystems affected by coffee effluents. Monitoring Programs: Establishing long-term monitoring for marine and freshwater systems downstream. Groundwater Studies: Investigating how effluents impact groundwater quality and community health.

These areas of research would enhance the understanding of coffee processing's environmental impacts and promote better management practices.

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APPENDICES

Appendix I**: An Introductory Letter**.

Kenya Methodist University,

School of Science and Technology,

P.O. Box 267-60200,

<u>MERU</u>

September 2023

Dear Respondent,

RE: MSC. RESEARCH PROJECT

I am a postgraduate student at Kenya Methodist University undertaking a research project as part of requirements for the award of the degree of Master of Science in Agriculture and Rural Development.

I am carrying a research on "**The Contaminating Effects of Coffee Processing Honey Water, Case of Othaya Coffee Society, Nyeri County,Kenya**".

The success of the study will depend on your co-operation. I hereby request you to respond to the Questionnaire items as honestly as possible and the best of your knowledge. The questionnaire is designed for this study only; therefore, the responses will confidentially be treated.

No name is required from any respondent.

Thanking you in advance.

Yours Faithfully,

Paul M. Mutua.

Appendix II**: Institution Questionnaire**

KENYA METHODIST UNIVERSITY

DEPARTMENT OF AGRICULTURE AND NATURAL RESOURCES

Institution Questionnaire

Declaration:

I am a postgraduate student at Kenya Methodist University undertaking a research project as part of requirements for the award of the degree of Master of Science in Agriculture and Rural Development. I am carrying a research on "The Contaminating Effects of Coffee Processing Honey Water, Case of Othaya Coffee Society, Nyeri County". I am kindly requesting for your time to answer the questions. The information provided in the following questionnaire will be used solely for academic purposes and will be treated with the utmost confidentiality of the participant.

Q1. What is your role in relation to surface water contamination control management in Nyeri County? …………………………………………………………………………………

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Q2. In what ways has Othaya Coffee Society contributed to economic development in Nyeri County? ....

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Q3. What are the main sources of water used for production and processing by Othaya Society?

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Q4. What are the main by-products associated with coffee processing at Othaya Society?

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Q5. Are you aware of any surface water contamination of River Tana? If yes, what do you attribute to this contamination?……………………………………………………………….

….……………………………………………………………………………………………

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Q6. In your opinion, has Othaya Coffee Society impacted negatively in the surface water contamination of River Tana? ………………………………………………………………..

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Q7. To what extent has the downstream population been affected by the surface water contamination of River Tana? ……………………………………………………………….

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Q8. In your opinion, are there proper coffee effluent management mechanisms enforced by Othaya coffee society management?

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Thank you for your prompt response

Appendix III**: Households' Questionnaire**

KENYA METHODIST UNIVERSITY

DEPARTMENT OF AGRICULTURE AND NATURAL RESOURCES

Declaration:

I am a postgraduate student at Kenya Methodist University undertaking a research project as part of requirements for the award of the degree of Master of Science in Agriculture and Rural Development. The study topic is "**The Contaminating Effects of Coffee Processing Honey Water, Case of Othaya Coffee Society, Nyeri County, Kenya**".

Kindly I request for your time to answer some questions. The information provided in the following questionnaire will be used for academic purposes and the utmost confidentiality of the participant will be observed. Please fill out the questionnaire appropriately.

SECTION A**: BACKGROUND INFORMATION**

3.1. 1. Please indicate your gender

Male ( )   Female ( )

2. What is your age (years)?

Between 20-30 ( ) Between 31-40 ( ) Between 41-50 ( ) 51 and above ( )

3. What is your education level?

Secondary ( ) College Certificate ( ) Diploma ( ) Bachelor ( ) Postgraduate ( )

4. How long have you used the water from this river?

Less than a year ( ) 1-5 years ( ) 6-9 years ( ) above 10 years ( )

SECTION B**: HOUSEHOLDS' SOCIOECONOMIC BENEFITS**

3.2 The following are some possible socioeconomic benefits the households derive from Othaya Coffee Society and Surface Water. Kindly evaluate the level of the benefits. Tick your response using the rating scale; (5-Strongly agree, 4-Agree, 3-Moderately, 2-Disagree, 1- Strongly disagree).

Households' Socioeconomic Benefits from Othaya Coffee Society and Surface Water	1	2	3	4	5
1. Othaya Coffee Society supports the surrounding households through employment and income generation					
2. Othaya Coffee Society contributes to economic development of Nyeri County					
3. Most surrounding households depend on surface water from River Tana for domestic consumption, aquaculture and irrigation					
4. Othaya Coffee Society produces coffee processing honey water as a by-product that supports livelihoods of the surrounding households					

SECTION C**: CONTAMINATING EFFECTS OF COFFEE PROCESSING HONEY WATER ON HOUSEHOLDS' HEALTH**

3.3 The following are some possible contaminating effects of coffee processing honey water on the health of the surrounding households. Kindly evaluate the level of the effects. Tick your response using the rating scale; (5-Strongly agree, 4-Agree, 3-Moderately, 2-Disagree, 1- Strongly disagree).

Contaminating Effects of Coffee Processing Honey Water on the health of the Surrounding Households.	1	2	3	4	5
1.Othaya society affects the surrounding households negatively through surface water contamination by coffee effluents					
2. Contaminated surface water releases nitrates and ammonium forming greenhouse gases leading to global warming.					
3. Contaminated surface water releases nitrogenous and phosphoric compounds that lead to eutrophication of surface water. Growth of algae in turn compete with aquatic creatures for available dissolved oxygen in the surface water leading to low aquatic population.					
4. Contaminated surface water causes body irritation, sight irritation (burning inside), spinning sensation (feeling drunk) and stomach/ breathing problems.					
5.Contaminated water causes waterborne disease (Bilharzia, Typhoid, Cholera, Diarrhea and Dysentery)					
6. Much Nitrates in the contaminated water could cause blue baby syndrome when humans consume it.					