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

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ABSTRACT

Kenya's economic growth heavily relies on agriculture, with coffee production being a key sub-sector. Coffee processing consumes significant surface water, generating coffee honey water as a by-product, which contaminates downstream water sources and affects local communities. This study aimed to assess the contaminating effects of coffee honey water on surface waters, determine contaminant levels, evaluate pollutant impacts, and analyze socio-economic effects on the population. A mixed research design was employed; involving four experimental blocks with three treatments per block, utilizing a total squares randomized design with four replicates to minimize variability. Twelve surface water samples were collected from upstream, interception, and downstream points, along with four untreated coffee honey water samples from lagoons. The physicochemical properties of these 16 samples were analyzed. Additionally, descriptive statistics from closed and open-ended questionnaires involving 79 respondents from the Othaya Coffee Society Management and 30 local households were analyzed. Findings indicated negative impacts on local communities due to water pollution from coffee processing, with high acidity, organic matter, nutrients, and suspended solids degrading water quality. The study concluded that effluents from wet coffee processing did not meet WHO standards for treated effluent discharge. Recommendations included ensuring treatment of coffee effluents before discharge, implementing proper wastewater treatment facilities in coffee industries, and enforcing regulations by authorities like NEMA. Further research is recommended to explore the effects of coffee pulp on water contamination and the impact of city planning policies on wastewater management in industrial areas such as Othaya town.

Keywords: A Conceptual model; Coffee Processing Honey Water; Dependent Variable (Y); Independent Variable (X); Intervening Variable; Mixed Research Design; Population; Pulping.

1. INTRODUCTION

Globally, both natural phenomena and human activities have significantly contributed to the contamination and degradation of surface water quality. This situation has been exacerbated by factors like global warming, posing threats to the sustainability of lakes and rivers. According to Bisekwa et al. (2021), despite water being a crucial resource for economic prosperity and human welfare, various human activities, including industrial agriculture, mining, and urbanization, continue to pollute surface water bodies. In African countries like Kenya, industrial effluents have been a major source of surface water contamination, exacerbated by poor agricultural practices (Tonui, 2018). The lack of adequate effluent management systems in most towns leads to indiscriminate discharge of industrial waste into the environment. Furthermore, there is a lack of widespread adoption of environmentally friendly technologies to mitigate the discharge of industrial effluents into surface waters. Recognizing the importance of water quality, the 2030 Agenda for Sustainable Development includes a specific target (SDG 6.3) aimed at improving water quality by reducing surface water contamination by 2030 (United Nations, 2016). This highlights the global commitment to addressing the issue of surface water pollution. Despite agriculture being a vital component of economic growth, it is also a major contributor to surface water pollution, accounting for seventy percent of contamination worldwide. Industrial activities, such as coffee processing, also contribute significantly to surface water contamination, posing risks to both aquatic ecosystems and human health (United Nations Environmental Programme [UNEP], 2016). These findings underscore the urgent need for comprehensive policies and measures to address surface water pollution globally and nationally.

1.1 Coffee Farming in Kenya

Coffee plays a vital role in agriculture, significantly contributing to economic development through foreign exchange earnings, livelihoods for family farmers, job creation, and food security (Agriculture and Food Authority- Coffee Directorate [AFA-CD], 2021). Annually, coffee generates approximately Kshs 23 billion in foreign exchange earnings, ranking fourth after tourism, tea, and horticulture (International Coffee Organization [ICO], 2021). The government acknowledges the strategic importance of the coffee sub-sector in the socio-economic livelihoods of coffee producers, aligning it with the pillars of Vision 2030 and the Big 4 Agenda (AFA-CD, 2021).Coffee cultivation in Kenya traces back to 1893 when missionaries initiated farming in Bura, Taita Hills, and later in Kibwezi (AFA-CD, 2021). Presently, coffee occupies around 119,675 hectares across 33 counties in Kenya, primarily in the Western, Rift Valley, Central, and Mt. Kenya regions (AFA-CD, 2021), as illustrated in Figure 1.1. Coffee

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thrives in high potential areas, typically at elevations between 1,400 and 2,200 meters above sea level, with temperatures ranging from 15 to 24 degrees Celsius, and deep, well-drained volcanic soils. Coffee cultivation in Kenya involves two main systems: smallholder farmers organized under cooperative societies and privately managed coffee estates. 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). Most coffee cultivation relies on rain-fed conditions, although some large estates utilize irrigation systems that demand significant water volumes for both cultivation and processing.

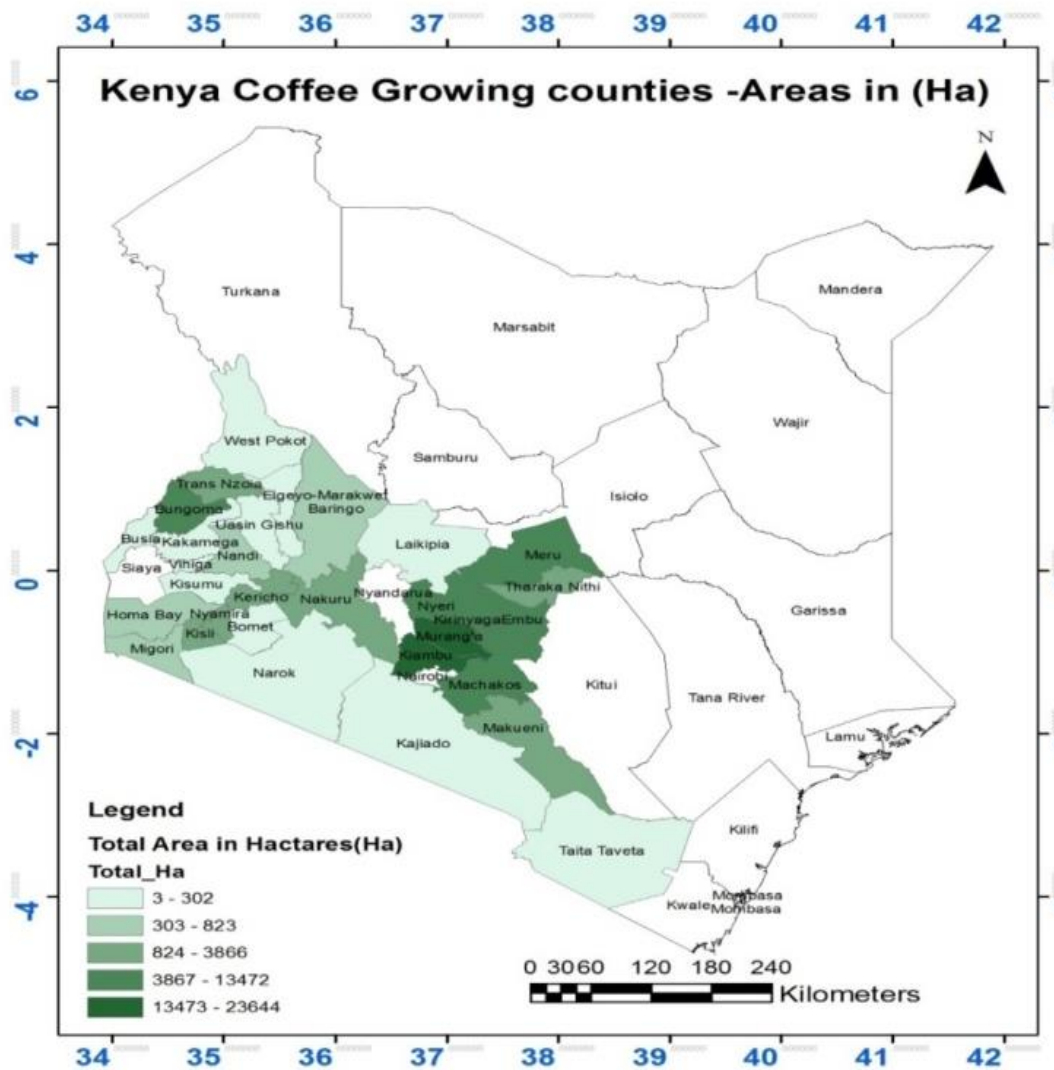

Figure 1.1: Map of Coffee Growing Counties in Kenya

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1.2 Coffee Processing and Surface Water Contamination

About 91% of coffee in Kenya undergoes pulping at coffee refineries managed by cooperatives and plantation estates, while approximately 9% is dried as Buni. Around 500 societies operate 1,010 washing stations, and estate plantations manage 3,030 washing stations, processing an average of 45,000 metric tons of clean coffee annually (AFA-CD, 2021). Most washing stations are situated near riverbanks and other water bodies due to the substantial water requirements for coffee processing (Kenya Agricultural Livestock Research Organizations-Coffee Research Institute [KALRO-CRI], 2017).

During harvesting, ripe cherries are selectively hand-picked from coffee trees, separating ripe berries from unripe or diseased ones to enhance coffee quality (KALRO-CRI, 2017). Typically, 22,500 liters of clean water are used to pulp 1,000 kg of outer redskin (pulp) from the beans, with no water recycling. Screens in the pulping machine then separate coffee beans from incomplete pulped cherries. The beans, known as parchment, undergo water density grading into parchments 1, 2, 3, and lights using the principle of floatation in compartments filled with water. The parchment beans still retain the silver skin layer, called "mucilage," which imparts sweetness and honey-like qualities to the coffee. To remove the mucilage, the beans undergo fermentation in large tanks for 24-36 hours, where enzymes break down the sugars and pectin into acids, gases, and alcohol, giving the coffee a wine-like taste (KALRO-CRI, 2017). After fermentation, the parchment beans are washed to remove any mucilage residues, and the used water drains into waste disposal pits, known as "lagoons," as one of the by-products called "*Coffee Processing Honey Wate*r." The wet parchment beans contain about 57% moisture content and are then dried either in the sun or mechanically to reduce moisture content to between 10.5% and 12.5%. Sun-drying occurs on wooden or metallic skin drying tables covered with polythene sheets to prevent re-wetting from rains and maintain coffee quality. However, waste disposal pits are inadequately designed and constructed to handle the large volume of generated coffee processing honey water. They lack firm linings or cemented floors to prevent seepage of the honey water into surface water bodies. During peak coffee processing periods, the raw coffee processing honey water may overflow from the waste disposal pits into surface water bodies, leading to significant surface water contamination (see Figure 1.2).

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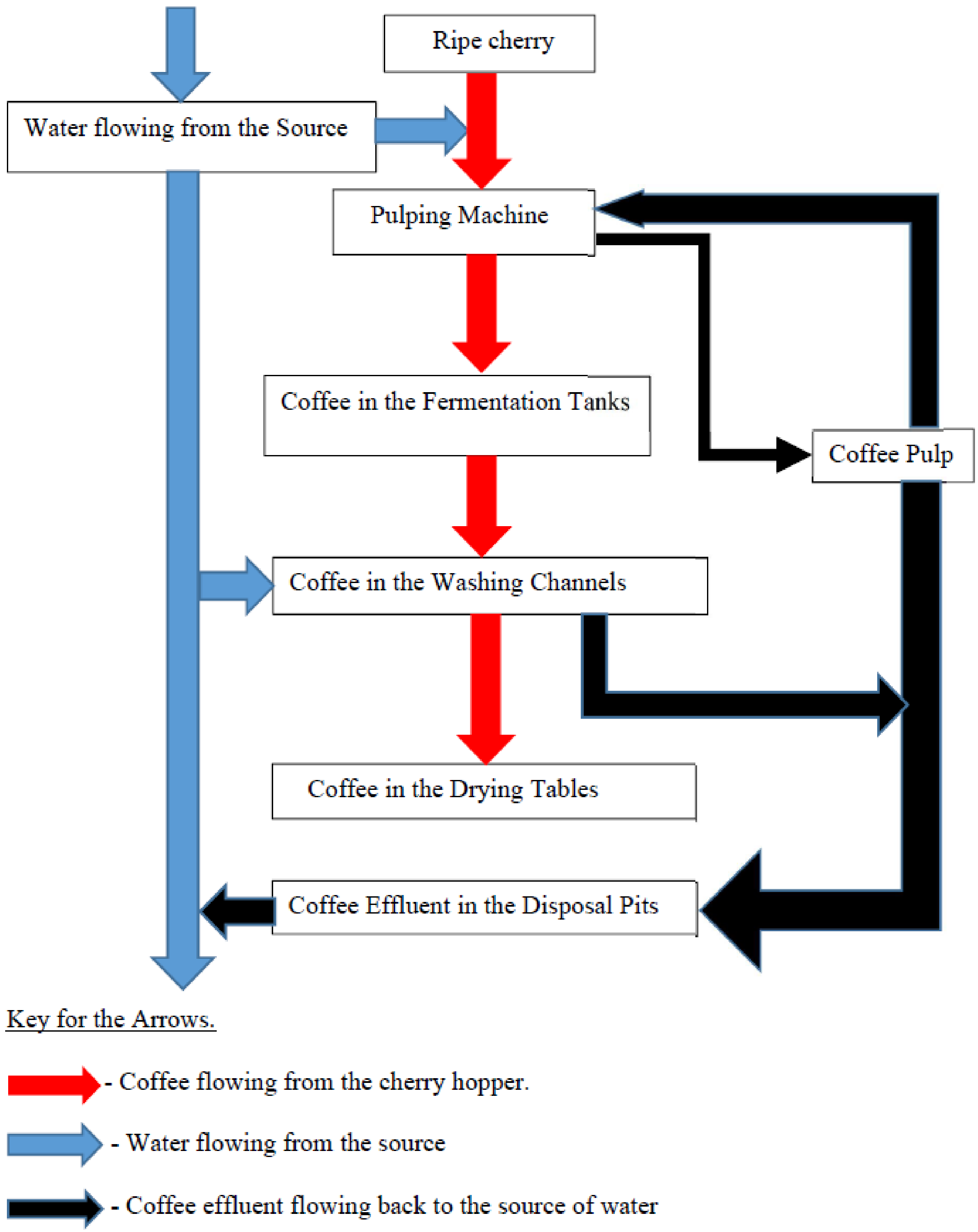

Figure 1.2: States in the primary coffee processing chain

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1.3 Statement of the Problem

Othaya, located in Nyeri County, hosts various industries, including tea, horticulture, aquaculture, and coffee. Coffee processing requires significant amounts of clean surface water, which, unfortunately, becomes contaminated due to the discharge of untreated coffee honey water. This contamination negatively affects the socio-economic well-being of the population reliant on the contaminated surface water. The release of untreated coffee processing honey water into surface water introduces various contaminants that have adverse effects, such as contributing to global warming by releasing nitrates and ammonium compounds into the atmosphere. Additionally, nitrogenous and phosphoric compounds from the contaminated water lead to eutrophication, fostering algal growth that competes with aquatic organisms for dissolved oxygen, thereby impacting the livelihoods of surrounding communities. Excessive nitrates in the contaminated water can even lead to health risks like blue baby syndrome when consumed by humans. Despite numerous studies on the impact of industrial effluents on water resources globally and locally, coffee effluents continue to pose a significant problem, causing contamination of surface water sources and escalating health risks for humans. However, there is limited literature on the contaminating effects of coffee honey water on surface waters in the country. Thus, this study aimed to assess the contaminating effects of coffee processing honey water on surface water, focusing on the Othaya Coffee Society in Nyeri County. The researcher also aimed to identify measures to reduce further contamination of surface water by coffee honey water.

1.4 Objectives of the Study

1.4.1 General Objective

To assess the contaminating effects of coffee processing honey water on surface water.

1.4.2 Specific Objectives

The specific objectives of the study were:

I. To determine the level of contaminants contained in coffee processing honey water.
II. To assess the extent of contaminating effects of coffee honey water on surface water.
III. To examine the socio-economic effects to the population from discharge of raw coffee honey water.
IV. To determine measures that could reduce further contaminating effects of coffee honey water on surface water.

1.5 Justification of the Study

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The study was undertaken to reduce contaminating effects of coffee honey water on surface surface water to the down population. Data from the study served as a baseline to know the level of contaminants in coffee processing honey water. The study guided in assessing the socio-economic effects to the population by discharge of raw coffee processing honey water. The study findings guided in developing measures that could reduce further socio-economic effects of coffee honey water on surface water contamination.

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. To what extent could the coffee processing honey water contaminate surface water?
iii. What could be some of the socio-economic 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 processing 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 Delimitation 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.

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1.9 Significance of the Study

It is anticipated that the findings of this study will 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 wastewater 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 will contribute to the enhancement of environmental sustainability within the industry. Moreover, the findings of the study will be instrumental in informing policy makers, water consultants, regulatory bodies, civil society organizations, development partners, and other stakeholders. These stakeholders can 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 will contribute to the preservation and protection of water resources, ensuring a healthier environment for all.

1.10 Assumptions of the Study

The researcher made the assumption that all respondents shared similar characteristics within the study, aiming to ensure uniformity in the data collected. To minimize variations in samples, experimental units comprising sixteen active washing stations were divided into four blocks. Samples were randomly selected from diverse populations, with subjects or treatments assigned randomly to groups, thereby ensuring homogeneity in variance across each group. It was assumed that participants fully comprehended the interview questions and responded honestly and candidly, thereby providing reliable data. Additionally, the instruments utilized were deemed effective in eliciting accurate responses. Furthermore, the researcher presumed that some members of households were affiliated with the Othaya Coffee Society and possessed sufficient knowledge about the society's operations and its economic benefits, thus contributing to their livelihoods. This assumption facilitated a deeper understanding of the societal dynamics and their potential implications on the research outcomes.

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.

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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.

2.0 THEORETICAL LITERATURE REVIEW

2.1 The two theories guided the research study.

2.1.1 Industrial Effluent Management Theory

The foundation of industrial effluent management theory lies in the principle that industries must treat and manage their effluents before releasing them into surface waters. Untreated industrial effluents, particularly coffee honey water, can contaminate surface waters and negatively impact the livelihoods of surrounding communities. Hai, Yamamoto, and Lee (2018) highlight the practical significance of this theory, which provides insights into the level of contaminants present in coffee processing honey water, the extent of its contamination of surface water, the socio-economic effects of raw coffee processing honey water discharge on communities, and potential measures to mitigate these contaminating effects. This theory underscores the hazardous nature of industrial effluents and emphasizes the need for proper management to prevent contamination of surface waters, as noted by McIntosh et al. (2017). In the context of the current study, industrial effluent management theory was instrumental in analyzing wastewater contaminating parameters, assessing the impact of industrial effluents on water sources, and recommending measures for Othaya coffee society management to mitigate the problem. Ultimately, this theory facilitated the achievement of the study's main objective.

2.1.2 The Deterministic Theory of Cause-Effect Relationships

The deterministic theory of cause-effect relationships asserts that understanding cause-effect relationships is crucial for decision-making. This theory guided the researcher in quantifying the

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contaminating effects of coffee honey water on surface water, thus supporting informed industrial effluent management measures. These measures can vary in complexity, starting with preliminary actions such as loading, which involve assessing the size of actual contaminating loads to prioritize reduction efforts based on cost-effectiveness (Mutamim et al., 2012). Additionally, mass contaminants can be determined by estimating loads from contaminating sources and considering water recovery capacity in water sources. Comparing the significance of different loadings can help evaluate their contribution to pollutant concentrations in receiving waters, informing effective measures to reduce contaminant levels (Mutamim et al., 2012).This theory was pertinent to the study as it facilitated understanding of how industrial coffee effluents could impact surface water sources in the Othaya coffee society. By providing insights into cause-effect relationships, the theory enabled the researcher to achieve the study's primary objective.

2.2 Surface Water Contamination

Water, a vital resource for all life forms including humans, is protected under the Environmental Management and Coordination Act (EMCA) of 2015, granting every citizen the right to access clean surface water. However, contamination of surface water has become a pressing socio-economic issue globally, impacting countries like Kenya. Human-generated contaminants have significantly polluted surface water, posing a threat to the rights of Kenyan citizens (Minuta et al., 2017). In Africa, inadequate access to clean surface water remains a persistent challenge, exacerbating the problem of contamination (Workinesh, 2017). Surface water contamination refers to any alteration in water quality caused by external toxic compounds, leading to detrimental effects on surrounding life forms. In Kenya and other developing nations, surface water contamination poses a significant obstacle to sustainable water resource management (Bisekwa et al., 2021). Nitrogenous and phosphoric chemicals are identified as major contaminants in surface water, capable of degrading water quality and posing risks to human health (Tesfalem et al., 2017). Effective control measures are essential to mitigate contaminating effects at their source and improve surface water quality. These measures include comprehensive monitoring of surface water properties through physical, chemical, and microbiological assessments, ensuring adherence to health policy guidelines set forth 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, can 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), 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 solvation 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 can contaminate surface water. It is a measure of the opacity of optical light, causing light to scatter

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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) 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

Bisekwa, et al. (2021) highlighted that despite its importance, coffee processing honey water significantly contaminates water sources. This water carries substantial quantities of carbohydrates, proteins, and fibrous compounds released during pulping and mucilage fermentation processes. Oxygen serves as a critical contaminating indicator in coffee processing honey water, influenced by the nitrogen and phosphorus content within it (Wubalem, et al., 2021). Other crucial factors determining its quality include pH, temperature, and total suspended solids. When raw coffee processing honey water is discharged into surface water, it emits a foul odor (Dessalegn, et al., 2017). The high concentration of contaminants in coffee processing honey water poses significant risks to both human health and aquatic life if discharged improperly (Mburu, 2014; Wubalem, et al., 2021).

2.4.1 Physicochemical Characteristics of Conventional Coffee Effluent

Both WHO (2016) and APHA (2017) 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

Parameters	**Range**
pH	3.9-4.4
Temperature (0^0C)	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)	1.09-2.7

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 socio-economic 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 socio-economic 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 nitrous oxide (N2O), methane (CH4), and carbon dioxide (CO2), thereby exacerbating climate change. Additionally, the discharge of nitrogenous and phosphoric compounds from contaminated surface water can 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) confirm 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 this issue, policies have been formulated at both international and national 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 water. In Kenya, the management of coffee processing honey water is a critical topic in discussions concerning the availability of coffee in international markets. Certification schemes such as Rainforest Alliance, Solidaridad, and Fair trade are now required to include the contaminating effects of coffee processing honey water management as part of their certification criteria (Bisekwa et al., 2021).

2.6.2 Private Sector Awareness and Surface Water Governance

Private sector entities utilize environmental awareness, including understanding the contaminating effects of coffee honey water on surface water, as a tool to aid various groups and individuals in addressing the challenges of surface water contamination. Through this approach, social groups, including the private sector, gain valuable experience and comprehension of the impacts of surface water contamination. Education regarding the contaminating effects of surface water empowers social groups and individuals to acquire knowledge and skills necessary for better life and the sustainable management of water resources, including water and wastewater.

This contributes to the promotion of clean and safe surface water. Tonui (2018) confirms that private sector initiatives aimed at raising awareness and educating about surface water governance help foster a balance between sustainable industrial growth and effective effluent management.

2.7 Existing Surface Water and Coffee Effluent Management Policy Framework

Kenya implemented the Water Act in 2016 to serve as a blueprint for the proper management of surface water, the enforcement of regulations governing its use, and the provision of wastewater services. This legislation not only addresses the conservation of water resources but also ensures the adequate supply of water for various needs while promoting the safe disposal of industrial effluents, including coffee processing honey water. Under the Water Act of 2016, the establishment of the Water Resources Management Authority (WARMA) as a regulatory body is mandated to: 1) Define and enforce guidelines, methods, and controls for the management and utilization of water resources and flood administration. 2) Regulate the use and management of water resources. 3) Process applications for water permits concerning water deliberations, usage, and encourage decision-making, issue, modify water permits, and enforce the conditions of those permits. Section 72 of the Act outlines penalties for discharging untreated industrial effluents into water ecosystems, thereby violating standards for controlling surface water contamination. Such actions constitute an offense punishable by a fine of up to one million shillings or imprisonment for a maximum of two years, or both, upon conviction. Additionally, offenders are liable for covering the costs associated with the removal and restoration of the affected area, including repair and compensation for any affected parties during the contamination of any surface water ecosystem.

2.8 Empirical Literature and Research Gaps

Several studies have investigated pollution loads, but only a few have delved into the impact of pollutants on natural or social environments. Tsigereda et al. (2013) examined the effectiveness of advanced versus conventional Wet Coffee Processing Technologies in Effluent Wastewater Quality. Their findings revealed that the wastewater failed to meet Burundi coffee discharge benchmarks, suggesting the need for wastewater treatment systems to safeguard the environment. However, the study was conducted outside Kenya and did not address the contaminating effects of coffee honey water on surface water, leaving a gap in the research.

Kosgey (2013) conducted a study on the determination of overwhelming metal poisons in sediment-water in the Athi waterway area, identifying Pb, Cd, Cr, Cu, and Ni in free-flowing water. The study highlighted exceptionally high concentrations of Pb in both water and silt, indicating non-compliance with Kenya’s industrial waste discharge protocols. Despite this, the study did not explore coffee effluent as a contaminant of surface water, revealing a research gap.

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Mburu (2014) investigated the comparative utilization of lime and moringa oleifera to remove suspended solids from coffee processing effluent. While the study demonstrated the efficacy of Moringa oleifera oil press cake in removing suspended solids, it overlooked the design of waste stabilization pits, indicating a gap in the research.

Dejen et al. (2015) studied the effects of coffee processing plant effluent on the physicochemical properties of receiving water bodies in the Jimma Zone, Ethiopia. Their findings highlighted the discharge of untreated coffee effluents into nearby pits, risking overflow into rivers and damaging surface waters and aquatic life. However, the study did not examine the contaminating effects of coffee honey water on surface water, revealing a research gap.

Ejeta et al. (2016) assessed the effect of effluent discharge from coffee refineries on the quality of river water in South-Western Ethiopia. Their findings indicated unsafe river water quality for human use due to high levels of physicochemical parameters. Yet, the study did not propose strategies to address this issue, indicating a research gap.

Kanyiri et al. (2017) focused on enhancing benefits from biomass wastes within small-medium coffee processing factories in Kiambu County, Kenya. While they explored the biomass benefits of coffee by-products, they did not investigate the contaminating effect of coffee effluent on surface water, highlighting a research gap.

Workinesh (2017) examined the effect of coffee processing industries' waste on water quality in the Gidabo watershed in southern Ethiopia. The study revealed that untreated coffee effluents discharged into nearby pits did not meet Ethiopia's effluent discharge standards, endangering surface waters and aquatic life. However, the study did not explore the contaminating effects of coffee honey water on surface water, indicating a research gap.

Tesfalem et al. (2017) conducted a study on the physicochemical parameters of wastewater effluents from the Kombolcha and Debreberhan Industrial Area in Ethiopia. They discovered exceptionally high concentrations of pH, EC, TDS, Chlorides, Sulfate, Nitrate, alkalinity, TSS, BOD, and COD compared to WHO guidelines. While their findings aligned with the researcher's intentions, the study was conducted outside the current study area and failed to address how the use of contaminated water would impact the livelihoods of surrounding communities, revealing a research gap.

Dessalegn et al. (2017) investigated the impact of wet coffee processing wastewater on downstream water quality, highlighting the potential overflow of untreated coffee effluents into natural watercourses, which could damage surface waters and aquatic life. Although their findings were in line with the current study's intention, they did not explore the contaminating effects of coffee honey water on surface water, indicating a research gap.

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Minuta et al. (2017) examined the impact of effluents from wet coffee processing plants on the Walleme River in Southern Ethiopia, revealing heavy contamination of river waters by untreated coffee effluent. While their findings aligned with the researcher's intentions, the study did not emphasize how the use of contaminated water would affect the socio-economic benefits of the surrounding community, indicating a research gap.

Dori (2017) studied the economic and environmental impact of selected wet coffee processing industries in the Gedeo Zone, Southern Ethiopia, highlighting the significant impact of untreated coffee effluent discharge on downstream water quality and the ecosystem. However, the study did not emphasize how the use of contaminated water would affect the socio-economic benefits of the surrounding community, indicating a research gap.

Tonui (2018) investigated the impacts of tea effluent discharge from the Kapkoros Tea factory into the Kipsonoi River in Bomet County, Kenya, revealing damage to surface waters and aquatic life. While the study aligned with the current study's intention, it did not focus on the effects of using contaminated water on the quality of processed tea, indicating a research gap.

Ijanu et al. (2019) explored coffee processing wastewater treatment methods in Malaysia, noting their effectiveness but highlighting their high cost compared to the financial status of most coffee societies in Kenya. However, the study was conducted outside Kenya and did not propose cheaper strategies to address the issue, indicating a research gap.

Overall, while many studies have assessed the impacts of industrial effluent on human health, few have specifically addressed the contaminating effects of coffee processing honey on surface water, highlighting the need for further research to bridge this gap.

2.9 Conceptual Model

A conceptual model explains the relationships of the variables under the study. Industrial Coffee Effluent is an independent variable; surface water contamination is a dependent variable; poor coffee effluent management system is an intervening variable. In this case, surface water contamination depends on the presence of industrial coffee effluents. When untreated industrial effluents discharge into water sources they contaminate surface waters. Contamination could be intervened by Industrial effluent management systems. On one hand, poor industrial effluent management systems contributes to water contamination. On the other hand, proper industrial effluent management systems could intervene on surface water contamination through government intervention policies and and private sector involvement.

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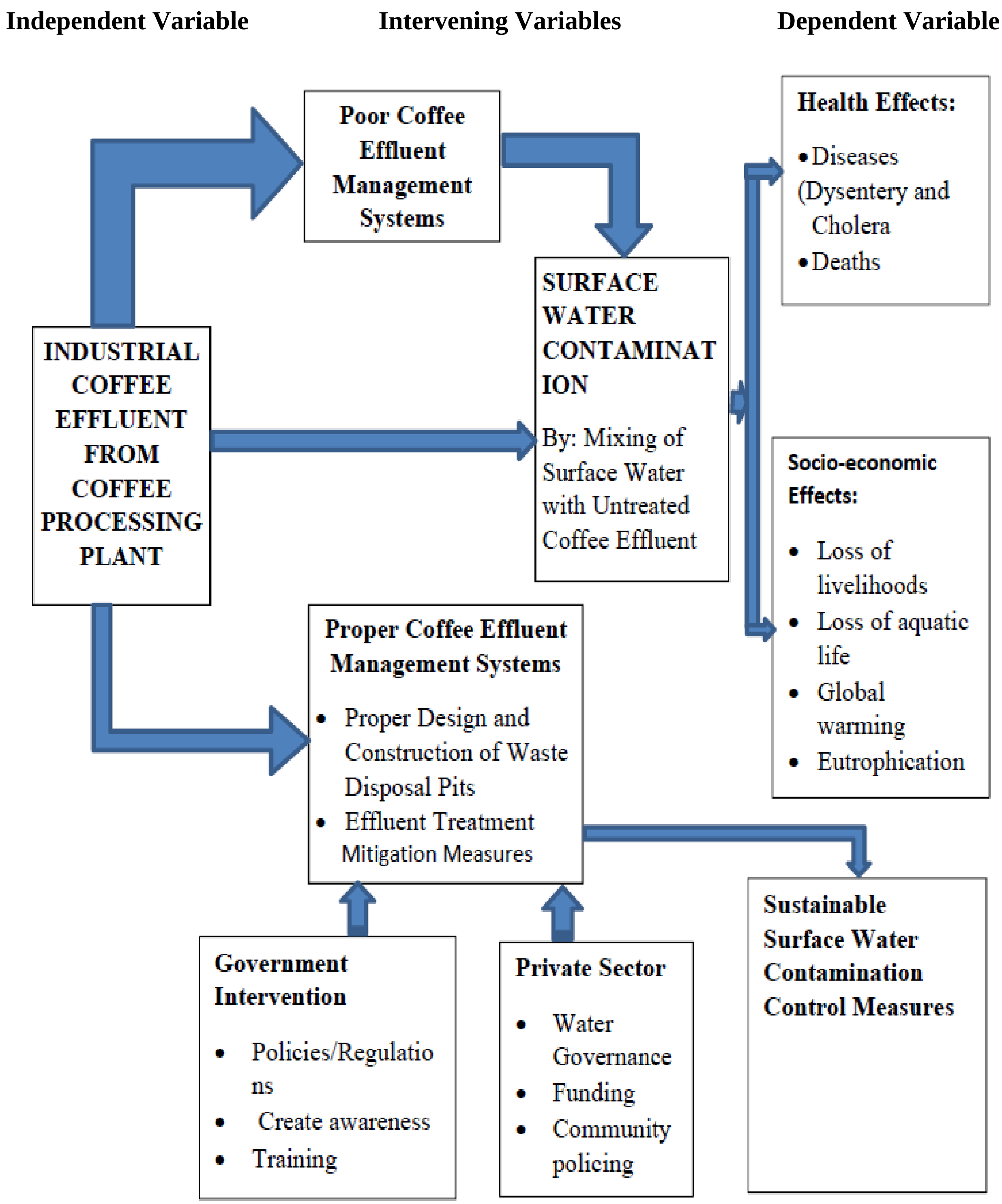

Figure 2.1: Conceptual Model

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3.0 MATERIALS AND METHODS

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 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 have grown in leaps and bounds over the years. Currently, the society has 19 factories and total membership of 15,000with 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 very many washing stations, a dry mill and a nursery that depend on huge amounts ofwater for production and processing from River Tana. The sixteen active washing stations include; Thuti, Chiga, Mahiga, Kagere, Gatuyaini, Ichamama, Kiaguthu, Kiruga, Gichichi, Iriaini, Gitugi, Rukira, Kiaga, Gura, Kagonye and Gitundu. There is easy access to all the mentioned society facilities due to the researcher's current nature of employment. 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.

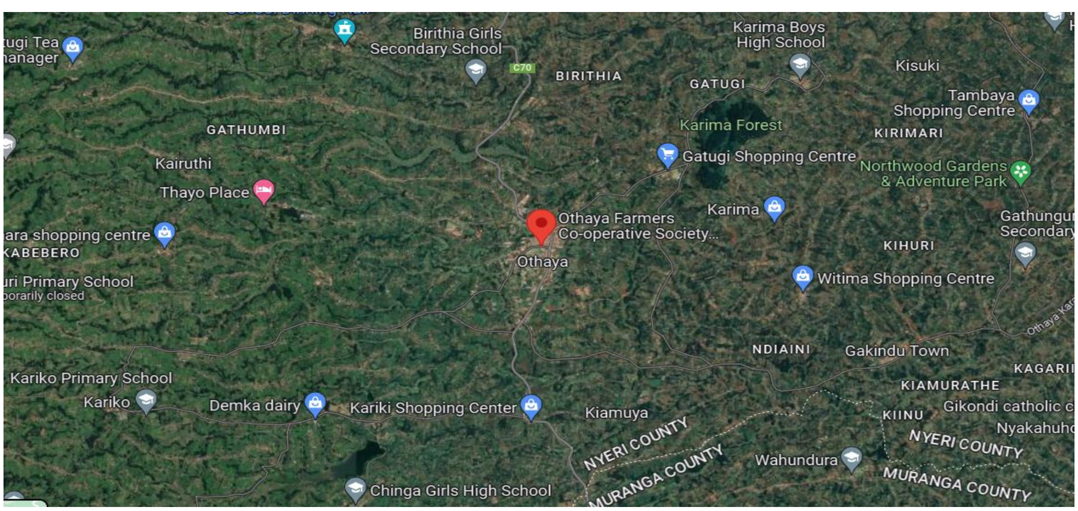

Figure 3.1: Map of the Othaya Sub-County and Study Area

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3.2 Research Design

The researcher used a mixed research design. This 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 generalizable 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; 1-3-Sub-Samples											

3.2.1 Analysis of Variance (ANOVA)

The analysis the variance guided in putting experimental units into blocks for easier analysis of samples. Blocking reduced the variability (variations) of experimental units as shown in table 3.2.

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Table 3.2: Analysis of Variance

Source of variation (SoV)	Degrees of freedom(df)	Sums of squares (SS)	Mean square (MS)	F	Sig.
Blocks (*B*)	3	64.32	21.44	3.54	0.061
Treatments (*Tr*)	2	201.86	100.93	16.63	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.

3.3 Surface Water and Coffee Processing Honey Water Sampling Procedures

Othaya Coffee Society processes its coffee between October and December and between March and May annually. The researcher selected three sampling sites in each of the four blocks (sixteen active washing stations) along River Tana near where the washing stations are situated. Twelve (12) samples were collected from the three (3) sampling sites that included upstream (UPS)-control sites with no contaminating effects of coffee effluent, entry point (ENP)-where heavy surface water contamination was occurring and downstream–to assess the surface water recovery level) with a distance of 100 meters apart. Four (4) other samples were collected from coffee effluent pits whose coffee effluents were not treated. A total of sixteen (16) samples for physicochemical analysis were taken during peak processing season from the sampling sites and at the same time. All the standard methods and instruments followed during sample collection were based on APHA operating manual (APHA., 2017). The samples were collected using 500 ml plastic vessels sterilized with nitric acid (10% v/v) and washed with purified water, and protective gloves were used to collect the assays. The sample bottles were sealed and stored in a freezer, kept at room temperature below 3°C to avoid changes in physicochemical properties, and immediately sent to the laboratory for physicochemical analysis. Data for pH level, temperature, total dissolved solids, and conductivity were taken at the sampling sites using a pH meter, TDS meter and conductivity meter, respectively. In the laboratory, COD, total nitrate ($N0_3^-$) and

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phosphate (PO_4^{3-}) were all measured using a spectrometer. Turbidity, DO, and BOD were all measured using standard APHA methods. Total suspended solids (TSS) were determined using a photometer.

3.4 Study Population

Mugenda, et al. (2003) alleges that population refers to a full set of objects, cases or individuals that have common characteristics. The population under study comprised Othaya Coffee Society management committee, the employees and the surrounding households.

3.4.1 Target Population for Othaya Coffee Society

Currently, there are about 1,500 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

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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 can 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**	**The Target Test Measure of Respondents**
Othaya Society 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 Othaya Coffee Society catchment area. The sample size was captured using a distance of 150 meters' radius. Descriptive survey design with an exploratory approach guided to collect qualitative data using both open and closed-ended questionnaires. The study interviewed all households residing within a 150-Meter radius to assess their perceptions, attitudes, habits, and opinions on the effects of untreated coffee honey water released into the nearby flowing surface water.

3.5 Validity and Reliability

3.5.1 Validity

Kothari (2004) states that content validity is the extent to which test items represent the subject matter they are intended to measure. It questions whether the collected data accurately reflects the intended measurement. The researcher used content validity to ensure the data collected with an instrument accurately represents a specific concept's domain. To confirm the instrument's content validity, the researcher sought opinions from scholars, experts, and industry managers.

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 different 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 refers to a technique utilized to gather information, including a one-on-one interaction between two or more individuals. Mburu, (2014) in his study utilized questionnaires as the key source of information and after that supplemented them with interviews and perceptions (Appendix III). The researcher employed the purposive testing strategy to get pertinent respondents for the interviews (Mugenda, et al., 2006).

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 as supported by (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 (^{0}C)	25
2	pH	6.5-8.5
3	BOD (mg/l) (5days at 20^{0}C)	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.

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3.8 Issuance of Research Permit and Ethical integrity

A research permit was issued by National Commission for Science, Technology & Innovation that allowed the researcher to collect data. The researcher informed the participants about the objectives of the study and the role they should play in the study prior to study participation. By signing an introductory letter, the participants indicated that they had understood and agreed to participate. The researcher informed participants of their rights to withdraw from participation as per their wishes at any point of the study. To ensure confidentiality, participants were not required to reveal their names or any other personal information that might disclose their identity. Data collected was treated as classified by the researcher and its access was restricted to the researcher, research assistants and the university supervisors. To answer the research questions at hand, the researcher used all collected data solely for the purposes of this study.

4.0 RESULTS AND DISCUSSION

The 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.

4.1 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 coded and analyzed.

4.1.1 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.

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Table 4.1: Gender of the Household Respondents.

Gender of Respondents	Frequency	Percentage (%)
Female	20	66.6
Male	10	33.4
Total	**30**	**100**

4.1.2 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 Tana River 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

4.1.3 Length of Water Use from River Tana

The findings in table 4.3 showed that 10% of males and 10% of females aged 1-5 years have used Tana River water (10% in total) and 30% of males and 35% of females have used Tana River water. indicates that you have used 9 years (33.3% combined). 60% of the men and 55% of the women (56.4% of the total) have used the water of the Tana River for more than 10 years.

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Table 4.3: Response on length of Water use from River Tana

Length of water use (Years)	**Respondents on Length of Water Use 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**

F-Frequency

4.2 Household's Socio-Economic Benefits

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

4.2.1 Othaya Coffee Society Contribution to Employment and Income Generation

The results showed that the Othaya Coffee Society supports surrounding households through employment and income generation. A Likert scale showed that, among 30 respondents: 22 completely agreed and 4 agreed. Three were moderate. Two were opposed and only one was strongly opposed, as shown in Figure 4.1.

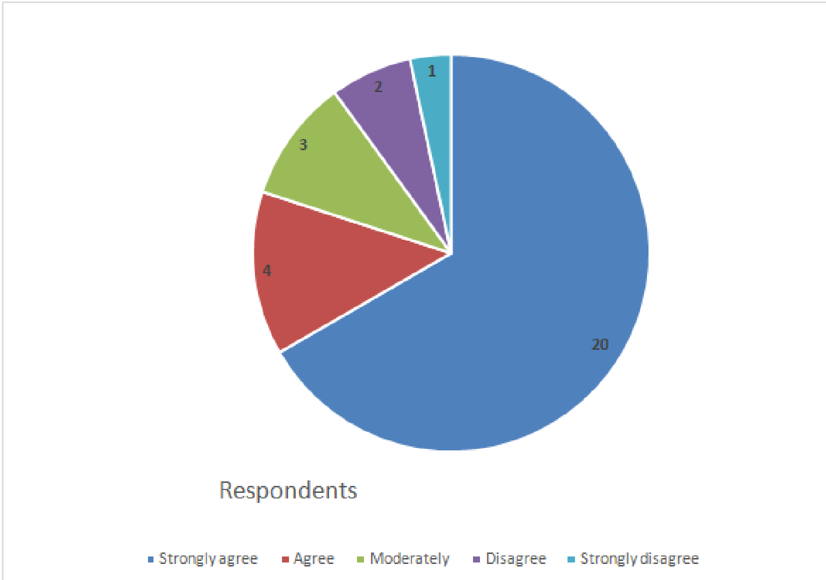

Figure 4.1: Response on Employment and Income Generation

4.2.2 Contribution of Othaya Society to Economic Development

The results show that the Othaya Coffee society is contributing immensely to the economic development of Nyeri County. A Likert scale showed that among the 30 respondents: 17 people completely agreed. 5 agreed. 4 were moderate. Two disagreed and two completely disagreed, as shown in Figure 4.2.

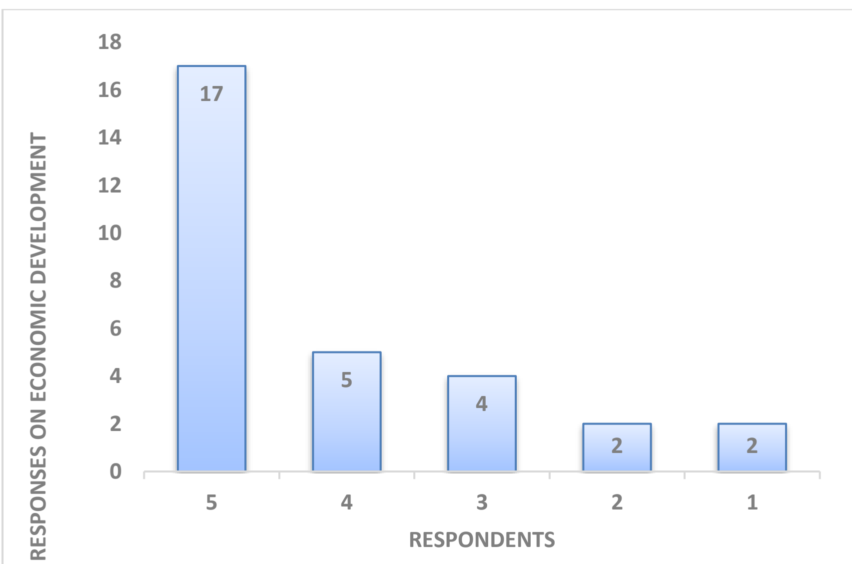

Figure 4.2: Response on Economic Development

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4.2.3. Household's Dependence on Surface Water

The results showed that most of the surrounding households depend on the surface water of the Tana River for their own consumption, aquaculture and irrigation. A Likert scale showed that among the 30 respondents: 21 completely agreed, 4 agreed. Three were moderate. As shown in Figure 4.3, one objected and only one objected completely.

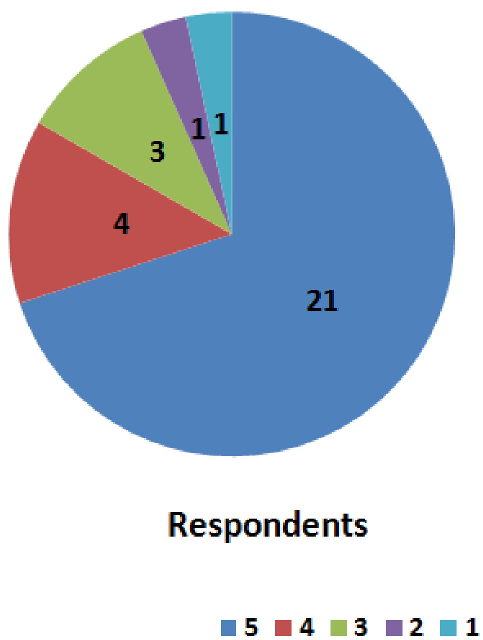

Figure 4.3: Response on Household's Dependence on Surface Water

4.2.4 Livelihood's Support from Coffee Processing Honey Water

The results indicated that the Othaya Coffee Society produces honey water from coffee processing as one of the by-products that supports the livelihoods of surrounding households. Another by-product is pulp. A Likert scale showed that among the 30 respondents: 22 people completely agree, 4 agreed. Two were moderate. One objected and only one objected completely, as shown in Figure 4.4.

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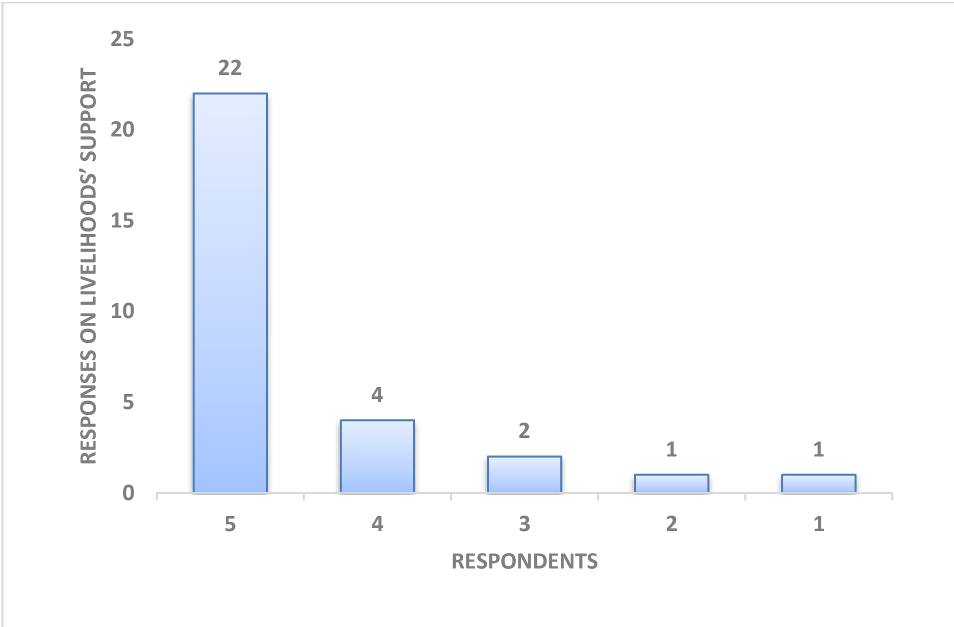

Figure 4.4: Response on Livelihood's Support from Coffee Processing Honey Water

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

4.3.1 Othaya Society has affected the Surrounding Community Negatively through Surface Water Contamination with Coffee Effluent

The findings showed that the Othaya community has a negative impact on surrounding communities by polluting surface waters with coffee runoff. 20 completely agreed, 4 agreed. Three were moderate. As shown in Figure 4.5, two disagreed and only one completely disagreed.

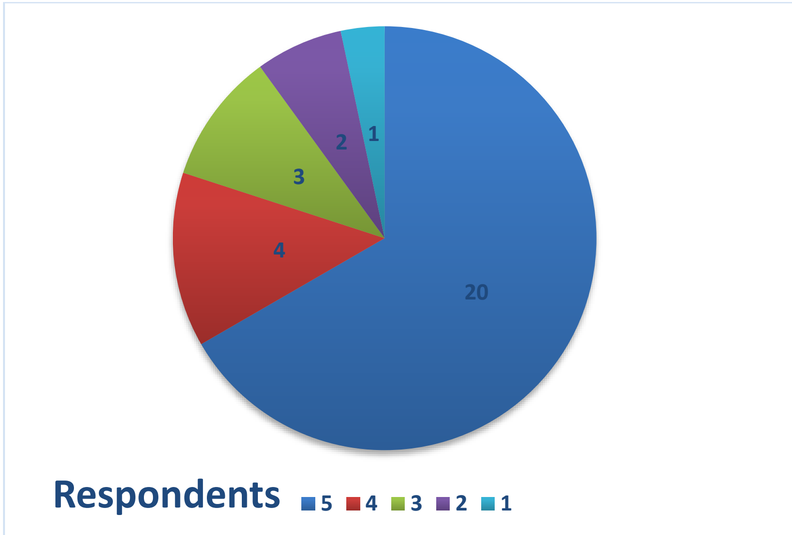

Figure 4.5: Response on Effects of Othaya Society through Coffee Effluent

4.3.2 Contaminated Surface Water Leads to Global Warming

The results indicated that polluted surface water releases nitrates and ammonium compounds into the atmosphere, forming greenhouse gases that lead to global warming. A Likert scale showed that among the 30 respondents: 17 people completely agree. 5 agreed. 4 were moderate. Two disagreed and two completely disagreed, as shown in Figure 4.6

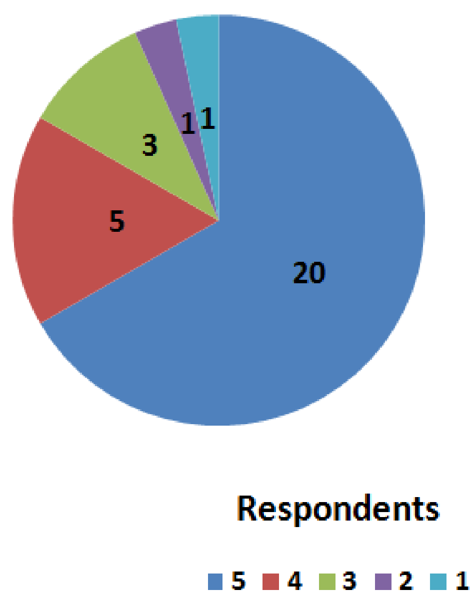

Figure 4.6: Effects of Contaminated Surface Water Leading to Global Warming

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4.3.3. Contaminated Surface Water Affects Aquatic Population

The results showed that contaminated surface water released compounds containing nitrogen and phosphorus, which lead to eutrophication of surface water. Algal growth then could compete with aquatic organisms for available dissolved oxygen in surface waters, resulting in reduced aquatic populations. A Likert scale showed that among the 30 respondents: 20 completely agreed. 5 agreed. Three were moderate. One disagreed and was the only one who completely disagreed, as shown in Figure 4.7.

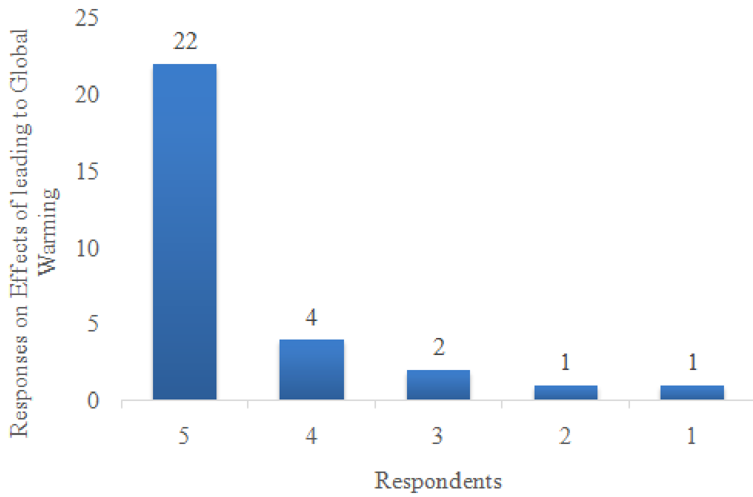

Figure 4.7: Response on Contaminated Surface Water Affects Aquatic Population

4.3.4 Contaminated Water Causes Waterborne Disease and Body Irritations

The findings indicated that contaminated water causes water-borne diseases (Bilharzia, typhoid fever, cholera, diarrhea, dysentery) and body inflammation, eye irritation (burning inside), dizziness (intoxication), and stomach/breathing problems has been shown to cause A Likert scale showed that among the 30 respondents: 21 completely agree. 5 agreed. Two were moderate. One disagreed and she was the only one who completely disagreed, as shown in Figure 4.8.

Irritations

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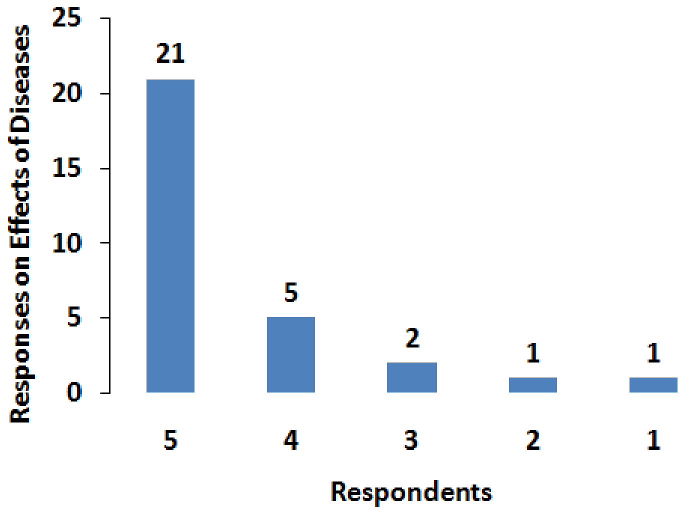

Figure 4.8: Effects of Contaminated Water Causing Waterborne Disease and Body

4.3.5 Nitrates in the Contaminated Water Cause Blue Baby Syndrome

The results indicated that ingesting nitrates in contaminated water caused blue baby syndrome. A Likert scale showed that among the 30 respondents: 12 people completely agree. 6 I agree. 7 were moderate. As shown in Figure 4.9, two disagreed and only three completely disagreed.

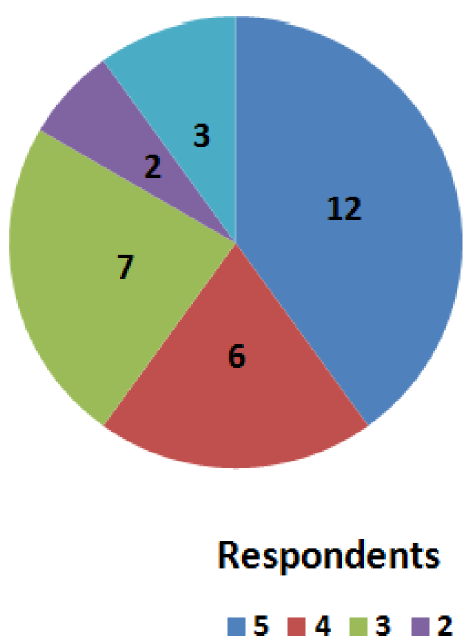

Figure 4.9: Effects of Nitrates from Contaminated Surface Water

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4.4 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 21 questionnaires were not returned.

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

A total of 48 employees responded. From the responses in the survey, 36 employees (75%) were aware of river surface water pollution by coffee runoff from company washing stations, whereas 12 employees (25%) were unaware of the river surface water pollution caused by coffee wastewater from the company's washing stations.

4.4.2 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.

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

4.5. Surface Water and Coffee Processing Honey Water collection procedures

Twelve (12) surface water samples and four (4) coffee wastewater samples were collected from three sampling points in each of the four blocks (16 active washing stations) along the Tana River, near the washing stations. Sampling points included an upstream (UPS control post, 100 meters away from contamination), an entry point (ENP with severe contamination), and a downstream (to evaluate surface water recovery).

4.5.1 Physicochemical Analysis

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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) 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

		Physical Variables				
Block/ Factory	**Sampling Site**	**pH**	**Temperature (^{0}C)**	**Electrical Conductivity (µS/cm)**	**Total Dissolved Solids (mg/l)**	**Turbidity (mg/l)**
Block 1 Chinga	Upstream	6.5	21.8	105.6	158	200
	Entry Point	5.25	20.6	690	1420	720
	Downstream	6.9	19.5	650	1360	660
Block 2 Ichamama	Upstream	6.3	20.5	109.5	170	195
	Entry Point	4.5	19.2	730	1370	700
	Downstream	6.6	19.8	675	1340	650
Block 3 Iriaini	Upstream	6.4	20.5	108.5	145	210
	Entry Point	4.3	20.9	665	1480	730
	Downstream	6.3	19.5	674	1240	640
Block 4 Rukira	Upstream	6.8	19.4	104.6	180	220
	Entry Point	3.8	18.8	720	1460	750
	Downstream	6.4	19.7	672	1320	670
		Chemical Variables				
Block/ Factory	**Sampling Site**	**Nitrate (mg/l)**	**Phosphate (mg/l)**	**Biological Oxygen Demand(mg/l)**	**Dissolved Oxygen (mg/l)**	**Chemical Oxygen Demand (mg/l)**
Block 1	Upstream	3.06	3.76	58	6.95	65
	Entry Point	4.35	4.45	294	6.10	365

Chinga	Downstream	3.24	3.64	80	5.5	85
Block 2 Ichamama	Upstream	3.16	3.47	70	6.90	90
	Entry Point	4.50	4.52	850	6.05	6150
	Downstream	3.29	3.85	120	5.6	125
Block 3 Iriaini	Upstream	3.40	3.96	60	6.92	155
	Entry Point	4.30	4.65	750	6.15	7085
	Downstream	3.26	3.78	102	5.8	154
Block 4 Rukira	Upstream	3.35	3.90	90	6.94	105
	Entry Point	4.45	4.62	830	6.12	7140
	Downstream	3.44	3.72	502	5.3	625

4.5.2 Discussion of Results

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 consistent 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 (BOD5) values also exceeded the WHO 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).

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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.

4.6 Measures To Reduce Further Contaminating Effects On Surface Water

Efforts to mitigate the polluting effects of industrial effluents on surface waters have been undertaken by various authorities, including regulatory bodies. However, the implementation of government laws and regulations aimed at reducing water pollution has been lacking. The study highlighted deficiencies in the industrial wastewater management framework of Othaya Coffee Society, including a lack of well-coordinated management policies. Additionally, there was a notable absence of regular monitoring and proper implementation of government guidelines regarding industrial wastewater management. Furthermore, effective government policy frameworks and penalties against companies and organizations that discharge untreated industrial wastewater were found to be lacking. This poses a significant risk to the health and safety of surface waters and the communities that rely on them. Moreover, there was a notable absence of private sector involvement in raising awareness and educating the community on surface water management in Othaya Coffee Society. Such involvement could play a crucial role in achieving a balance between sustainable industrial growth and effective wastewater management practices.

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

The study assessed the contamination of surface water by coffee processing honey water using the Othaya Coffee Society in Nyeri County as a case study. The objectives were to determine contaminant levels, assess contamination effects, examine socio-economic impacts, and identify measures to reduce further contamination. Primary data was collected from field visits and laboratory analyses, while secondary data came from reports, publications, and other sources. Stratified and simple random sampling were used, along with descriptive surveys and qualitative data collection methods like questionnaires, interviews, and observations. Surface and honey water samples were analyzed for physicochemical properties, and qualitative data was coded and analyzed using PASW and spreadsheet software. Descriptive statistics, such as tables, pie charts, and graphs, were used to present results. Key findings included: Households benefit socio-economically from the Othaya Coffee Society and River Tana. The society supports local households through employment and income generation, contributing to Nyeri County's economic development. Many households rely on River Tana for water, aquaculture, and irrigation; Coffee processing produces honey water and pulp, which support local livelihoods. However, 61% of respondents reported that coffee wastewater polluted River Tana; Contaminated water released nitrates and ammonium, contributing to greenhouse gas emissions and global warming. It also contained nitrogen and phosphorus, leading to eutrophication, algal blooms, and reduced aquatic populations; Consuming contaminated water could cause diseases such as bilharzia, typhoid fever, cholera, diarrhea, dysentery, body inflammation, eye irritation, dizziness, stomach, and breathing issues. Excess nitrates could cause blue baby syndrome; Interviews revealed inadequate coffee wastewater management by Othaya Society. Waste pits were poorly designed, and existing waste management systems failed to control pollution; Physico-chemical analysis showed highly acidic water with high organic loads (BOD5 and COD), nutrients (nitrate and phosphate), and suspended solids. Downstream water quality was significantly worse than upstream, indicating untreated coffee wastewater pollution. The study found that the Othaya Coffee Society lacked an effective industrial wastewater management framework with well-coordinated policies. There was insufficient regular monitoring and implementation of government guidelines on industrial wastewater management. There were no effective government policies or penalties against companies discharging untreated wastewater, endangering public health and surface waters. Additionally, there was inadequate private sector involvement in raising awareness and education on surface water management in Othaya Coffee Society. This gap hinders the balance between sustainable industrial growth and effective wastewater management. The study concluded that coffee wastewater contamination adversely affected downstream livelihoods, necessitating further intervention to prevent ongoing community harm.

5.2 Conclusions

Based on the results, the study concluded that the Othaya Coffee Company, like other coffee processors, discharges untreated coffee wastewater into surface waters. Most employees surveyed felt that their companies lacked adequate coffee wastewater management systems. These effluents significantly impact water pollution by altering the physical, chemical, and biological properties of the receiving water body, such as the Tana River. Consequently, surrounding communities are vulnerable to various diseases and illnesses due to water pollution. The study confirmed that some local residents, especially those living closer to and relying on the River Tana for water, found their water contaminated by the Othaya Association's coffee wastewater, posing a health hazard. The study assessed surface water pollution from two perspectives: workers and the community. From the workers' perspective, some respondents suggested treating coffee wastewater before disposal and supported good agricultural practices.

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From the community's perspective, respondents included views on prevention measures and reported types of infections. The results highlighted the need to raise awareness among water users about avoiding chemical overuse in tap water, promoting afforestation, and improving agricultural practices. Some unaffected respondents suggested using treated water as a mitigation measure. The study concluded that effluents from wet coffee processing do not comply with WHO limits for treated coffee effluent discharged into surface water. Even after stabilization in landfill pits, the contamination potential from coffee wet processing plants remains high. To comply with surface water quality regulations and restore surface water quality, it is necessary to find economical and adaptable technologies for treating coffee processing effluents.

5.3 Recommendations

Based on the conclusions, the study recommends several measures:

Treatment of Coffee Effluents: Othaya Coffee Society Management should ensure that coffee effluents are treated before discharge into surface waters. All coffee industries in the study area must have proper wastewater treatment facilities on their premises to discharge treated wastewater into receiving water bodies. These treatment facilities should be regularly checked for efficiency by responsible authorities. Additionally, suitable disposal pits (lagoons) should be designed to control coffee effluent seepage into water bodies.

Enforcement of Policies and Regulations: Responsible authorities such as the National Environmental Management Authority (NEMA) should continuously enforce policies and regulations on wastewater discharge. The Ministry of Water and Irrigation, especially WARMA, should ensure strict adherence to water quality regulations to control or prevent surface water contamination. Regulations like the "polluter pay principle" should be enforced to hold industrial owners accountable for environmental damage, including compensating affected communities and revoking licenses of non-compliant industrial owners.

Handling of Coffee Honey Water: Proper handling of coffee honey water is essential to avoid health risks associated with diseases like typhoid fever and cholera, which result from the use of contaminated surface water. The community along the River Tana should be sensitized about the risks of using contaminated water and educated on alternative safe water sources to protect their health and livelihoods.

Reinforcement of Environmental Impact Assessment and Audit: There should be reinforcement of Environmental Impact Assessment (EIA) prior to establishing industrial facilities and Environmental Audit for existing industries. This would help anticipate environmental impacts, including water contamination, and ensure adequate measures are in place for effluent management, treatment efficiency, and capacity assessment.

5.4 Areas of Further Study

The study focused on evaluating the contaminating effects of coffee honey water on surface water in the Othaya catchment area and along the Tana River, specifically referencing the Othaya Coffee Society in Nyeri County. However, it suggests areas for further research and investigation:

City Planning Policies: Further research could explore the influence of city planning policies on wastewater management from industrial areas in Othaya town. Understanding these policies could provide insights into better waste management practices.

Coffee By-Products: While the study examined the effects of coffee honey water, it did not assess the impact of other coffee by-products, such as pulp, on surface water contamination. Future research could delve into this aspect to comprehensively understand the overall impact of coffee processing on water quality.

Extension to Other Coffee-Growing Counties: The study recommends extending the investigation to the other thirty-three coffee-growing counties in Kenya, with specific reference to the Othaya Coffee Society. This broader scope would provide a more comprehensive understanding of the contaminating effects of coffee processing on surface water across different regions.

End Point Contamination: The study did not assess the contaminating effects of coffee effluents at endpoints such as the ocean, surface water bodies, and groundwater. Conducting further research in these areas would help establish proper measures to ensure the safety of marine, surface, and groundwater resources, thus contributing to a healthier environment overall.

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