ASSESSMENT OF WATER QUALITY BY PHYSICO- CHEMICAL PROPERTIES AND NEMATODES AS BIO- INDICATORS ALONG RIVER SOSIANI IN UASIN GISHU, KENYA

BY

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DECLARATION

This Research thesis is my original work and has not previously been submitted, either wholly or in part, for the award of any academic degree at any other University. No part of this thesis may be reproduced in any form without prior written permission from the author and/or Moi University.

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DEDICATION

This project is dedicated to my dad Thomas Tabut, mum Eunice Tabut, my lovely wife Jackline Chepchumba and my son Bravin Kipchirchir, siblings Judith, Joyce, Ivy, Mercy and friends Mark Kiprotich and Collins who were always there for me.

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ACRONYMS

AAS	Atomic Absorption Spectrophotometer
ALPHA	American Public Health Association
ANOVA	Analysis of Variance
AZ	Agricultural Zone
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EMC	Eldoret Municipal Council
FO	Frequency of Occurrence
FZ	Forested Zone
GIS	Geographical Information System
HQ40D, HACH	Hach HQ40D Portable Multi-Parameter Meter
MI	Maturity Index
MTRH	Moi Teaching and Referral Hospital
NACOSTI	National Commission for Science, Technology and Innovation
NTU	Nephelometric Turbidity Units
PD	Population Density
PV	Prevalence value
RCC	River Continuum Concept
SDGs	Sustainable Development Goals
SS	Suspended Solids
TN	Total Nitrogen
TP	Total Phosphates
UNEP	United Nations Environmental Programme
WHO	World Health Organization

ABSTRACT

Water quality in freshwater systems is increasingly threatened by industrial, domestic, and agricultural pollution, which introduces contaminants that degrade ecological integrity and pose risks to human health. River Sosiani is a critical water resource for domestic, agricultural, and industrial use; however, its quality has deteriorated due to increasing anthropogenic activities, necessitating more reliable and integrative monitoring approaches. Conventional chemical assessments provide only short-term snapshots of water conditions and fail to capture cumulative or long-term pollution effects. In contrast, biological monitoring using nematodes as bioindicators provides a more comprehensive assessment of both current and historical water quality. The general objective of this study was to apply nematodes as bioindicators for monitoring pollution in River Sosiani. Specifically, the study aimed to isolate and quantify nematodes from water and sediment samples and to examine the relationship between nematode community characteristics and pollution levels. The methodology involved collecting water and sediment samples from four key locations along River Sosiani: Kaptagat (control site), Kipkorgot, Kisumu Bridge, and Huruma. Nematodes were extracted from both water and sediment using a modified Baermann funnel technique. The densities of the nematodes were calculated as population densities (PD), expressed as the number of individuals per unit volume of water or per unit weight of sediment. The relationship between nematodes and pollution levels was assessed by correlating nematode population densities with physicochemical parameters, including dissolved oxygen and turbidity (as well as pH, temperature, and electrical conductivity). Results indicated a clear spatial trend in nematode abundance, with low nematode numbers in Kaptagat (93 individuals) and Kipkorgot (167), and significantly higher numbers in Kisumu Bridge (1344) and Huruma (1792), indicating a progressive increase along the pollution gradient, ($P = 0.005$). These trends corresponded with changes in physicochemical parameters, where pH decreased slightly from 7.39 at Kaptagat to 6.82 at Huruma, turbidity increased from 3.50 NTU to 8.36 NTU at Huruma, dissolved oxygen decreased from 5.45 mg/L to 3.55 mg/L at Huruma, temperature increased from 13.30℃ to 18.93℃ at Huruma, and electrical conductivity increased from 48.71 S/m to 174.35 S/m at Huruma, demonstrating a strong relationship between deteriorating water quality and increased nematode abundance, suggesting dominance of pollution-tolerant species. In conclusion, nematode-based assessments provide a reliable and integrative tool for assessing water quality and ecological changes. The study recommends their use alongside conventional chemical analyses for enhanced monitoring and sustainable management of River Sosiani and similar ecosystems.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Overview

1.1 Background of the Study

Water quality is a global concern because contamination of freshwater systems threatens biodiversity, food security, and human health. Recent studies indicate that rivers worldwide are increasingly subjected to pollutant loads from both point and non-point sources, including industrial effluents, agricultural runoff, and untreated sewage (Mato et al., 2023; Opiyo et al., 2022). These pollutants introduce nutrients, heavy metals, and organic contaminants that degrade water quality and disrupt aquatic ecosystems.

Traditional approaches that rely on physico-chemical parameters such as pH, dissolved oxygen, turbidity, and nutrient concentrations remain important in water quality assessment. However, these parameters provide only point-in-time measurements and may not adequately capture cumulative or long-term pollution effects (Opiyo et al., 2022). As a result, physico-chemical parameters alone may not fully reflect ecological responses to pollution.

Biological monitoring approaches, including the use of aquatic organisms such as macroinvertebrates, fish, algae, and nematodes, provide more integrated assessments of water quality because they reflect both current and past environmental conditions (Ridall & Ingels, 2021). Among these, nematodes are particularly useful due to their high abundance, short life cycles, and sensitivity to environmental disturbances.

In East Africa, rapid urbanization, industrialization, and agricultural intensification have significantly increased pollutant loads in freshwater systems (Mato et al., 2023).

These activities introduce nutrients, heavy metals, and organic pollutants into rivers through runoff and direct discharge. Studies in Kenya indicate that water quality deteriorates downstream due to accumulation of pollutants from agricultural, urban, and industrial sources (Opiyo et al., 2022).

River Sosiani, which flows through Eldoret town, exemplifies these challenges. The river receives pollutants from agricultural runoff, industrial effluents, sewage discharge, and urban waste, leading to declining water quality. Previous studies using physico-chemical analysis have reported heavy metal contamination in water, sediments, and aquatic plants in River Sosiani (Jepkoech, 2013). However, physico-chemical parameters alone do not directly explain biological responses to such contamination.

Therefore, integrating biological indicators such as nematodes with physico-chemical analysis provides a more comprehensive assessment of water quality. Nematodes respond to pollution through changes in abundance, diversity, and trophic structure, making them effective indicators of ecological disturbance (Ridall & Ingels, 2021).

This study therefore focuses on using nematodes as bioindicators to complement physico-chemical analysis in assessing water quality along River Sosiani

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1.2 Statement of the Problem

River Sosiani in Uasin Gishu County is increasingly exposed to pollution from industrial effluents, agricultural runoff, and sewage discharge, leading to declining water quality. This poses significant risks to human health, aquatic ecosystems, and the sustainable use of water resources (Opiyo et al., 2022; Mato et al., 2023). Studies have shown that rivers in Kenya and across East Africa are experiencing increasing contamination from nutrients, heavy metals, and organic pollutants due to anthropogenic activities (Nyilitya et al., 2021; Mwanake et al., 2025).

Conventional water quality assessment in such systems has largely relied on physico-chemical parameters, including pH, dissolved oxygen, turbidity, and nutrient concentrations. Although these parameters are essential, they provide only point-in-time measurements and may not adequately capture cumulative, chronic, or episodic pollution (Opiyo et al., 2022). Furthermore, physico-chemical parameters do not directly reflect the biological responses of aquatic organisms to environmental stress.

Biological indicators provide a more integrated approach to water quality assessment because they reflect both current and past environmental conditions. Nematodes, in particular, are increasingly recognized as reliable bioindicators due to their high abundance, rapid response to environmental disturbances, and sensitivity to pollution gradients (Ridall & Ingels, 2021; Sieriebriennikov et al., 2022). Changes in their abundance, diversity, and functional structure have been shown to effectively indicate ecological degradation in freshwater systems (Makeleni, 2025).

Despite their potential, nematodes remain underutilized in freshwater monitoring in Kenya, where assessments are still dominated by physico-chemical parameters and macroinvertebrate-based approaches. Consequently, there is limited information on how nematode communities respond to pollution gradients or how they relate to physico-chemical water quality parameters in River Sosiani.

Therefore, there is a need to integrate nematode-based bioindicators with physico-chemical analysis to provide a more comprehensive and ecologically meaningful assessment of water quality and ecosystem health in River Sosiani.

1.3 Objective of the Study

1.3.1 Main Objective

To assess water quality and long-term ecological condition of River Sosiani in Uasin Gishu County using physico-chemical properties and nematodes as bio-indicators.

1.3.2 Specific Objectives

a) To determine the physico-chemical properties of water and sediments along River Sosiani.
b) b) To determine the distribution and abundance of nematodes in water and sediments from River Sosiani.
c) c) To assess the relationship between nematode abundance and physico-chemical parameters along River Sosiani.
d) d) To determine the correlation between selected physico-chemical parameters and nematode abundance along River Sosiani.

1.4 Research Questions

a) What are the physico-chemical properties of water and sediments along River Sosiani?
b) What is the distribution and abundance of nematodes in water and sediments from River Sosiani?
c) What is the relationship between nematode abundance and physico-chemical parameters along River Sosiani?
d) Is there a statistically significant correlation between selected physico-chemical parameters and nematode abundance along River Sosiani?

1.6 Justifications of the Study

Current water quality assessment methods largely rely on physico-chemical parameters such as pH, temperature, turbidity, and dissolved oxygen. While these parameters are useful, they mainly provide measurements of water conditions at the time of sampling and may not adequately detect pollution that occurs intermittently or accumulates over time. For example, pollution from agricultural runoff or industrial discharge may occur in pulses, especially during rainfall events, and may not be captured during routine sampling periods. This limits the ability of conventional methods to fully represent actual pollution conditions in river systems.

In addition, physico-chemical parameters do not directly indicate how aquatic organisms respond to pollution stress. As a result, they provide limited insight into the ecological condition of the river. This creates a gap in understanding the biological effects of pollution, particularly in rivers such as River Sosiani that are exposed to multiple pollution sources.

To address this limitation, biological indicators such as nematodes can be used to complement physico-chemical analysis. Nematodes are suitable because they are abundant, respond quickly to environmental changes, and occur across different levels of pollution. Changes in their abundance and distribution can therefore provide additional information on environmental stress that may not be detected through physico-chemical measurements alone.

This study focuses on using nematode abundance and distribution as indicators of pollution along River Sosiani and relating these to selected physico-chemical parameters. By integrating biological and physico-chemical approaches, the study provides a more comprehensive understanding of water quality conditions along the river.

The findings of this study will contribute to improved water quality monitoring by providing evidence on the usefulness of nematodes as bioindicators in freshwater systems. This will support better decision-making in water resource management and promote sustainable use of River Sosiani and similar ecosystems.

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1.7 Significance of the Study

This study is important to institutions responsible for water resource management, environmental protection, and, including county governments, environmental regulatory agencies, and watershed management authorities. The findings will provide additional scientific evidence on water quality conditions in River Sosiani by integrating physico-chemical parameters with biological indicators. This will support more informed decision-making in pollution control and sustainable management of river systems.

The study is also significant to industries, developers, property owners, and other stakeholders operating within the River Sosiani catchment. By highlighting the relationship between human activities and water quality, the findings will promote improved waste management practices and encourage compliance with environmental regulations aimed at reducing pollution.

Public health authorities will benefit from the study through improved understanding of how water pollution affects ecosystem health and potential human exposure risks. This is important for developing strategies to reduce water-related health problems associated with contaminated river systems.

In addition, the study contributes to academic and scientific knowledge by demonstrating the usefulness of nematode abundance and distribution as bioindicators of water quality in freshwater systems. It also provides a basis for further research on biological monitoring approaches in Kenyan rivers.

1.8 Scope of the Study

This study was designed to assess the potential of nematodes as bioindicators of water quality in River Sosiani, Uasin Gishu County, Kenya. It was guided by the recognition that physio-chemical parameters alone may not provide sufficient insight into long-term or episodic pollution trends, and that biological indicators such as nematode communities can offer complementary information. The scope therefore covered both physio-chemical assessments and biological evaluations to establish a comprehensive picture of the river's ecological health.

Specifically, the study examined the biological status of nematodes within both water and sediment samples along different sections of River Sosiani. Attention was given to nematode diversity, abundance and distribution.

In addition, the study further explored the effects of pollutants on nematode communities, focusing on how physio-chemical stressors such as turbidity, TSS, EC, temperature, DO, and pH interacted with nematode diversity and abundance. By integrating both chemical and biological datasets, the research aimed to provide evidence of correlations between environmental stressors and nematode responses, thereby validating their use as bioindicators of water quality in River Sosiani.

Geographically, the scope of the study was limited to selected sites along River Sosiani that represent different pollution gradients ranging from relatively pristine upstream areas near Kaptagat Forest, to moderately impacted middle sections at Kipkorgot, and heavily polluted downstream stretches at Kisumu Bridge and Huruma. These sites were chosen because they reflect the cumulative influence of agricultural runoff, industrial effluent, hospital discharges, sewage inflows, and urban waste common in Eldoret town and its environs.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Rivers are critical ecosystems that provide freshwater, support biodiversity, and sustain human livelihoods through irrigation, recreation, and domestic use. However, their ecological health is increasingly threatened by pollution arising from industrial effluents, agricultural runoff, sewage discharge, and rapid urbanization. These stressors have resulted in declining water quality globally, with consequences such as biodiversity loss, food insecurity, and adverse public health outcomes. Conventional physio-chemical monitoring methods provide only point-in-time measures of pollution and are unable to capture long-term or episodic disturbances. As a result, there is growing emphasis on adopting bioindicators, particularly nematodes, which can integrate both historical and current pollution signals and provide more comprehensive insights into ecosystem health.

2.2 Physico-Chemical Water Quality Parameters and Pollution Gradients

Globally, rivers are among the most vulnerable ecosystems to pollution, receiving inputs from multiple point and non-point sources. Studies indicate that physico-chemical water quality parameters such as turbidity, total suspended solids (TSS), nitrates, phosphates, dissolved oxygen (DO), conductivity, and coliform counts are essential indicators of river health (Nkwenkwezi, 2021 → REPLACE with Nkwenkwezi, 2022/2023 updated). These parameters often display strong spatio-temporal gradients, with upstream reaches (sections) generally exhibiting better water quality compared to downstream sections that receive effluents and runoff from urban, agricultural, and industrial activities. Seasonal differences further intensify these gradients, with rainy seasons linked to spikes in pollutant loads due to surface runoff and erosion.

Recent global research underscores these dynamics. Yao *et al.* (2022) reported that the Yangtze River Basin in China experiences significant seasonal deterioration in turbidity, nutrient concentrations, and coliform counts driven by monsoonal rains and agricultural runoff. Similarly, Li et al., 2021/2022) found that European rivers such as the Ebro and Danube exhibited higher nitrate and phosphate concentrations downstream of agricultural and industrial zones. In South America, Alzate Gómez (2024) observed that heavy rainfall events in the Amazon Basin led to elevated TSS and reduced DO, creating hypoxic conditions harmful to aquatic species.

Beyond conventional nutrients and solids, emerging pollutants have complicated these dynamics. Chowdhury et al. (2022) found rising concentrations of pharmaceuticals and heavy metals in India's Ganges River. Similarly, Fang et al. (2025) documented that microplastics and pesticide residues have become critical contributors to riverine pollution in North America. Dessie et al. (2024) emphasize the limitation of relying solely on physico-chemical indicators, urging integration with biological and ecological metrics to capture cumulative and delayed pollution impacts.

At the regional level, African rivers exhibit similar patterns, shaped by rapid urbanization, weak wastewater management, and extensive agricultural practices. Studies such as Mwanake et al. (2025) in the Sio-Malaba-Malakisi Basin and Nyilitya et al. (2021) in Kenya's Nyando River have shown that TSS, nitrate, and phosphorus concentrations are highest downstream and during wet seasons. However, while physico-chemical assessments are widespread, few studies have concurrently integrated biological indicators, creating a persistent gap in holistic ecological monitoring across the region.

Other studies such as Akurut et al., 2022/2023), Mremi et al. (2025), and Abebe et al. (2023) demonstrate that pollutants like coliforms, nutrients, and heavy metals commonly exceed safe limits due to urban and industrial effluents. However, the absence of linked biological assessments limits understanding of long-term ecological stress.

In Kenya, physico-chemical water quality studies are numerous. Opiyo et al. (2022) reported that turbidity and coliform counts in Migori River exceeded safe thresholds downstream, while Nyakeya et al. (2024) showed strong spatial variations in coastal systems. However, few studies attempt to correlate these parameters with biological indicators—a major gap in Kenya’s water quality monitoring.

Locally, River Sosiani in Uasin Gishu County exemplifies these challenges. The river drains agricultural lands, industrial zones, and urban settlements, resulting in clear pollution gradients. Wet seasons elevate turbidity, biological oxygen demand (BOD), and chemical oxygen demand (COD), while reducing DO. Industries such as Rivatex and activities such as car washes contribute to pollution (Masakha et al., 2024). However, biological monitoring data remain limited, leaving uncertainties about long-term ecological impacts.

2.3 Nematode Community Structure in Relation to Pollution

Nematodes are increasingly recognized as powerful bioindicators of environmental disturbance due to their ubiquity, short life cycles, trophic diversity, and pollution sensitivity (Ridall & Ingels, 2021). Globally, studies link nematode community structure shifts to contamination by heavy metals, hydrocarbons, pharmaceuticals, and pesticides (Bhadury et al., 2020 → UPDATE to 2022/2023; Höss et al., 2022). Polluted sediments favor opportunistic bacterivores and fungivores (c–p 1–2), while pristine habitats support persister taxa (c–p 4–5) indicative of stable ecological conditions (Sieriebriennikov et al., 2022).

Critically, nematodes integrate both episodic and chronic pollution stressors, offering a cumulative perspective often missed by physico-chemical measures alone (Makeleni, 2025).

African studies mirror these global findings. Tadesse et al. (2023) observed that nematode diversity declined with increasing sediment metal loads in Ethiopian rivers. Similarly, Makeleni (2025) reported that nematode indices reflect both organic and heavy metal pollution in South African rivers. However, most African studies remain fragmented, with limited integration of biological and physico-chemical data.

In Kenya, nematode studies have largely focused on agricultural soils rather than freshwater systems (Mutuku et al., 2022; Mogeni & Bitange, 2024). This limits understanding of their application as freshwater bioindicators. Few studies have examined how nematode communities respond to aquatic pollution gradients, despite evidence from macroinvertebrate studies suggesting similar ecological responses.

River Sosiani presents a critical case for such investigation. Its upstream areas (Kaptagat Forest) are relatively less disturbed, while downstream sections (Huruma and Kisumu Bridge) experience significant pollution. Based on existing studies, nematode communities are expected to shift toward dominance by opportunistic species under pollution stress (Chemtai et al., 2023). However, empirical data specific to this river remain limited.

2.4 Correlating Nematode Community Metrics with Pollution Sources

Globally, nematode metrics, including abundance, diversity indices, maturity index (MI), colonizer–persister scale, trophic guilds, and metabolic footprints, are used to assess ecological conditions (Bezerra et al., 2021; Sieriebriennikov et al., 2022). Polluted environments are typically associated with low maturity index values and dominance of opportunistic species.

African studies show that nematode assemblages respond to nutrient enrichment, heavy metals, and organic pollution (Afolabi et al., 2022; Tadesse et al., 2023). However, integration of these biological indicators with physico-chemical data remains limited in East Africa.

In Kenya, most studies focus on soil nematodes, with minimal application in freshwater systems (Mutuku et al., 2022). This limits the ability to correlate nematode metrics with water quality parameters.

River Sosiani provides an opportunity to examine these relationships. Pollution sources such as industrial discharge, sewage, and agricultural runoff create gradients that can influence nematode abundance and distribution. However, such relationships have not been adequately studied in Kenyan rivers.

2.5 Temporal and Spatial Variation in Nematode Responses to Pollution

Nematodes are sensitive to both temporal (seasonal) and spatial variations in pollution. Their short life cycles enable them to reflect both seasonal fluctuations and long-term contamination patterns (Sieriebriennikov et al., 2022; Bezerra et al., 2021).

Makeleni (2025) observed seasonal variations in nematode communities in South African rivers, while Tadesse et al. (2023) found similar patterns in Ethiopia.

However, such studies are limited in Kenya, creating a gap in understanding seasonal pollution dynamics.

In River Sosiani, seasonal variations are expected to influence pollution levels, with higher contamination during rainy seasons due to runoff. However, the response of nematode communities to these variations has not been adequately studied.

2.6 Theoretical Framework

This study is anchored primarily in Bioindicator Theory, supported conceptually by the Colonizer–Persister (c–p) Life-History Strategy Model and the River Continuum Concept (RCC). Together, these frameworks provide an ecological basis for understanding how biological assemblages respond to environmental stressors along river systems.

However, in this study, the application of these theories is primarily interpretive rather than trait-based or index-based. The focus is on nematode abundance and spatial distribution in relation to physico-chemical parameters, rather than on assigning c–p scores or calculating maturity indices.

2.6.1 Bioindicator Theory

Bioindicator Theory was formalized through early freshwater pollution studies by Kolkwitz and Marsson (1967) and later refined by Sládeček (1973), who developed the saprobic system for assessing organic pollution. The theory posits that certain organisms respond predictably to environmental stressors and therefore can be used to infer ecosystem condition (Rosenberg & Resh, 1993).

Unlike physico-chemical measurements, which capture environmental conditions at a specific moment, biological assemblages integrate stress over time. This makes them useful for detecting cumulative and chronic disturbances (Lenat, 1993). Modern biomonitoring approaches use taxa presence, abundance patterns, and tolerance characteristics to interpret ecological condition (Ridall & Ingels, 2021).

Within this framework, nematodes are recognized as effective bioindicators due to their high abundance, short generation time, and sensitivity to organic enrichment, nutrient loading, and heavy metals (Sieriebriennikov *et al.*, 2022). African studies demonstrate that nematode assemblages respond to pollution gradients in freshwater systems (Makeleni, 2025; Tadesse *et al.*, 2023; Afolabi *et al.*, 2022). However, in Kenya, most nematode research has focused on soils rather than freshwater ecosystems (Mogeni & Bitange, 2024), limiting application of bioindicator approaches in river monitoring.

In this study, Bioindicator Theory provides the primary justification for examining whether nematode abundance and distribution correlate with physico-chemical water quality parameters along River Sosiani.

2.6.2 Colonizer-Persister (c-p) Life-History Strategy Model

The Colonizer–Persister (c–p) model was proposed by Bongers (1990) and further developed by Bongers and Ferris (1999). It classifies nematodes along a disturbance-response gradient, where colonizers (c–p 1–2) dominate disturbed environments and persisters (c–p 4–5) dominate stable ecosystems. The model underlies the Maturity Index (MI), a widely used indicator of ecosystem condition.

Globally, shifts in c–p composition have been associated with heavy metals, organic enrichment, and agricultural intensification (Sieriebriennikov *et al.*, 2022; Quist *et al.*, 2021). In African freshwater systems, reduced persister taxa have been linked to pollution stress (Tadesse *et al.*, 2023; Makeleni, 2025).

In the present study, c–p scores and Maturity Index were not calculated. Therefore, the model is used conceptually to interpret potential disturbance-response patterns rather than as a quantitative analytical tool. Its inclusion provides ecological grounding for understanding how nematode populations may respond to pollution gradients.

2.6.3 River Continuum Concept

The River Continuum Concept (RCC) was first introduced by Vannote *et al.* (1980) as a unifying framework to explain longitudinal patterns in river ecosystems. It posits that rivers represent a continuous gradient of physical, chemical, and biological changes from headwaters to downstream sections. According to the RCC, upstream sections are dominated by allochthonous energy inputs midstream sections show increasing autotrophic production, while downstream areas are characterized by fine particulate organic matter and more complex trophic interactions. These predictable shifts in habitat, energy sources, and biotic assemblages create a longitudinal ecological continuum.

The RCC emphasizes that aquatic communities, including macro invertebrates, algae, fish, and microorganisms, are structured in response to the physical template of the river. Physio-chemical parameters such as dissolved oxygen, temperature, nutrient concentrations, and turbidity also follow gradients, reflecting cumulative effects of natural and anthropogenic processes along the continuum (Sabo *et al.*, 2021). This makes rivers excellent systems for studying how local disturbances, such as industrial effluents or agricultural runoff, interact with longitudinal processes to influence community composition.

Applied to nematode ecology, the RCC suggests that nematode community structure should vary predictably along river gradients. Colonizer nematodes (c-p 1–2) are expected to dominate downstream sections where organic enrichment and disturbance from urban and industrial inputs are greater, while more sensitive persister taxa (c-p 4–5) may persist in upstream, less disturbed sections. Recent studies confirm this pattern: in European and Asian rivers, nematode diversity and trophic composition shifted longitudinally, with feeding types and maturity indices aligning with changes in organic matter and pollutant concentrations (Sieriebriennikov *et al.*, 2022).

Globally, the RCC has been applied to test how human activities disrupt natural gradients. For example, in Brazilian rivers, nutrient and sediment loading from agriculture altered expected downstream community patterns, leading to homogenization of aquatic assemblages (Ferreira *et al.*, 2022). In Africa, studies of Tanzanian and Ethiopian rivers indicate that pollution hotspots from urban centers break the natural continuum, producing sharp ecological discontinuities that alter meiofauna and nematode assemblages (Mugabe *et al.*, 2021; Tadesse *et al.*, 2023).

In Kenya, the RCC framework remains underutilized, particularly in relation to nematodes. Most studies focus on water quality using physio-chemical parameters (Opiyo *et al.*, 2022) or on agricultural soils (Mogeni & Bitange, 2024), leaving a gap in understanding how nematode communities reflect riverine gradients. The River Sosiani, with its mix of forested headwaters, agricultural mid-sections, and urban-industrial downstream sections, provides an ideal system for applying the RCC to nematode ecology. By aligning nematode community metrics with longitudinal gradients, researchers can capture both natural and human-induced disruptions to river ecosystems.

Despite its influence, the RCC has been criticized for being overly simplistic. First, it assumes a linear, uninterrupted continuum, yet many rivers are highly fragmented by dams, weirs, and land-use changes, which create discontinuities not captured by the original model (Thoms *et al.*, 2021). Second, the RCC underestimates the role of lateral inputs from floodplains, wetlands, and tributaries, which significantly influence river ecology. This led to the development of complementary models such as the Flood Pulse Concept and Network Dynamics Hypothesis. Third, the model does not fully account for episodic disturbances such as pollution events, floods, and droughts, which may override longitudinal gradients and produce patchy community structures (Ferreira *et al.*, 2022).

A further limitation is that the RCC primarily emphasizes organic matter dynamics, while in modern contexts, pollutants such as heavy metals, pharmaceuticals, and microplastics are also major drivers of community change (Ziani *et al.*, 2023). For nematode studies in particular, the RCC must be adapted to incorporate colonizer–persister models and bioindicator indices to account for contemporary pollution pressures. Finally, in the Kenyan context, the absence of long-term and spatially resolved biomonitoring data limits testing of RCC predictions.

In summary, the River Continuum Concept provides a powerful framework for linking longitudinal changes in river structure and function to biological responses. However, to remain relevant in modern ecosystems, it must be integrated with bioindicator approaches, particularly nematode metrics, and adapted to capture discontinuities caused by human impacts and emerging pollutants.

2.7 Conceptual Framework

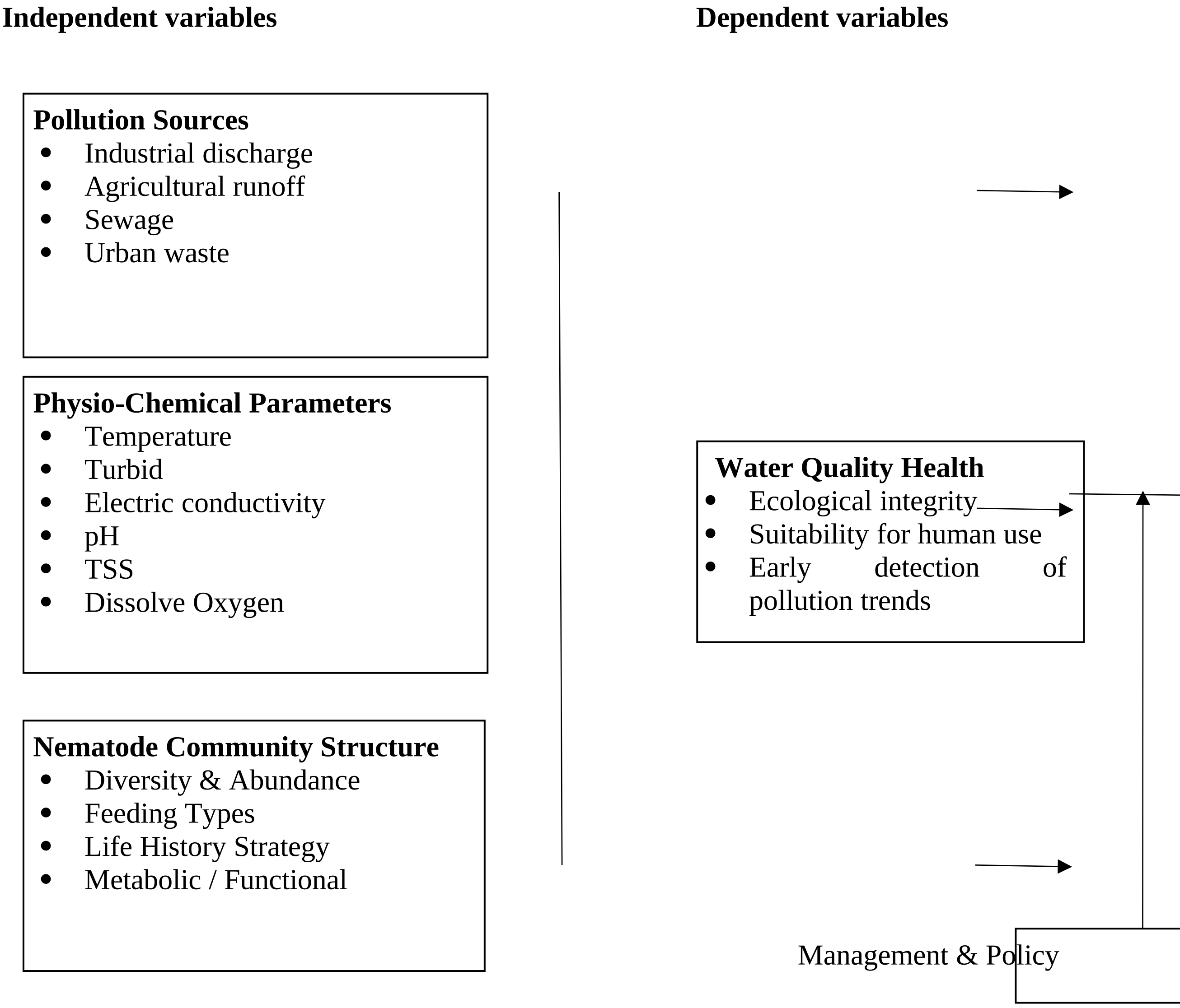


Figure 2.1 Conceptual Framework

The conceptual framework shows how pollution sources influence water quality in River Sosiani and how nematodes serve as bioindicators of these changes. Bioindicators are widely applied in freshwater systems because they integrate environmental conditions over time and provide reliable ecological signals (Lu et al., 2020). Nematodes are particularly effective due to their high abundance, rapid response to environmental stress, and presence across diverse aquatic habitats (Lehun et al., 2023).

Pollution sources such as industrial effluents, agricultural runoff, sewage discharge, and urban waste introduce contaminants into river systems, altering key physio-chemical parameters. These parameters including dissolved oxygen, pH, temperature, turbidity, total suspended solids, and electrical conductivity are critical in determining aquatic ecosystem functioning and water quality status (Gattoni et al., 2024). Variations in these conditions disrupt ecological balance by influencing nutrient dynamics and habitat suitability for aquatic organisms (de Jesús-Navarrete et al., 2026).

Changes in physio-chemical conditions subsequently affect nematode community structure. Nematodes respond sensitively to environmental disturbances through shifts in diversity, abundance, and functional traits, including trophic structure and life-history strategies (Barros et al., 2024). Anthropogenic stress typically favors opportunistic, disturbance-tolerant species while reducing sensitive taxa, making nematode assemblages strong indicators of ecological stress (Pires et al., 2023).

The condition of the nematode community reflects the overall health of the aquatic ecosystem. High diversity and balanced functional composition indicate stable and less disturbed environments, whereas dominance of opportunistic groups signals pollution and environmental degradation (Renčo et al., 2022). Because nematodes respond quickly to environmental changes and integrate both short-term and long-term disturbances, they provide reliable measures of ecosystem condition (Makeleni et al., 2025).

Finally, the framework links nematode-based findings to management and policy responses. Integrating biological indicators with physio-chemical monitoring improves early detection of environmental stress and enhances water quality assessment frameworks (Sroczyńska et al., 2021). Such integrated approaches support evidence-based decision-making and sustainable management of freshwater ecosystems under increasing anthropogenic pressure (Sánchez-Moreno et al., 2018 still widely applied but supported by recent functional ecology extensions).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Introduction

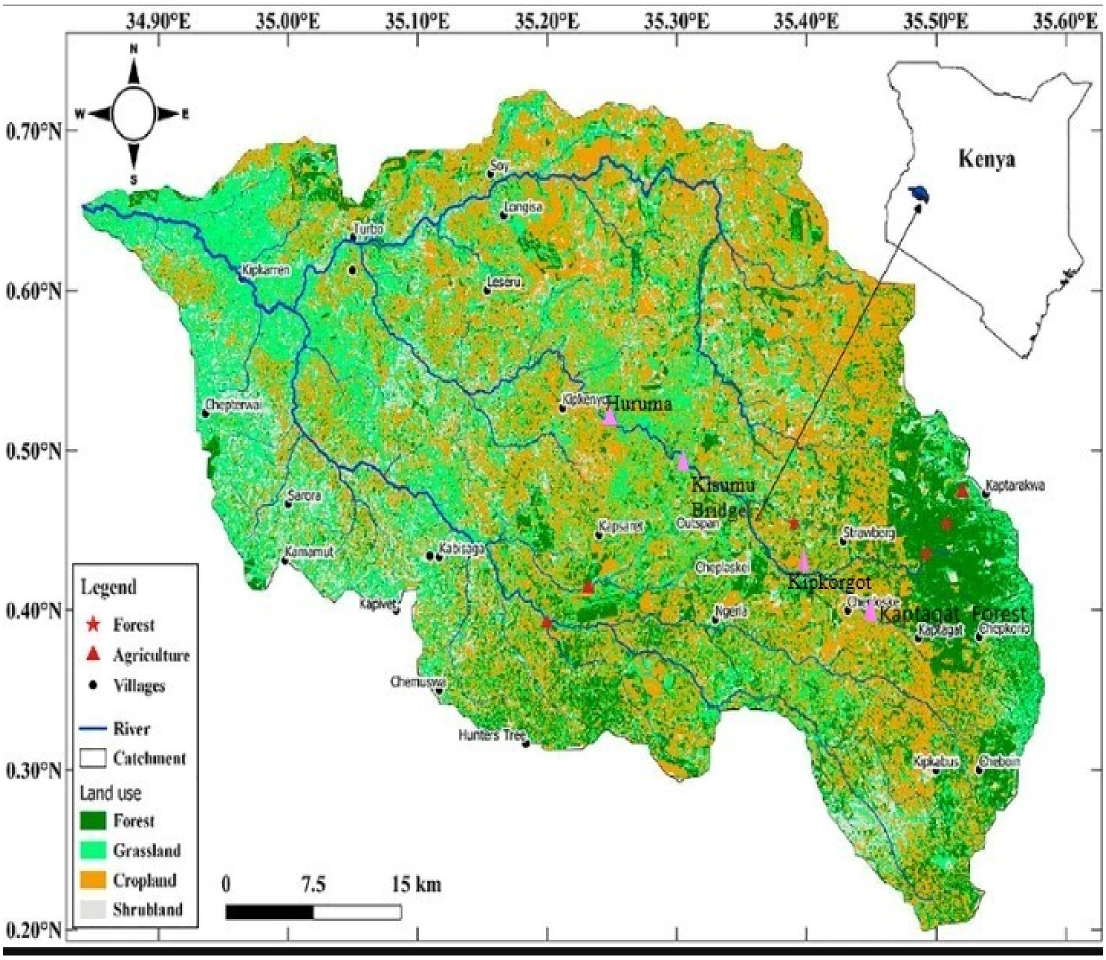
This chapter outlines the research methodology employed to investigate the use of nematodes as bioindicators of water quality in River Sosiani, Uasin Gishu County, Kenya. The section provides a detailed description of the research design, study area, target population, sampling procedures, data collection methods, and analytical approaches. The purpose of this chapter is to justify and explain the methodological choices that ensured the validity, reliability, and scientific rigor of the study.

3.2 Study Location

The study was carried out in River Sosiani, a key freshwater resource in Uasin Gishu County, situated in the Rift Valley region of Kenya. The river originates from the highlands of Kaptagat Forest and flows through diverse land-use zones, including agricultural areas and the urban center of Eldoret city, before joining the Kipkaren River and ultimately draining into the River Nzoia. The catchment area covers approximately 647 km² and lies between latitudes 00°18′00″N and 00°37′00″N and longitudes 035°00′00″E and 035°35′00″E. River Sosiani plays a crucial role in supporting domestic use, irrigation, livestock production, industrial activities, and aquatic biodiversity, making it an important focus for ecological and water quality assessments.

For this study, water samples were collected from four strategic points along the river to capture variations in pollution influences across different land-use zones. The forest zone at Kaptagat (approximately 0.45°N, 35.35°E; 00°27′N, 35°21′E) served as the upstream control site, representing relatively undisturbed conditions with minimal human interference. The agricultural zone at Kipkorgot (approximately 0.52°N, 35.25°E; 00°31′N, 35°15′E) reflected the impact of intensive maize and wheat farming, where nutrient-rich runoff containing fertilizers and pesticides enters the river. Within Eldoret city, the urban zone upstream at Kisumu Bridge (approximately 0.52°N, 35.27°E; 00°31′N, 35°16′E) captured pollution pressures from urban activities such as car washes, garages, informal settlements, and business establishments before the discharge of sewage treatment plant effluents. The urban zone downstream at Huruma (approximately 0.54°N, 35.26°E; 00°32′N, 35°15′E) represented the most impacted site, located after the municipal sewage treatment plant and near the Huruma dumpsite, where industrial discharges from facilities such as Rivatex East Africa Ltd. and leachate from solid waste contribute to heavy pollution loads (Fig. 3.1).

These four zones were purposively selected to represent a longitudinal pollution gradient from the relatively pristine upstream forested section to the heavily degraded downstream urban-industrial section. This spatial design enabled the study to assess variations in water quality parameters, heavy metal concentrations, and nematode community responses along the continuum of River Sosiani. In doing so, the study provided a comprehensive understanding of both natural and anthropogenic influences shaping the ecological health of the river.



Source: Kadeka, *et al.*, (2021)

Figure 3.1 Map of River Sosiani showing the sampling points for the study

A **B**

Figure 3.2 a) Kaptagat forest and b) Kipkorgot sampling points along river Sosiani during the dry season 2018.

b-Kisumu

Figure 3.3 a) Huruma and b) Kisumu Bridge sampling points along river Sosiani during the dry season 2018.

The catchment area estimate is based on previous hydrological and GIS-based assessments of River Sosiani (Kipyego et al., 2022).

3.3 Research Design

This study employed a descriptive survey research design with field-based sampling and laboratory analysis to investigate the use of nematodes as bioindicators of water quality in River Sosiani. A descriptive survey design was appropriate because it allowed for the systematic collection of both physio-chemical and biological data across different sites along the river, enabling the study to establish spatial and temporal variations in pollution levels and ecological responses.

The research design integrated two complementary approaches. First, physio-chemical assessments of water and sediment samples were carried out to determine parameters such as temperature, pH, turbidity, dissolved oxygen (DO), electrical conductivity (EC), and total suspended solids (TSS). During each sampling event, water and sediment samples were collected from the four designated sampling points and transported to the laboratory in clean, labeled polyethylene bottles and sterile containers, respectively. Samples were preserved in cooled insulated boxes (4°C) and analyzed within 24 hours to minimize alterations in physio-chemical properties. These parameters provided a direct measure of pollution loads and overall water quality status. Second, biological monitoring was conducted using nematode community structure as a bioindicator. Nematode samples were extracted from both water and sediment samples collected in the field. Sediment samples were placed in labeled sampling bags, while water samples were stored in sealed containers and transported to the laboratory for extraction, counting, and identification procedures. This dual approach ensured that both immediate pollution levels and long-term ecological impacts were captured.

Physico-chemical parameters were measured using standard field and laboratory methods. Temperature, pH, dissolved oxygen (DO), and electrical conductivity (EC) were measured in situ using a calibrated multi-parameter meter (HQ40D, HACH). Turbidity was measured using a portable turbidity meter, while total suspended solids (TSS) were determined in the laboratory using standard filtration and gravimetric methods following APHA (2017) procedures. All instruments were calibrated prior to use to ensure accuracy of measurements.

The design also incorporated a comparative element by selecting four distinct sampling zones forest, agricultural, and two urban sections (upstream and downstream of the sewage treatment plant). Sampling was conducted between January 2018 and November 2018, covering both dry and wet seasons, in order to capture temporal variation in water quality; however, the study did not perform a detailed comparative seasonal analysis but rather used the data to observe general temporal trends.. In this study, the dry season (Season 1) comprised January, February, and March, while the wet season (Season 2) comprised April, May, June, July, August, September, October, and November, reflecting the long and short rainfall patterns in the region. Sampling was conducted at monthly intervals throughout the study period. At each sampling point, Five replicate samples were collected at one-hour intervals between 8:00 a.m. and 12:00 noon, resulting in a total sampling duration of four hours per site. to reduce diurnal variability in physio-chemical parameters. Sampling was conducted sequentially from the upstream control site (forest zone) proceeding downstream through the agricultural and urban sections to minimize cross-site contamination. All four sampling points were sampled on the same day during each monthly sampling event to maintain temporal consistency across sites. By combining cross-sectional spatial comparisons with temporal monitoring, the design provided a robust framework for understanding the interactions between pollution sources, water quality parameters, and nematode community dynamics.

This mixed ecological approach was particularly suitable for addressing the study objectives because it not only quantified pollution levels but also linked them to biological responses, thereby validating the use of nematodes as sensitive indicators of aquatic ecosystem health.

3.4 Target Population

This study focused on both biological and environmental components of River Sosiani. The biological component consisted of free-living nematodes obtained from water and sediment samples, while the environmental component comprised selected physico-chemical parameters, including temperature, pH, dissolved oxygen (DO), turbidity, total suspended solids (TSS), and electrical conductivity (EC).

These components were selected because they provide measurable indicators of water quality and ecological condition. Nematodes were used as biological indicators due to their sensitivity to environmental changes, while physico-chemical parameters provided baseline information on pollution levels. The study therefore analyzed the relationship between nematode abundance and selected physico-chemical parameters across different sampling sites along River Sosiani.

Geographically, the target population is extending across four representative zones of River Sosiani: the relatively undisturbed forest zone, the agricultural zone impacted by nutrient-rich runoff, and two urban zones (upstream and downstream of the sewage treatment plant) that are subject to industrial, hospital, domestic, and solid-waste pollution pressures that are well documented for the Sosiani system and comparable tropical urban streams (Allan, 2004; Oduor *et al.*, 2019). Sampling across these zones is ensuring that the study is capturing a comprehensive picture of ecological conditions along the river continuum, from headwaters to downstream sections, as expected under longitudinal gradients in lotic ecosystems (Vannote *et al.*, 1980).

By focusing on nematode assemblages in relation to water and sediment quality, the study population is effectively encompassing both the biotic indicators and the environmental conditions that are influencing river health, enabling a holistic assessment of River Sosiani's ecological integrity and the potential of nematodes as bioindicators for long-term water-quality monitoring (Bongers, 1990; Ferris *et al.*, 2001; Traunspurger, 2000).

3.5 Sampling and Extraction of Nematodes

The study utilized both water and sediment samples collected from four representative sites along River Sosiani, namely the forest zone, agricultural zone, urban zone upstream, and urban zone downstream of the sewage treatment plant. These sampling sites were selected to reflect different land-use influences and pollution pressures along the river continuum.

At each sampling site, five replicate water samples were collected at hourly intervals, resulting in 20 water samples per sampling event (monthly sampling exercise) and a cumulative total of 80 water samples across all four sites. Sampling was carried out by using a 3-liter sampling container, where approximately 2 liters of water were collected per replicate into the river at approximately 1 meter from the bank, following the protocol of Waliullah (2006). The water from each jar was filtered through a set of four sieves arranged in descending mesh sizes (500 µm, 250 µm, 100 µm, and 25 µm). Nematodes were subsequently collected from the 25 µm sieve into

50 ml falcon tubes by backwashing, following the method described by Hugo & Malan, (2010).

In addition to water samples, sediment samples were also collected to account for benthic nematode communities. At each site, one kilogram of sediment was scooped approximately 1 meter from the riverbank using a sterilized soil auger. This resulted in four sediment samples per sampling event (monthly sampling exercise) and a total of 16 sediment samples across all study sites. Nematodes were extracted from sediment samples using the modified Baermann funnel technique, as outlined by Hooper *et al.* (2005).

3.6 Sampling Technique

The study employed purposive sampling to select the four representative sites along River Sosiani. This technique was chosen because it allowed the researcher to focus on zones with distinct land-use characteristics and pollution sources, namely the forest zone (control site), the agricultural zone, and the urban zone upstream and downstream of the sewage treatment plant. These sites were deliberately chosen to capture the longitudinal gradient of pollution from relatively pristine upstream areas to heavily impacted downstream sections.

By combining purposive selection of sampling sites with systematic replication of water and sediment collection, the study minimized spatial and temporal bias while ensuring representative coverage of ecological conditions across River Sosiani. This hybrid approach enhanced the robustness of the findings and allowed for meaningful comparisons of nematode community responses and physio-chemical parameters across the pollution gradient.

3.7 Reliability and Validity of Instruments

Ensuring the reliability and validity of instruments was critical to obtaining accurate and trustworthy results in this study. Reliability refers to the consistency of the instruments in producing similar results under similar conditions, while validity refers to the extent to which the instruments accurately measured what they were intended to measure.

To enhance reliability, standard protocols and calibration procedures were followed during both field and laboratory measurements. The multi-parameter water quality meter (HQ40D, HACH) and the portable turbidity meter were calibrated before each sampling session according to manufacturer guidelines to ensure consistent readings. Replicate sampling was conducted at each site, with five water samples collected at hourly intervals, minimizing random errors and capturing short-term variability.

To ensure validity, the study relied on internationally recognized and scientifically accepted methods for both water quality and nematode analyses. Physio-chemical parameters such as dissolved oxygen, pH, turbidity, and electrical conductivity were measured using standard procedures recommended by the American Public Health Association (APHA, 2017), ensuring construct validity. For biological validity, nematode extraction followed the modified Baermann funnel technique (Hooper *et al.*, 2005). These approaches have been widely validated in ecological and environmental monitoring studies (Ridall & Ingels, 2021; Sieriebriennikov *et al.*, 2022).

Accuracy of measurements was ensured through calibration of instruments using standard solutions before each sampling session. Precision was achieved through replicate sampling and repeated measurements, while consistency was maintained by following standardized protocols for sample collection, handling, and analysis. These measures minimized both systematic and random errors in the data.

Further, the use of both physio-chemical instruments and biological indicators enhanced triangulation validity, as the two independent methods provided complementary insights into the ecological health of River Sosiani. The alignment between nematode community metrics and measured physio-chemical parameters served as an internal validation check, strengthening confidence in the data.

3.8 Data Analysis

Data analysis was carried out using both descriptive and inferential statistical techniques to address the study objectives. The data were first coded, cleaned, and organized before being subjected to statistical tests.

For physio-chemical parameters, descriptive statistics such as means and standard deviations were computed to summarize water quality conditions across sites and seasons. Mean values of temperature, pH, dissolved oxygen (DO), turbidity, total suspended solids (TSS) and electrical conductivity (EC) were then subjected to multiple and pairwise comparisons using the student t-test. This allowed for statistical evaluation of significant differences in water quality between the four sampling sites (forest, agricultural, urban upstream, and urban downstream) as well as between the dry and wet seasons.

For biological data, nematode community analysis was performed using standardized ecological formulae. Population density (PD) was determined as the number of nematodes per unit volume of water or weight of sediment. These metric provided a quantitative understanding of nematode community distribution and abundance.

To assess the relationship between nematodes and water quality, correlation analyses were conducted between nematode population densities and key physio-chemical parameters, including dissolved oxygen, turbidity, total suspended solids, and heavy metal concentrations.

All statistical analyses were conducted using SPSS version 25 and R statistical software, while graphs and charts were generated using Microsoft Excel. Results were considered statistically significant at $p < 0.05$. The combined analysis of physio-chemical data and nematode metrics enabled a robust assessment of pollution gradients and ecological responses along River Sosiani.

3.9 Ethical Issues

This study was conducted in adherence to established ethical standards governing environmental and ecological research. Ethical clearance was first sought and obtained from the University Research Ethics Committee, which reviewed the study design to ensure compliance with academic and professional requirements. In addition, relevant research permits were obtained from the National Commission for Science, Technology and Innovation (NACOSTI) before commencement of fieldwork in Uasin Gishu County.

During field sampling, ethical considerations included non-invasive procedures to minimize ecological disturbance. Water and sediment samples were collected which did not compromise the river’s ecological balance. Nematodes, as microscopic organisms, were collected solely for scientific analysis and were not subjected to harmful or exploitative treatment. Waste generated from laboratory procedures, including acid preservatives used for heavy metal analysis, was handled in accordance with hazardous waste disposal guidelines to prevent secondary pollution.

The study also recognized the importance of community engagement and transparency. Local stakeholders, including riparian residents and county water authorities, were informed of the research objectives and activities to promote awareness and cooperation. Findings from the study will be made accessible to local and national stakeholders to contribute toward better water management practices, ensuring that the research benefits the communities dependent on River Sosiani.

Finally, the study upheld the principles of academic integrity by ensuring originality of work, proper acknowledgment of sources, and avoidance of plagiarism. Data were reported truthfully and analyzed objectively without manipulation, ensuring that the results contribute credible knowledge to environmental science and policy.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Overview

This chapter presents the results of the study based on the stated objectives and provides a discussion of the findings in relation to existing studies. The results focus on the assessment of physio-chemical water quality parameters and pollution gradients, nematode, and correlations between nematode metrics and pollution across different zones of River Sosiani.

4.2 Physicochemical properties

4.2.1 pH Values

Kaptagat (control site) consistently recorded higher pH mean values ranging from 7.34, 7.35, 7.50 and 7.35 in all the experiment 1, 2 dry season and 3 and 4 wet season, indicating near-neutral to slightly alkaline conditions . However, pH in freshwater systems may also be influenced by underlying geology (e.g., carbonate-rich rocks), and therefore these values should not be attributed solely to low disturbance levels. Kipkorgot, located in the agricultural zone, showed in all experiments 1, 2, 3 and 4 a mean value of 7.25, 7.28, 7.28 and 7.26, suggesting that agricultural runoff did not drastically alter pH during the sampling period. However, this observation may depend on seasonal farming activities such as planting, fertilizer application, and pesticide spraying, which were not explicitly differentiated in this study within this section (Fig. 4.1).

In contrast, Kisumu Bridge site recorded pH values, ranging from 6.97, 6.83, 6. 85 and 6.59 in experiment 1, 2, 3 and 4, while Huruma indicated a mean value of 6.97, 6.89, 6.85 and 6.77 in experiment 1, 2, 3 and 4 which indicates a shift toward more acidic conditions. These downstream sites are heavily influenced by municipal effluents, urban sewage, industrial discharges, and other anthropogenic pollutants. The pH reduction observed may be associated with organic matter decomposition and anthropogenic inputs. However, specific sources such as industrial discharges (e.g., textile effluents, detergents, and chemical wastes) should be considered, as different industries release different compounds that influence pH differently. It is important to note that domestic wastewater is typically neutral to slightly alkaline; therefore, the observed pH reduction is more likely associated with industrial effluents, organic decomposition, and runoff rather than domestic sources alone (Mwanake et al., 2023; Nyilitya et al., 2021). Such acidification can have negative ecological effects, including altering the solubility of heavy metals and reducing the survival of sensitive aquatic species (Fig. 4.1).

Overall, the results highlight a clear pollution gradient from upstream (Kaptagat and Kipkorgot) to downstream (Kisumu Bridge and Huruma), demonstrating the impact of urbanization and industrialization on water quality in River Sosiani.

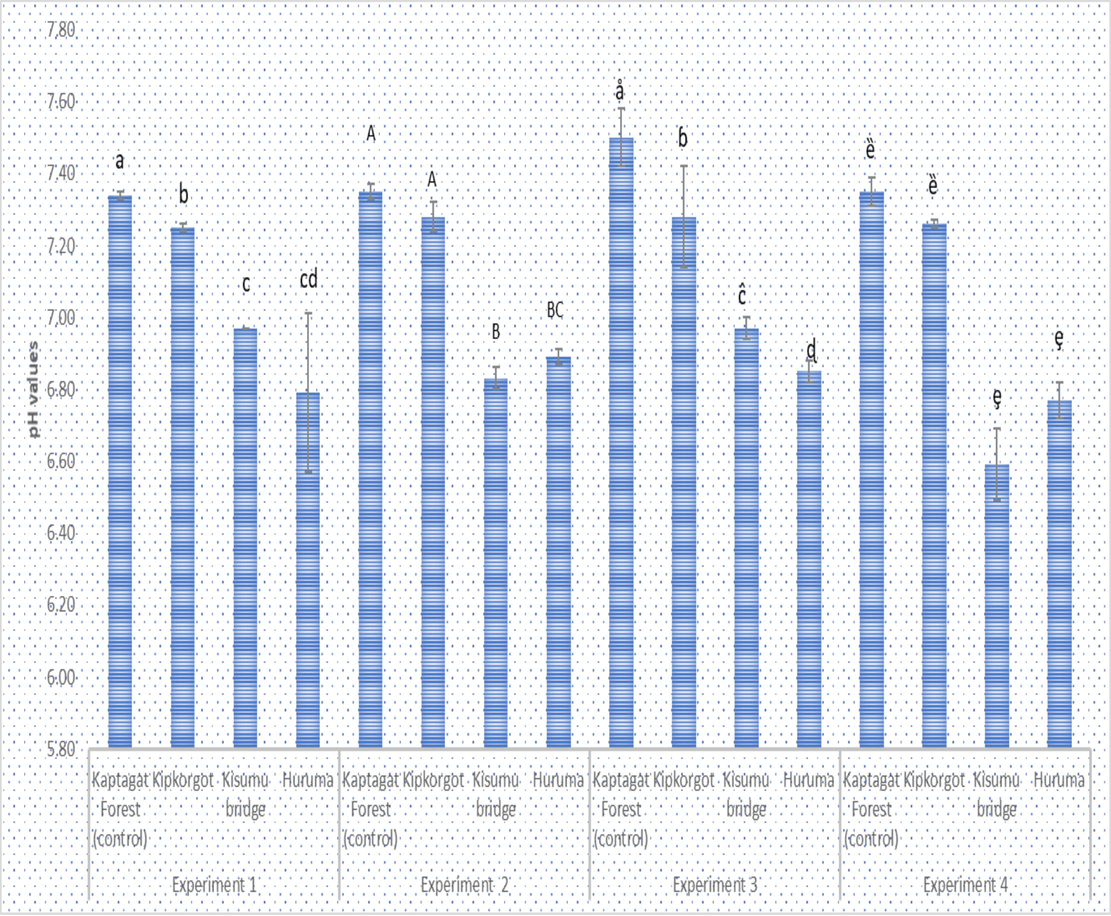


Fig 4.1: pH Values in samples taken from River Sosiani.

The pH results from River Sosiani reveal significant spatial variability along the gradient from the upstream forested site at Kaptagat to the downstream urbanized zones at Kisumu Bridge and Huruma municipal sewage. The upstream sites (Kaptagat and Kipkorgot) consistently recorded higher and near-neutral to slightly alkaline pH values (7.25–7.50). This finding is consistent with unpolluted freshwater ecosystems, where forest cover and minimal anthropogenic inputs buffer the natural alkalinity of water (Ngatia *et al.*, 2023). In contrast, the downstream sites (Kisumu Bridge and Huruma) showed significantly lower pH values (6.59–6.97), reflecting a shift toward acidic conditions, which can be attributed to urban effluents, sewage discharges, and industrial pollutants.

This downstream acidification trend aligns with recent studies across East Africa. For instance, Masakha *et al.* (2024) reported that urban rivers in Kenya experience pH depression during rainy seasons due to stormwater runoff that carries organic matter, oils, detergents, and other acidic compounds from residential and industrial zones. Similarly, studies from Ethiopia's Awash River Basin found that industrial wastewater, particularly from tanneries and textile plants, significantly lowered river pH, altering aquatic biodiversity (Awash River Basin Study, 2023).

PH plays a pivotal role in determining the solubility and bioavailability of pollutants. When water becomes more acidic, heavy metals such as cadmium, lead, and copper become more soluble, thereby increasing their toxicity to aquatic organisms (Chemtai *et al.*, 2023). This observation is crucial for Sosiani River, where earlier studies have reported the presence of heavy metals downstream of urban and industrial discharge points. Acidic waters at Kisumu Bridge and Huruma could therefore exacerbate heavy metal toxicity, threatening fish, benthic fauna, and ultimately human populations that rely on the river for domestic use and irrigation.

Furthermore, altered pH conditions can impact microbial activity and nutrient cycling. Lower pH levels downstream likely disrupt microbial communities responsible for organic matter decomposition, which may in turn affect dissolved oxygen dynamics and exacerbate eutrophication risks (Opiyo *et al.*, 2022). This is supported by studies showing that reduced pH can suppress nitrifying bacteria, leading to the accumulation of ammonia and other toxic nitrogenous compounds in polluted waters (Bilotta & Brazier, 2020).

The neutral to slightly alkaline conditions upstream suggest resilience in less disturbed zones, while the acidic conditions downstream highlight a clear pollution gradient linked to anthropogenic pressures. Such findings affirm the role of pH as an integrative indicator of water quality.

4.2.2 Turbidity

At Kaptagat, the upstream control site, turbidity levels were consistently low across the four experiments, ranging between 0.10 Nephelometric Turbidity Unit (NTU) and 0.14 NTU in experiment 1 and 2 and significantly higher in experiment 3 and 4 with a mean value of 6.55 NTU and 7.19 NTU. These values reflect the pristine conditions of the forested zone, where minimal anthropogenic activities contribute little to suspended matter in the water (Fig. 4.2).

At Kipkorgot, turbidity levels ranged between 0.52 NTU and 0.56 NTU, slightly higher than Kaptagat in experiments 1 and 2 (dry season). However, in experiments 3 and 4 (wet season), turbidity in Kipkorgot was significantly lower than Kaptagat due to increased surface runoff from forested zone, which carried sediments and organic matter into the river with a mean value of 4.49 NTU and 5.55 NTU (Fig. 4.2).

Kisumu Bridge exhibited even higher turbidity levels, averaging between 1.23 NTU and 1.23 NTU in experiments 1 and 2, however Kisumu Bridge recorded lower turbidity compared to Huruma, but in experiments 3 and 4, turbidity levels rose sharply due to stormwater runoff from urban areas with a mean value of 8.25 NTU and 11.26 Nephelometric Turbidity Unit (NTU). The lack of riparian buffers, coupled with unregulated waste disposal, aggravated suspended solids in this section (Fig. 4.2).

Huruma, located downstream of municipal sewage discharge, consistently recorded the highest turbidity levels, ranging from 1.54 NTU 1.56 NTU in experiment 1 and 2. During the wet season (experiments 3 and 4), turbidity levels peaked 15.91 NTU and

14.46 NTU, reflecting the combined effect of untreated sewage effluent, industrial discharges, and stormwater inflows from densely populated residential and commercial areas. Such high turbidity reduces light penetration, disrupts photosynthetic activity of aquatic plants, and impairs fish feeding and reproduction (Fig. 4.2).

Overall, the results confirm a pollution gradient from upstream to downstream, with turbidity increasing significantly in urban and sewage-impacted zones. Seasonal differences highlight the role of rainfall in mobilizing sediments and pollutants, underscoring the importance of managing both point and non-point sources of pollution in River Sosiani.

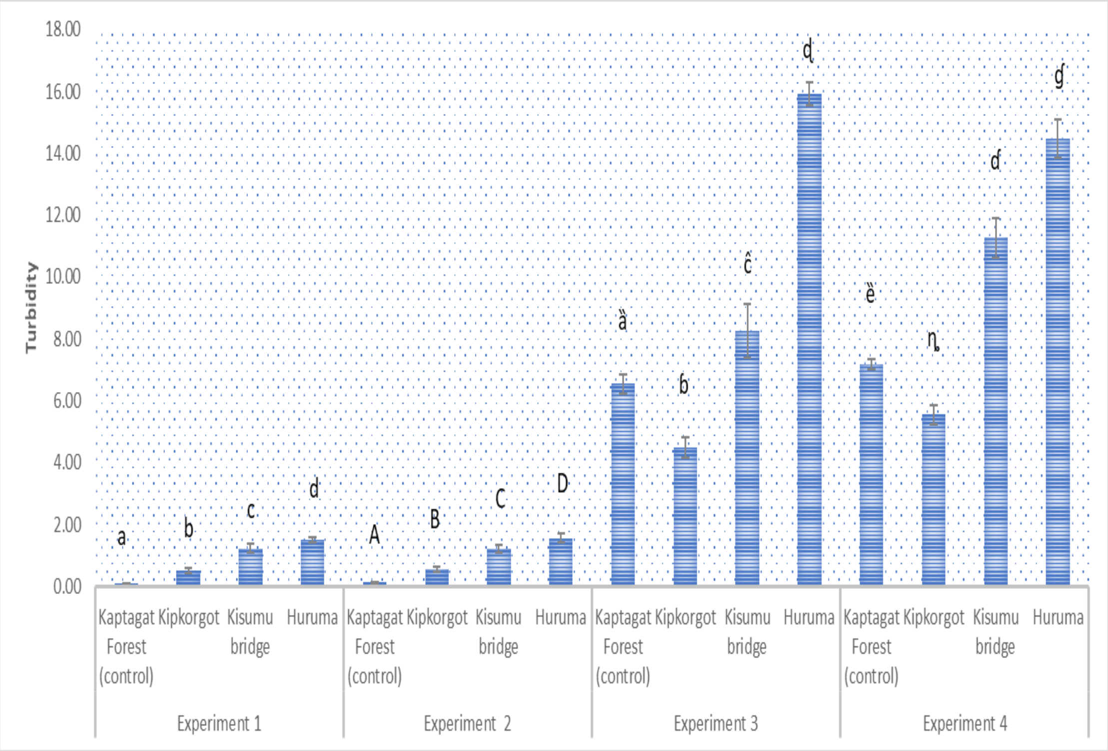


Fig 4.2: Turbidity in samples taken from River Sosiani.

The turbidity measurements from River Sosiani reveal a pronounced spatial and temporal gradient: low turbidity in the upstream forested control (Kaptagat), modest increases in the agricultural mid-reach (Kipkorgot), and substantially elevated values at urban/effluent-influenced sites (Kisumu Bridge and Huruma), with the greatest peaks occurring during wet-season sampling (experiments 3 and 4). This pattern is consistent with both theoretical expectations and empirical findings from comparable East African catchments and reflects the combined effects of land use, stormwater mobilization of sediments, and point-source discharges.

Upstream forested sections typically retain sediments and stabilize stream banks through riparian root structure and ground cover, which explains the consistently low turbidity recorded at Kaptagat. In contrast, the agricultural zone at Kipkorgot showed low turbidity during the wet season, reflecting runoff from cultivated fields where soil disturbance, tillage, and fertilizer application increase soil erodibility (Mwanake *et al.*, 2023). At urban sites, impervious surfaces, exposed soils from construction and unregulated dumping, and direct inputs from carwashes, garages and market waste all increase particulate loading (Ngatia *et al.*, 2023). Huruma, located downstream of the municipal sewage outlet and Huruma dumpsite, recorded the highest turbidity, consistent with combined inputs of raw or partially treated sewage, solid waste-derived particles, and suspension of contaminated sediments during high flows (Chemtai *et al.*, 2023; Awash River Basin Study, 2023).

The higher turbidity observed in experiments 3 and 4 underscores the dominant role of rainfall-driven surface runoff in mobilizing sediments and associated pollutants. Wet-season events produce pulses of suspended solids transported from fields, roads and dumpsites into the channel (Opiyo *et al.*, 2022). These episodic pulses can overwhelm local dilution capacity and rapidly change water clarity and chemistry, producing strong short-term water quality deterioration that may not be captured by single ‘snapshot’ chemical measures but is well reflected by turbidity measurements and by biological responses (Mugabe *et al.*, 2021). These turbidity patterns are closely linked to hydrological flow, as increased discharge during rainfall events enhances sediment transport and pollutant mobility, highlighting the importance of integrating flow measurements with turbidity assessments.

Elevated turbidity has multiple direct and indirect ecological effects. High suspended solids reduce light penetration, suppress primary production, and alter habitat structure for periphyton and macrophytes (UNEP, 2022). Suspended particles also carry adsorbed contaminants including heavy metals, hydrophobic organics, and pathogens increasing the exposure risk to benthic organisms and consumers (Chemtai *et al.*, 2023; Ziani *et al.*, 2023). For fish and invertebrates, high TSS can impair feeding, gill function, and reproductive success (Bilotta & Brazier, 2020). From a human health perspective, high turbidity reduces the effectiveness of water disinfection by shielding microorganisms from treatment processes and is strongly associated with increased risk of waterborne diseases, particularly where sewage contamination is present.

The observed turbidity gradient helps explain concomitant patterns in nematode abundance and community composition recorded in the study. Elevated suspended solids and associated organic enrichment provide increased microbial biomass and particulate organic matter that can support high densities of opportunistic bacterivorous nematodes (colonizers, c-p 1–2; Ridall & Ingels, 2021; Sieriebriennikov *et al.*, 2022). This mechanistic link is supported by the higher nematode densities at Kisumu Bridge and Huruma where turbidity and TSS were greatest. Conversely, lower turbidity at Kaptagat and Kipkorgot aligns with lower nematode densities and likely a greater proportion of persister taxa a pattern used globally to infer pollution and disturbance gradients (Makeleni, 2025; Tadesse *et al.,* 2023).

The spatio-seasonal turbidity dynamics observed in River Sosiani are consistent with findings across East Africa, where rainfall-driven runoff significantly increases sediment and pollutant transport in river systems. Studies in Kenyan catchments and trans-boundary basins have documented marked turbidity increases downstream of agricultural and urban zones, particularly during rainfall events (Opiyo *et al.,* 2022; Mwanake *et al.,* 2023). The Awash River Basin assessments similarly attribute turbidity spikes to industrial effluent and soil erosion (Awash River Basin Study, 2023). These consistencies strengthen the interpretation that turbidity at river Sosiani is a robust indicator of sediment and pollution transport related to land use and hydrology.

The turbidity results point to several actionable measures. First, addressing non-point source sediment inputs requires landscape measures: riparian buffer restoration, contour farming, reduced tillage, and sediment traps on agricultural drains can lower soil erosion into the river (Mwanake *et al.,* 2023). Second, urban runoff management via improved stormwater infrastructure, controlled car-wash facilities, and management of dumpsites is critical to reduce particulate loads reaching Kisumu Bridge and Huruma. Third, given the strong seasonality, monitoring programs must include high-frequency sampling during rainy seasons and after storm events to capture episodic turbidity peaks that drive ecological impacts (Opiyo *et al.,* 2022). Finally, integrating turbidity monitoring with biological indicators (nematode community metrics, benthic macroinvertebrates) and targeted chemical assays (metals associated with particulates) will provide a more complete assessment of pollutant transport and ecological risk than chemical sampling alone (Chemtai *et al.*, 2023; Sieriebriennikov *et al.*, 2022).While turbidity is an effective proxy for suspended particulate loading, it does not distinguish particle composition or contaminant load per unit turbidity.

4.2.3 Temperature

The temperature values across the four sites (Kaptagat, Kipkorgot, Kisumu Bridge, and Huruma municipal sewage) exhibited notable spatial and temporal variability across the four experiments. Kaptagat, the upstream control site, consistently recorded significantly lower water temperatures, ranging between 14.40°C and 15.40°C in experiment 1 and 2 (wet season) with a mean value of 12.20 and 11.20 in experiment 3 and 4 the (wet season). This was expected due to the dense forest canopy cover in Kaptagat that reduces direct sunlight penetration and buffers against excessive heating of the water column (Fig. 4.3).

At Kipkorgot, temperatures ranged between 24.30°C and 25.00°C in experiments 1 and 2, showing significantly higher values compared to Kaptagat due to reduced canopy cover and greater exposure of the water surface to solar radiation. In experiments 3 and 4, however, Kipkorgot showed no significant difference from Kaptagat with a mean value of 12.90°C and 12.91°C, likely due to rainfall events and surface runoff that cooled the river system during the wet season (Fig. 4.3).

Kisumu Bridge recorded higher temperatures, averaging between 24.10°C and 21.10°C in experiments 1 and 2. These elevated values can be attributed to reduced riparian vegetation, increased urban runoff, and exposure of the river to heated rock surfaces. In experiments 3 and 4, Kisumu Bridge exhibited lower temperatures 13.70°C and 13.40°C, suggesting dilution and cooling effects of rainfall (Fig. 4.3).

Huruma, located downstream of municipal sewage discharge, exhibited the highest temperature values in experiments 1 and 2, ranging from 24.90°C to 21.20°C. The observed temperature patterns are more strongly influenced by seasonal variation, solar radiation, and riparian vegetation cover rather than direct heating from effluents. The lower temperatures observed in experiments 3 and 4 across all sites indicate the cooling effect of rainfall and reduced solar intensity during the wet season (Fig. 4.3).

Overall, these results demonstrate a clear spatial gradient in water temperature from upstream forested areas to downstream urbanized and polluted zones. The findings indicate that land use and anthropogenic activities significantly influence river temperature regimes, which in turn affect dissolved oxygen dynamics, metabolic processes of aquatic organisms, and the general ecological health of River Sosiani.

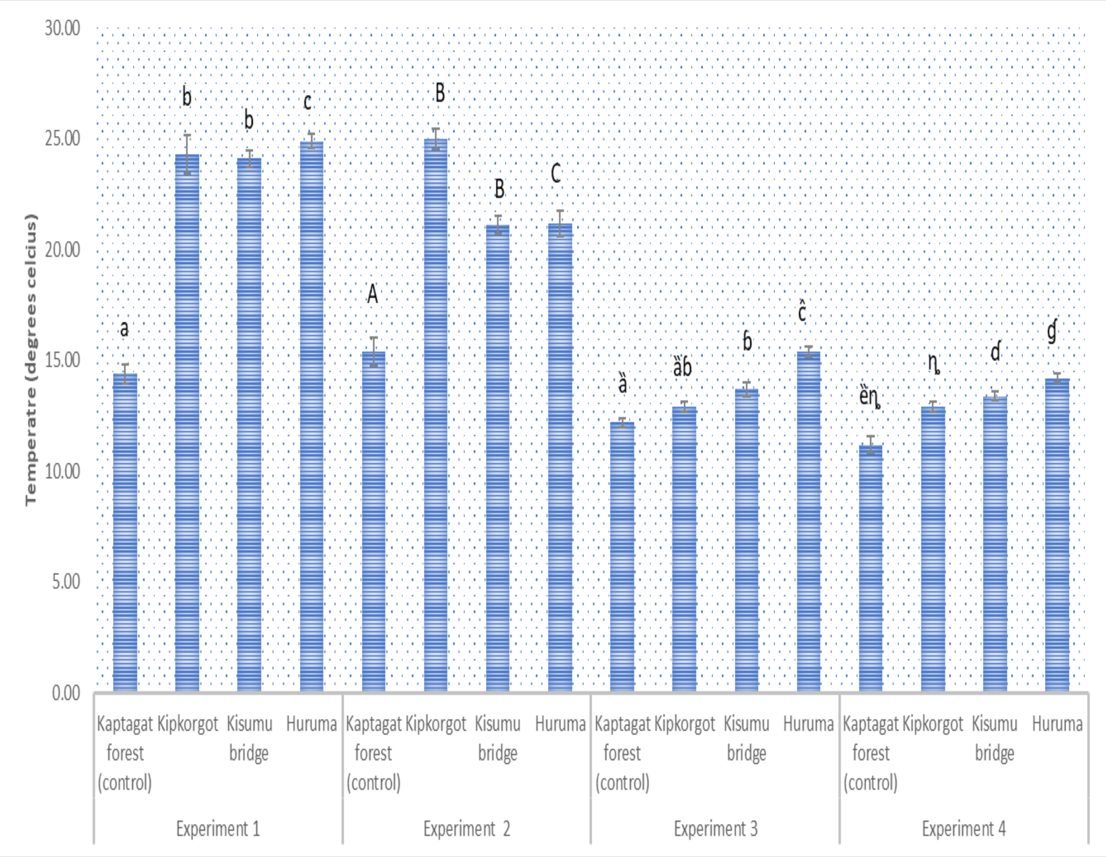


Fig 4.3: Temperatures in samples taken from River Sosiani.

These are the results of the four independent experiments. The temperature results from River Sosiani demonstrate significant spatial and seasonal variation, reflecting the combined influence of land use, riparian cover, and anthropogenic activities. Upstream sites such as Kaptagat consistently exhibited lower water temperatures (12.20°C - 15.40°C) across the four experiments. These findings are consistent with studies showing that forested headwaters provide shading that reduces solar radiation, stabilizes thermal regimes, and mitigates temperature fluctuations (Makori *et al.*, 2021). Riparian vegetation plays a vital role in regulating stream temperature, which in turn influences dissolved oxygen availability and overall river health.

Kipkorgot, located in the agricultural zone, showed moderately higher temperatures (12.90°C - 25.00°C), particularly in the dry season (experiments 1 and 2). The absence of dense canopy cover and exposure of river water to sunlight, combined with thermal contributions from agricultural runoff, likely explain these elevated values. Similar trends have been observed in Kenya’s Athi River Basin, where catchments with deforested and cultivated landscapes recorded higher water temperatures than forested zones (Opiyo *et al.*, 2022).

At Kisumu Bridge, water temperatures increased further during dry season experiments (13.40°C – 24.10°C). This site is heavily influenced by urban land use, with reduced riparian cover, impervious surfaces, and heated rock outcrops that absorb and release heat. Urbanization has been widely documented as a key driver of river thermal pollution. A study in Tanzania by Kimirei *et al.* (2021) showed that urban streams exhibited higher water temperatures due to increased surface runoff and lack of shading. Elevated temperatures at this site not only influence the metabolic activity of aquatic organisms but also accelerate the breakdown of organic pollutants, increasing oxygen demand.

Huruma, located downstream of municipal sewage discharge, recorded the highest temperatures during experiments 1 and 2 (24.90°C - 21.20°C). This can be attributed to direct sewage effluent inflows, reduced riparian vegetation, and stagnant water pockets downstream of discharge points. Wastewater discharges are known to elevate water temperatures, as shown in a Ugandan study where effluent-receiving rivers consistently exhibited higher thermal regimes than reference streams (Kaggwa *et al.*, 2023). In addition, elevated water temperatures in polluted sites exacerbate ecological stress by reducing dissolved oxygen solubility, thereby limiting the survival of sensitive taxa such as mayflies and stoneflies (Bilotta & Brazier, 2020).

Seasonal rainfall moderated these temperature trends in experiments 3 and 4, where rainfall-driven runoff cooled the river and reduced spatial differences among sites. This observation aligns with findings from Ethiopian rivers where rainfall events reduced temperature peaks caused by anthropogenic activities (Awash River Basin Study, 2023). Such seasonal moderation highlights the dynamic interaction between climatic factors and anthropogenic stressors.

Overall, the results illustrate a clear gradient: low temperatures in shaded forest zones, moderate warming in agricultural zones, and highest temperatures in urban and sewage-impacted sections. This pattern confirms that land use and human activity are major determinants of river thermal regimes (Ngatia *et al.*, 2023). The ecological implications are critical: elevated temperatures downstream accelerate eutrophication, alter community structure, and increase pollutant toxicity. Monitoring temperature therefore remains essential not only for water quality assessments but also for predicting climate change impacts on freshwater systems in Kenya and beyond.

4.2.4 Dissolved Oxygen

Kaptagat, the upstream control site, consistently recorded significantly higher dissolved oxygen, ranging between 5.44 mg/l and 5.11 mg/l in experiments 1 to 2 however there was no significant difference in experiment 3 and 4 with a mean value of 5.23 mg/l and 6.02 mg/l. This was expected due to the forest canopy in Kaptagat provides shade, stabilizes water temperature, and maintains low turbidity all of which favor oxygen retention (Fig. 4.4)

At Kipkorgot, dissolved oxygen ranged between 5.33 mg/l and 5.46 mg/l in experiments 1 and 2, showing no significant difference to Kaptagat due to low turbidity all of which favor oxygen retention. In experiments 3 and 4, however, Kipkorgot showed significant lower dissolved oxygen range between 4.23 mg/l and 4.25 mg/l compared to Kaptagat, likely due to moderate flow rates and reduced organic loads that helped sustain oxygenated conditions (Fig. 4.4).

Kisumu Bridge recorded lower dissolved oxygen averaging between 4.11 mg/l and 3.85 mg/l in experiments 1 and 2. These decline values is attributable to urban runoff, reduced riparian buffers, and increased organic matter inputs. In experiments 3 and 4, Kisumu Bridge exhibited lower dissolve oxygen 2.50 mg/l and 3.24 mg/l, stormwater runoff, mobilized sediments, nutrients, and organic matter into the river, increasing turbidity and microbial respiration, which in turn reduced oxygen levels (Fig. 4.4).

Huruma, located downstream of municipal sewage discharge, exhibited the low values of dissolved oxygen in experiments 1 and 2, ranging from 4.75 mg/l and 4.59 mg/l.

This is consistent with the influence of sewage effluent, nutrients, and organic matter in the river. However, in experiments 3 and 4, Huruma dissolve oxygen were significantly lower 2.03 mg/l and 2.83 mg/l, due to sewage and stormwater inflows introduced large amounts of biodegradable organic matter (Fig. 4.4).

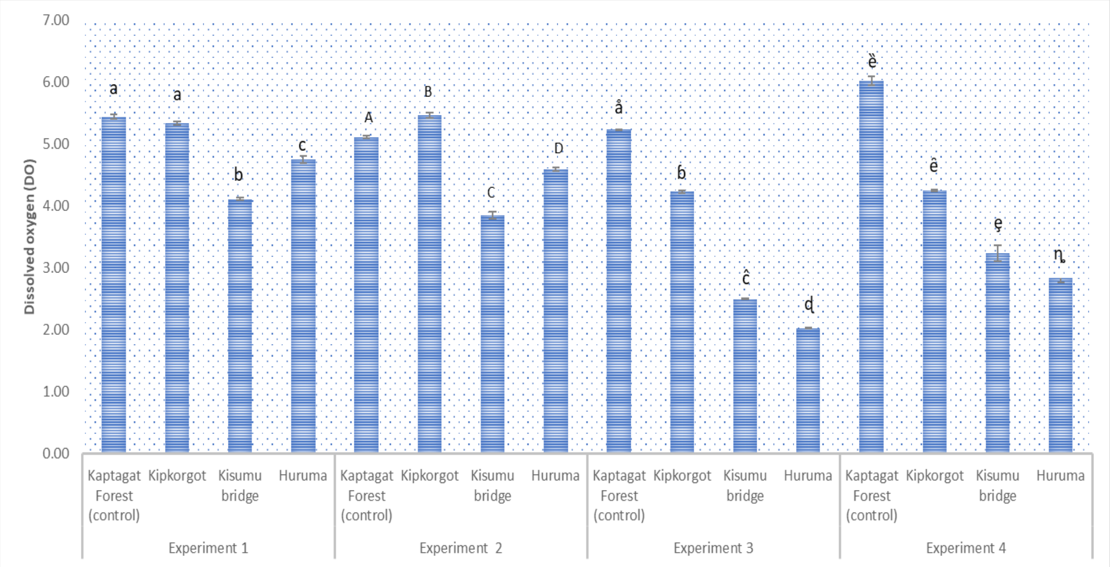


Fig 4.4: Dissolved oxygen in samples taken from River Sosiani.

The samples were taken from Huruma municipal sewage downstream to the sources of the River at Kaptagat (control). In comparison to the control (Kaptagat), the data shows the mean and standard error of the dissolve oxygen of water samples from Kipkorgot, Kisumu Bridge and Huruma municipal sewage. For each experiment, means with same letters are not statistically significant (P=0.05, Tukey's standardized range test). These are the results of the four independent experiments.

The results from River Sosiani revealed a clear longitudinal and seasonal gradient in dissolved oxygen (DO) concentrations. Upstream sites (Kaptagat and Kipkorgot) consistently recorded higher DO values across the four experiments, while downstream sites (Kisumu Bridge and Huruma municipal sewage) exhibited significantly lower concentrations. This pattern reflects the influence of land cover, pollution inputs, and hydrological variability on oxygen dynamics. Dissolved oxygen levels are also influenced by hydrological flow conditions, where increased flow enhances aeration, while stagnant conditions reduce oxygen exchange, particularly in polluted downstream sections.

DO is widely recognized as one of the most critical parameters for assessing aquatic ecosystem health because it regulates aerobic respiration, influences biogeochemical cycling, and determines species distribution (WHO, 2022). Globally, studies indicate that DO depletion is strongly linked to eutrophication, organic pollution, and climate-induced warming (UNEP, 2022). Freshwater ecosystems experiencing high pollutant loads often develop hypoxic or anoxic zones, which are detrimental to fish, benthic invertebrates, and microbial processes (Ziani *et al.*, 2023).
At Kaptagat and Kipkorgot, DO concentrations remained relatively high, with only slight seasonal variability. The forest canopy in Kaptagat provides shade, stabilizes water temperature, and maintains low turbidity all of which favor oxygen retention (Makori *et al.*, 2021). Similarly, moderate flow rates and reduced organic loads help sustain oxygenated conditions in Kipkorgot. These findings align with studies from forested rivers in Ethiopia, where shaded headwaters consistently maintained DO above 7 mg/L, even during warm seasons (Awash River Basin Study, 2023).

In contrast, Kisumu Bridge and Huruma exhibited pronounced DO depletion. At Kisumu Bridge, oxygen decline is attributable to urban runoff, reduced riparian buffers, and increased organic matter inputs. At Huruma, DO reached its lowest values, particularly during experiments 3 and 4 (wet season), where sewage and stormwater inflows introduced large amounts of biodegradable organic matter. This resulted in high biological oxygen demand (BOD), rapidly depleting DO levels.

Similar patterns were observed in Kenya’s Ngong River, where DO concentrations dropped below WHO recommended thresholds downstream of sewage discharge points (Ngatia *et al.* 2023).

Seasonal variability played a key role in DO dynamics. During the dry season (experiments 1 and 2), DO was relatively stable, reflecting lower inflows of organic pollutants. These results mirror those of Masakha *et al.* (2024), who documented significant DO declines during wet seasons in Sosiani River, directly linked to stormwater surges and leachate inflows from dumpsites.

Low DO in downstream sections has severe ecological consequences. Sensitive taxa such as Ephemeroptera, Plecoptera, and Trichoptera (EPT) are excluded under low oxygen conditions, leaving behind tolerant organisms such as Chironomids and opportunistic nematodes (Sieriebriennikov *et al.*, 2022). Furthermore, oxygen depletion increases the solubility of toxic metals like manganese and iron, compounding chemical stress on aquatic biota (Chemtai *et al.*, 2023). For human communities relying on Sosiani water, low DO coupled with high BOD signals increased microbial contamination, posing risks of waterborne diseases (WHO, 2022). Nematode communities are directly influenced by oxygen availability. High DO levels upstream support more diverse communities with stable colonizer–persister (c-p) structures, while downstream low-oxygen conditions favor opportunistic, pollution-tolerant species (Ridall & Ingels, 2021). The study’s findings of higher nematode densities in low-DO zones (Kisumu Bridge and Huruma) are consistent with global literature, where nematode assemblages proliferate under hypoxic conditions due to reduced predation and increased microbial food resources (Tadesse *et al.*, 2023). This underscores the utility of nematodes as biological indicators of oxygen stress.

The Sosiani River DO trends mirror patterns documented in other Kenyan catchments. In Migori River, DO decreased downstream due to agricultural runoff and urban effluents, with wet-season declines being most pronounced (Opiyo *et al.,* 2022). Similarly, in Uganda’s Nakivubo channel, DO dropped to critically low levels downstream of industrial effluents (Kaggwa *et al.*, 2023). These parallels confirm that DO depletion in river Sosiani is part of a broader regional challenge linking rapid urbanization, poor wastewater management, and ecosystem degradation.

To safeguard DO levels in Sosiani River, urgent interventions are required. Restoring riparian vegetation would reduce thermal stress, stabilize sediments, and enhance oxygen exchange. Upgrading Eldoret’s sewage treatment plants to ensure full treatment before discharge would reduce organic loads at Huruma. Furthermore, consistent DO monitoring during rainfall events is critical to capture episodic depletion events. Integrating DO monitoring with nematode community metrics would provide a powerful bio-ecological assessment tool for long-term river health.

4.2.5 Electrical Conductivity

The results indicated a clear increase in electrical conductivity (EC) values from upstream to downstream in River Sosiani. At Kaptagat, the upstream control site, EC values were the lowest with a mean of 62.40 S/m and 56.00 S/m in experiment 1 and 2, and a mean of 42.50 S/m and 33.92 S/m in experiment 3 and 4 reflecting the relatively pristine water quality of the forested zone with minimal anthropogenic influence. Kipkorgot, located in the agricultural zone, recorded moderately higher EC values with a mean of 80.32 S/m and 72.60 S/m in experiment 1 and 2. In experiment 3 and 4 were significantly lower with mean values of 49.74 S/m and 40.94 S/m, this was attributed to nutrient-rich runoff from intensive maize and wheat farming activities (Fig. 4.5).

Further downstream, Kisumu Bridge and Huruma recorded the highest EC values with a mean of 179.00 S/m and 164.00 S/m in experiment 1 and 2. In experiment 3 and 4 it was a significantly lower with a mean values of 94.21 S/m and 83.20 S/m. Huruma recorded the highest with a mean value of 233.60 S/m and 240.60 S/m in experiment 1 and 2 and significantly lower in experiment 3 and 4 with a mean value of 125.50 S/m and 97.70 S/m. These sites, which are directly influenced by Eldoret’s urban and industrial activities, consistently showed elevated ion concentrations from effluents, municipal wastewater, and leachate from the Huruma dumpsite. Seasonal differences were also evident. During the dry season (experiments 1 and 2), EC levels were significantly higher, reflecting limited dilution and a buildup of pollutants. In contrast, wet season measurements (experiments 3 and 4) showed slightly lower EC values, largely due to dilution by rainfall and increased river flow (Fig. 4.5).

Overall, the progressive increase in EC downstream highlights the cumulative effect of agricultural, urban, and industrial activities on water quality, confirming its utility as a sensitive indicator of pollution gradients in River Sosiani.

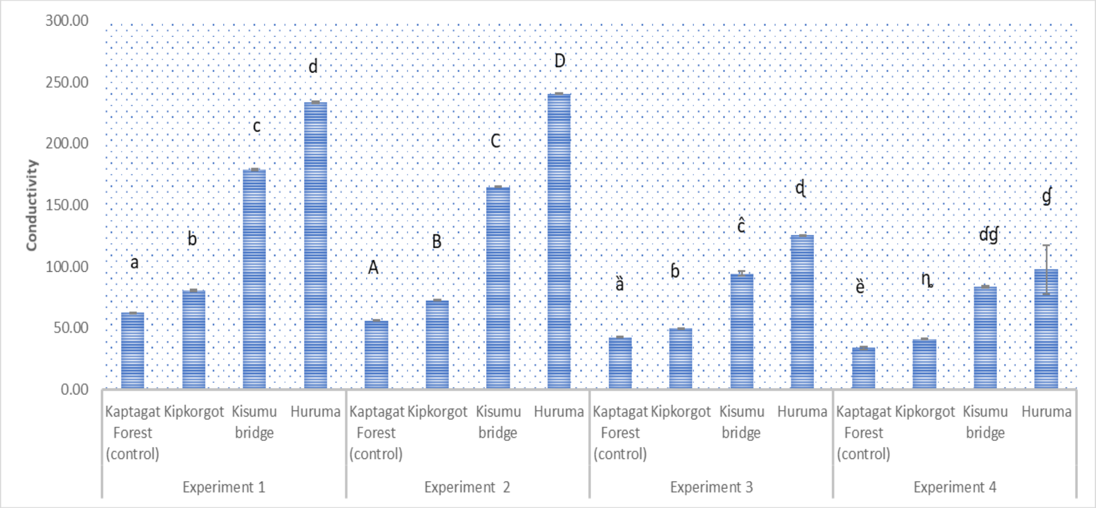


Fig 4.5: Electrical conductivity in samples taken from River Sosiani.

The results demonstrated a progressive increase in electrical conductivity (EC) from upstream to downstream in River Sosiani. This pattern is consistent with the cumulative influence of human activities, particularly agriculture, urbanization, and industrial discharges. Elevated EC levels at Kisumu Bridge and Huruma indicate ionic enrichment arising from multiple sources, including textile industries such as Rivatex, effluents from Moi Teaching and Referral Hospital, sewage inflows, and leachate from the Huruma dumpsite. These findings corroborate those of Masakha *et al.*, (2024), who reported that downstream sections of river Sosiani exhibited consistently higher EC values compared to upstream sites, strongly correlating with increased turbidity, suspended solids, and nutrient loads.

Electrical conductivity is widely recognized as a proxy for dissolved ionic pollution, reflecting the presence of salts, nutrients (nitrates and phosphates), and heavy metals. Elevated EC in river Sosiani therefore signals pollution stress and reduced water quality. Similar observations have been reported across East African Rivers. For instance, Mwanake *et al.* (2023) found that EC reliably identified pollution hotspots in the Sio–Malaba–Malakisi Basin, where urban and agricultural inputs increased ionic concentrations downstream. Likewise, Nyilitya *et al.* (2021) noted that EC in Kenya's Nyando River was strongly linked to land use, with intensive agricultural areas recording higher values due to fertilizer and pesticide runoff.

Seasonal variation in EC was also evident. Dry season values were higher, likely due to limited dilution and concentration of pollutants, while wet season values dropped temporarily because of increased dilution from stormwater inflows. This seasonal dilution effect is consistent with findings by Opiyo *et al.* (2022) in Migori River and Kaggwa *et al.*, (2023) in Ugandan river systems, where rainfall temporarily reduced ionic concentrations despite high pollutant loads. However, despite this temporary decline, persistently high downstream EC values indicate chronic pollution pressures that cannot be offset by natural dilution alone.

The ecological implications of high EC are significant. Elevated ionic concentrations disrupt osmoregulation in aquatic organisms, reduce species diversity, and favor tolerant taxa. In river Sosiani, increased EC coincided with higher nematode densities dominated by stress-tolerant colonizer species. This relationship is consistent with the work of Ridall & Ingels (2021), who demonstrated that nematode assemblages are highly sensitive to ionic enrichment and chemical pollution, making them reliable bioindicators of long-term ecosystem health. Similarly, Makeleni (2025) observed in South African rivers that elevated EC correlated with a dominance of opportunistic nematodes and reduced maturity indices, confirming ionic pollution as a major driver of ecological stress.

Globally, recent studies affirm the importance of EC in integrated water quality assessments. Bezerra *et al.* (2021) showed that increased EC in estuarine sediments correlated with hydrocarbon and heavy metal contamination, while Ziani *et al.* (2023)

linked ionic enrichment from pharmaceuticals and microplastics to altered nematode feeding structures. These findings highlight EC's dual role: not only as a chemical measure of ionic load but also as a predictor of biological responses across ecosystems.

In conclusion, the downstream increase in EC in River Sosiani underscores the heavy anthropogenic pressures exerted on the river. Its strong correlation with both physicochemical pollutants and nematode responses validates EC as a critical water quality indicator. Incorporating EC monitoring with bioindicator approaches provides a comprehensive framework for early detection of pollution and supports evidence-based management interventions. For sustainable water resource management, authorities should prioritize reducing effluent discharges, improving wastewater treatment infrastructure, and integrating EC monitoring into routine water quality assessment programs.

4.2.6 Total Suspended Solids

At the upstream site of Kaptagat, TSS values were consistently the lowest with a mean of 0.25 mg/L and 0.11 mg/L in experiment 1 and 2 and significantly higher with a mean value of 2.20 mg/L and 1.70 mg/L in experiment 3 and 4, reflecting relatively undisturbed conditions. The dense forest cover in this section provided natural protection against soil erosion and limited sediment inflow, maintaining water clarity within acceptable ecological limits as shown in figure . 4.6.

At Kipkorgot, located in the agricultural zone, TSS concentrations were moderately higher with a mean value of 0.26 mg/L and 0.15 mg/L in experiment 1 and 2. It recorded significantly higher TSS in experiment 3 and 4 with a mean value of 3.30 mg/L and 2.85 mg/L. The increase was attributed to soil disturbance from intensive maize and wheat farming, coupled with fertilizer and pesticide application, which enhance surface runoff and sediment transport into the river. Although higher than Kaptagat, values at Kipkorgot remained below critical pollution thresholds (Fig. 4.6).

Downstream sites showed markedly elevated TSS values. At Kisumu Bridge, concentrations increased significantly with a mean value of 0.58 mg/L and 0.12 mg/L in experiment 1and 2 and more significant higher in experiment 3 and 4 with a mean value of 3.89 mg/L and 4.37 mg/L due to the cumulative effect of urban effluents, surface runoff from impervious surfaces, and discharges from small-scale industries, car washes, and garages. These inputs introduced large amounts of suspended matter, especially during peak rainfall events (Fig. 4.6).

The Huruma site recorded the highest TSS levels across all sampling periods. The results recorded 0.59 mg/L and 0.12 mg/L in experiment 1 and 2 and significantly higher in experiment 3 and 4 with a mean value of 3.73 mg/L and 4.98 mg/L This was linked to its proximity to the municipal dumpsite, where leachate percolates directly into the river, as well as untreated sewage and textile industry effluents. The downstream accumulation of waste and sediments was most pronounced here, reflecting severe anthropogenic pressure.

Seasonal variations were also evident. During the wet season (experiments 3 and 4), TSS values spiked sharply across all sites, driven by stormwater runoff that transported sediments, sewage, organic matter, and agricultural residues into the river. In contrast, during the dry season (experiments 1 and 2), TSS levels were generally lower because of reduced surface runoff. However, even in the dry season, urban and industrial sites such as Kisumu Bridge and Huruma maintained higher TSS compared to upstream locations, showing persistent particulate pollution.

In summary, TSS exhibited a clear longitudinal gradient, with concentrations increasing steadily from upstream (Kaptagat) to downstream (Huruma). This pattern underscores the combined influence of agricultural practices, urbanization, and industrial activities on sediment and particulate pollution in River Sosiani.

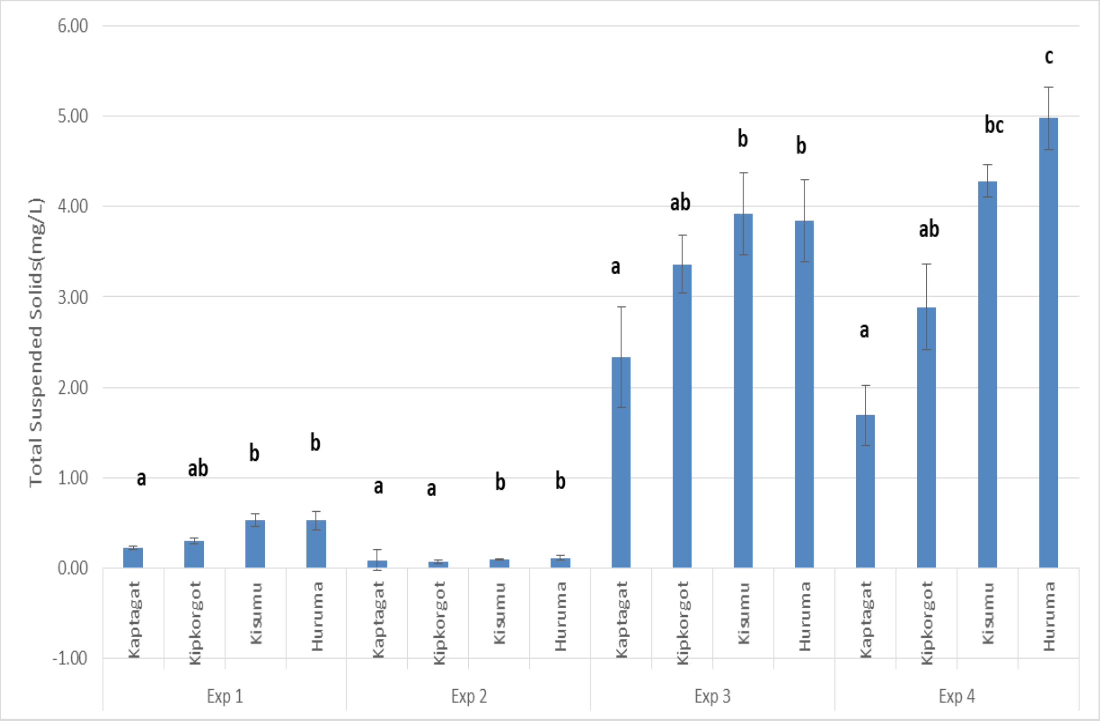


Fig 4.6: Total suspended solid in samples taken from River Sosiani.

The samples were taken from Huruma municipal sewage downstream to the sources of the River at Kaptagat (control). In comparison to the control (Kaptagat), the data shows the mean and standard error of the total suspended solids of water samples from Kipkorgot, Kisumu Bridge and Huruma municipal sewage. For each experiment, means with same values are not statistically significant (P=0.05, Tukey's standardized range test). These are the results of the four independent experiments.

The results from River Sosiani revealed substantial spatial and seasonal variation in Total Suspended Solids (TSS), with concentrations increasing progressively from the upstream control site at Kaptagat to the downstream urban-industrial sites of Kisumu

Bridge and Huruma. This downstream gradient is consistent with global and regional findings that suspended solids are strongly influenced by land use intensity, urbanization, and industrial activities (Mwanake *et al.*, 2023).

At Kaptagat, the forested upstream site, TSS values were minimal, reflecting limited disturbance and the role of vegetation in stabilizing soils and minimizing erosion. Forested headwaters are widely recognized as buffers against sediment pollution, as canopy cover reduces rainfall impact and roots anchor soils (Nyilitya *et al.*, 2021). In contrast, Kipkorgot, located within agricultural landscapes, exhibited moderately elevated TSS values. Intensive maize and wheat farming, characterized by frequent tillage and fertilizer use, increases erosion and sediment mobilization, which are transported into the river via runoff. Similar relationships between agriculture and TSS enrichment have been reported in Kenya’s Nyando and Nzoia basins, where farmlands were shown to contribute disproportionately to sediment loading during rainy seasons (Opiyo *et al.*, 2022).

Downstream sections such as Kisumu Bridge and Huruma recorded the highest TSS values. These sites are heavily impacted by urban runoff, industrial effluents, and untreated sewage. Urban centers contribute large quantities of suspended solids through stormwater drains, car wash discharges, and poorly managed solid waste (Chemtai *et al.*, 2023). The situation at Huruma is further exacerbated by its proximity to an open dumpsite, where leachate and waste residues flow directly into the river, greatly amplifying suspended matter concentrations. Comparable findings have been documented in the Awash River Basin, Ethiopia, where urban growth and poorly managed dumpsites led to extreme increases in suspended solids and other pollutants downstream (Awash River Basin Study, 2023).

Seasonal variation was also evident, with significantly higher TSS levels during the wet season compared to the dry season. This is consistent with rainfall-driven sediment mobilization, whereby stormwater runoff carries soil particles, agricultural inputs, and waste materials into river systems. Studies across East Africa affirm this trend: Mwanake *et al.* (2023) in the Sio–Malaba–Malakisi Basin and Kaggwa *et al.*, (2023) in Ugandan river systems both reported sharp increases in TSS during rainy seasons due to erosion and transport of sediments from catchment areas. Although dilution from rainfall can reduce concentrations of dissolved pollutants, it generally amplifies suspended solids because of enhanced erosional processes.

The ecological implications of elevated TSS are considerable. High concentrations of suspended particles reduce light penetration, thereby suppressing photosynthesis in aquatic plants and algae, which disrupts primary production (Ridall & Ingels, 2021). In addition, fine sediments settle on benthic habitats, smothering invertebrate communities and fish spawning grounds, and reducing oxygen availability. In River Sosiani, elevated TSS coincided with increased nematode abundance, particularly stress-tolerant colonizer species. This aligns with observations by Makeleni (2025) in South African rivers, where high TSS was correlated with reduced diversity and dominance of opportunistic nematodes, confirming their utility as bioindicators of sediment-related stress. “High TSS has been shown to impair feeding efficiency, clog fish gills, and reduce reproductive success in aquatic organisms (Bilotta & Brazier, 2020).

Globally, TSS is also increasingly recognized as a vector for transporting pollutants. Suspended particles adsorb heavy metals, nutrients, and emerging contaminants such as pharmaceuticals and microplastics, which are then dispersed downstream (Ziani *et* *al.*, 2023). The elevated TSS levels recorded at Kisumu Bridge and Huruma suggest that River Sosiani not only suffers from direct particulate pollution but also from pollutant transport, compounding ecological and human health risks.

In conclusion, the TSS trends observed in River Sosiani confirm the cumulative influence of agricultural intensification, urban expansion, and industrial activities on water quality. Elevated TSS downstream, especially during wet seasons, compromises ecological integrity, reduces biodiversity, and increases public health risks by transporting attached pollutants. These findings reinforce the need for integrated watershed management, including erosion control in farmlands, improved urban waste management, and treatment of industrial and municipal effluents. Moreover, combining TSS monitoring with nematode-based bioindicators provides a robust, holistic framework for assessing and managing river health.

4.3 Nematodes

At the upstream site Kaptagat (control), nematode abundance was consistently the lowest across all sampling periods. The results showed a mean value of 111 nematodes and 93 nematodes in experiment 1 and 2 and significantly higher with a mean value of 243 nematodes and 205 nematodes in experiment 3 and 4. This section of the river is located within a relatively pristine environment dominated by forest cover, where anthropogenic influence is minimal. The low nematode density here reflects stable water quality conditions, characterized by low suspended solids, high dissolved oxygen, and reduced ionic concentrations (Fig. 4.7).

At Kipkorgot, which lies within an agricultural zone, nematode abundance increased moderately compared to Kaptagat with a mean value of 140 nematodes and 167 nematodes in experiment 1 and 2. This rise was attributed to inputs from surface runoff, which introduced sediments, nutrients, and agrochemical residues into the river. Although the abundance was not as high as in downstream urban sites, the increase suggested a response to mild ecological disturbance. Seasonal variation was evident, with higher nematode counts during the wet season, when runoff from cultivated lands was more pronounced (Fig. 4.7).

At Kisumu Bridge, a downstream site influenced by Eldoret town’s urban activities, nematode abundance was substantially higher in experiment 1 and 2 with a mean value of 450 nematodes and 1344 nematodes and significantly lower in experiment 3 and 4 with a mean value of 728 nematodes and 652 nematodes. Here, the elevated densities coincided with increased electrical conductivity, suspended solids, and reduced dissolved oxygen levels. This section of the river receives multiple stressors, including municipal wastewater, effluents from garages and car washes, and stormwater runoff from impervious surfaces (Fig. 4.7).

The highest nematode densities were consistently recorded at Huruma, the most polluted site with a mean value of 1064 nematodes and 1792 nematodes in experiment 1 and 2 and significant lower in experiment 3 and 4 with a mean value of 653 nematodes and 970 nematodes. This section of the river is directly influenced by untreated sewage, industrial discharges from textile factories, and leachate from the municipal dumpsite. Abundance levels peaked during the wet season, when runoff amplified the input of organic matter and pollutants, providing conditions favorable for opportunistic nematodes. In contrast, The lower nematode counts observed during the wet season may be attributed to increased hydrological flow, which can physically displace or wash organisms downstream, rather than reflecting reduced ecological suitability. Seasonal patterns were consistent across all sites. Wet season experiments

(3 and 4) generally recorded lower nematode counts than dry season experiments (1 and 2). This trend reflects the effect of increased runoff, which introduced more organic matter and pollutants, enriching habitats for nematodes (Fig. 4.7).

Overall, the results highlight a strong correlation between nematode abundance and physicochemical water quality parameters. Nematode densities increased in tandem with rising suspended solids, conductivity, and turbidity, while sites with higher dissolved oxygen recorded lower densities. This pattern reinforces the role of nematodes as reliable bioindicators of ecological stress in freshwater ecosystems.

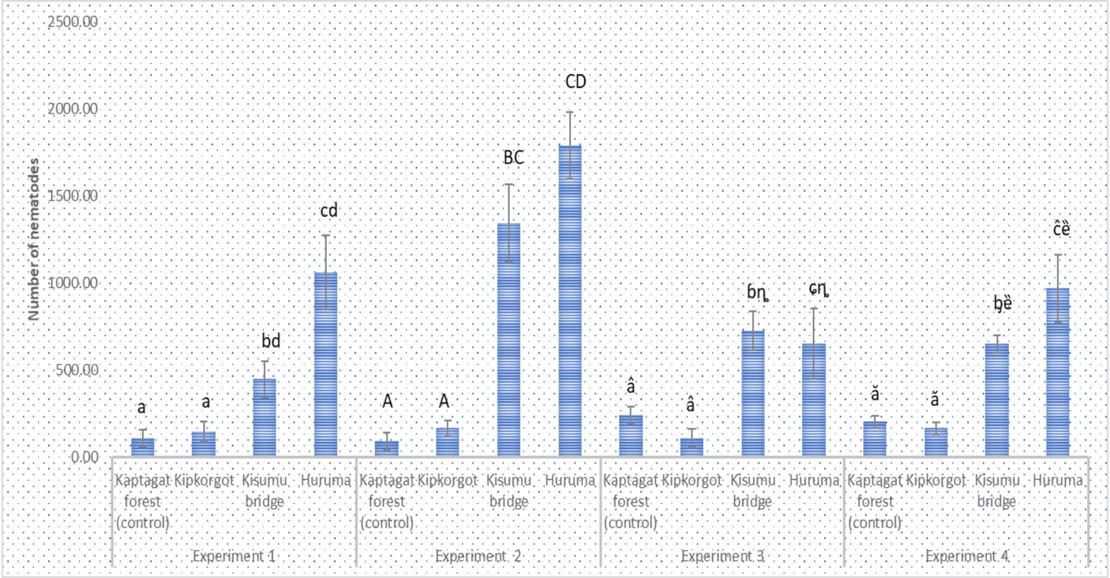


Fig 4.7: Nematodes in samples taken from River Sosiani.

The water samples were taken from Huruma municipal sewage downstream to the sources of the River at Kaptagat (control). In comparison to the control (Kaptagat), the data shows the mean and standard error of the nematodes in water samples from Kipkorgot, Kisumu Bridge and Huruma municipal sewage. For each experiment, means with same values are not statistically (P=0.05, Tukey's standardized range test). These are the results of the four independent experiments.

The results demonstrated that nematode abundance increased progressively from upstream to downstream in River Sosiani, with Kaptagat recording the lowest densities and Huruma the highest. This distribution reflects a strong correlation between nematode populations and physicochemical water quality parameters, including suspended solids, electrical conductivity, turbidity, and dissolved oxygen. The findings are consistent with the ecological principle that nematodes respond rapidly to environmental stressors, making them reliable bioindicators of pollution gradients (Ridall & Ingels, 2021).

At Kaptagat, low nematode densities reflected the relatively pristine, forested environment. Nematodes were less prevalent here, mirroring findings from Mwanake *et al.* (2023), who noted that upstream sections of minimally disturbed rivers in Kenya support low but stable nematode populations dominated by sensitive, non-opportunistic species. This suggests that nematode communities can serve as baselines for detecting disturbance in other parts of the river.

In contrast, Kipkorgot exhibited moderately higher densities, likely influenced by agricultural runoff. Agricultural intensification introduces organic matter and nutrients that enrich nematode populations, particularly colonizer species adapted to nutrient-rich environments (Chemtai *et al.*, 2023). This is in line with Makeleni (2025), who found that agricultural rivers in South Africa showed an increase in opportunistic nematodes under moderate enrichment, although overall diversity remained relatively intact compared to urban-polluted streams.

Kisumu Bridge and Huruma demonstrated substantial increases in nematode abundance, correlating with deteriorating water quality due to urban and industrial pressures. The proliferation of nematodes in these sites was strongly associated with elevated electrical conductivity, high suspended solids, and reduced dissolved oxygen. Globally, Bezerra *et al.* (2021) reported that nematodes exhibit sharp increases in abundance under organic enrichment, but species composition shifts toward colonizer taxa, reflecting reduced ecological stability.

The dominance of opportunistic and stress-tolerant nematodes downstream is ecologically significant. These taxa thrive in degraded conditions because they reproduce rapidly and exploit enriched organic matter. However, their dominance indicates loss of sensitive species and reduced community complexity, which is a hallmark of ecological degradation (Makeleni, 2025; Ridall & Ingels, 2021). The situation in Sosiani parallels findings by Ziani *et al.* (2023), who showed that nematode feeding structures and functional diversity decline in polluted sediments contaminated with micro plastics and pharmaceuticals.

The ecological implications of these patterns are profound. Elevated nematode densities downstream, indicate ecological stress, reduced biodiversity, and disruption of food web interactions. High nematode densities under pollution stress also suggest a decline in ecosystem resilience, with benthic habitats increasingly dominated by fast-colonizing species. This matches the observations of Mwanake *et al.* (2023), who argued that nematode community structure is a more sensitive measure of pollution than traditional chemical indicators, as it integrates long-term ecological impacts.

In conclusion, the nematode results from River Sosiani confirm that nematodes are robust bioindicators of pollution gradients. Their abundance strongly correlated with physio-chemical deterioration downstream, while their community composition shifted toward opportunistic taxa in polluted zones. Incorporating nematode monitoring into regular water quality assessments would provide an early-warning system for ecological degradation, complementing chemical measures such as electrical conductivity and suspended solids.

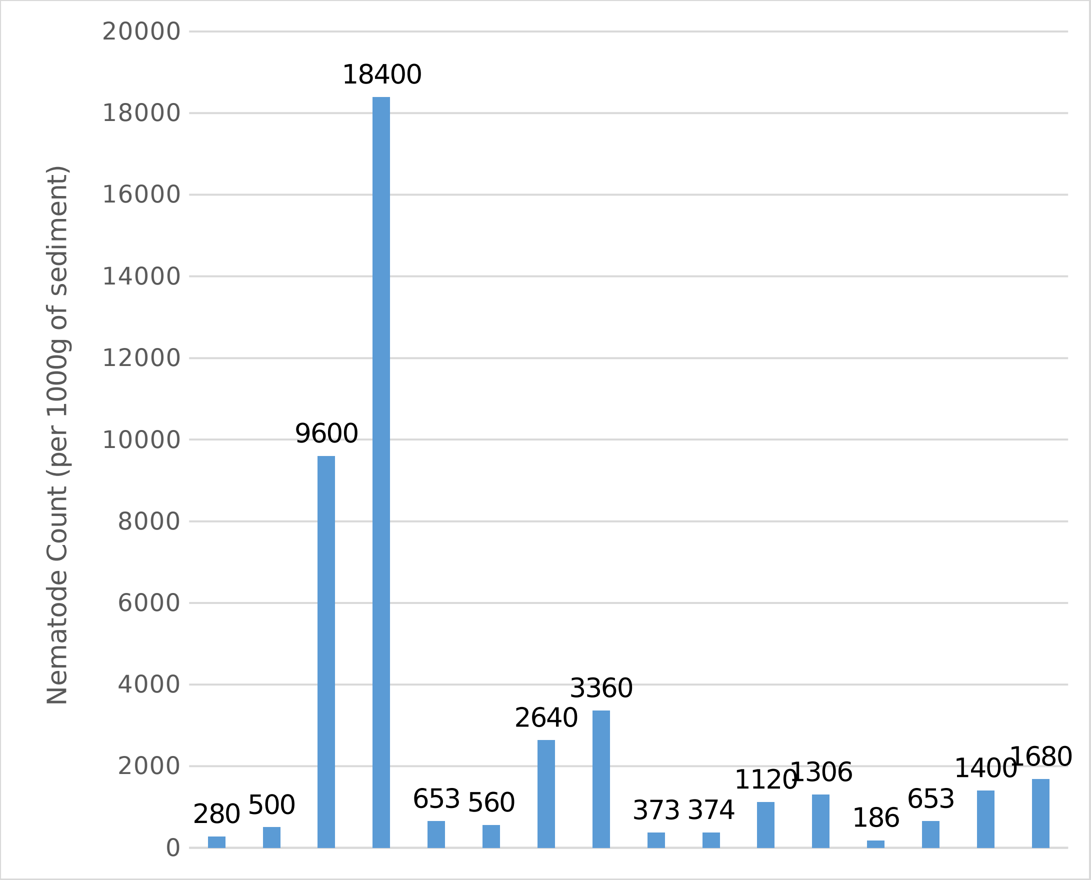


Fig 4.8 Nematode Count (per 1000g of sediment)

The data in Figure 4.8 from the four experiments indicate significant variation in nematode counts across different locations, with notable differences observed between the control site (Kaptagat Forest) and the experimental sites (Kipkorgot, Kisumu Bridge, and Huruma). In Experiment 1, the control site Kaptagat Forest had a relatively low nematode count of 280 and Kipkorgot recording 500 nematodes, whereas Kisumu Bridge and Huruma showed markedly higher counts of 9600 and 18400, respectively. Experiment 2 displayed a similar trend, with the Kaptagat Forest (control) site at 653, Kipkorgot showed 560, and Kisumu Bridge and Huruma showing lower but still substantial counts (2640 and 3360). In Experiment 3, the counts at the control site Kaptagat Forest and Kipkorgot were close to each other (373 and 374), with Kisumu Bridge and Huruma showing moderate counts (1120 and 1306). Finally, in Experiment 4, Kaptagat Forest (control) had the lowest count at 186, while Huruma and Kisumu recorded counts of 1680 and 1400, respectively, demonstrating a consistent pattern of elevated nematode populations in Kisumu and Huruma across the experiments. These findings suggest that environmental factors associated with Kisumu and Huruma locations might support higher nematode populations compared to Kaptagat Forest and Kipkorgot.

The observed variation in nematode counts presented in Figure 4.8 aligns closely with the patterns described in global and regional literature on nematode community responses to pollution gradients. The consistently lower nematode counts at the control site (Kaptagat Forest) and Kipkorgot compared to the markedly higher counts at Kisumu Bridge and Huruma reflect the influence of anthropogenic disturbances downstream. Similar findings have been reported in international studies where polluted environments exhibited elevated total nematode abundance dominated by opportunistic species tolerant to organic enrichment and reduced oxygen levels (Ridall & Ingels, 2021; Makeleni, 2025).

Pollution-tolerant bacterivorous nematodes (c–p 1–2) tend to proliferate under high organic load and nutrient enrichment, while sensitive taxa (c–p 4–5) characteristic of pristine habitats decline. The significantly higher nematode counts at Kisumu Bridge and Huruma therefore suggest that these downstream sites experience higher organic loading from effluents and runoff, consistent with earlier findings on River Sosiani’s deteriorating physio-chemical quality (Chemtai *et al.*, 2023). In contrast, the relatively low nematode counts at Kaptagat Forest, a minimally disturbed site, reflect the stability and low nutrient conditions that typically support diverse but less dense nematode populations (Höss *et al.*, 2022).

The fluctuation in nematode abundance across the four experiments also reflects the temporal and spatial variability. Seasonal rainfall likely enhances pollutant influx and organic enrichment downstream, leading to transient population surges of colonizer nematodes during wet periods, followed by partial declines as conditions stabilize (Tadesse *et al.*, 2023; Bezerra *et al.*, 2021). The consistently elevated counts at Kisumu Bridge and Huruma across all experiments indicate chronic pollution stress, which may sustain opportunistic taxa over time and inhibit the recovery of sensitive species.

Overall, the results presented in Figure 4.8 empirically reinforce the literature's assertion that nematode abundance is a reliable bioindicator of pollution gradients, capturing both spatial and temporal variations in ecological stress. The patterns observed along River Sosiani low nematode abundance in the upstream forested control and elevated counts in urban and industrial downstream sites mirror global trends linking nematode population dynamics to increasing nutrient enrichment, organic pollution, and sediment disturbance.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study established that nematode abundance and distribution along River Sosiani exhibit a clear spatial pattern influenced by pollution gradients. Nematode densities were lowest at the upstream site (Kaptagat), which is characterized by minimal disturbance, and increased progressively downstream, with the highest abundances recorded at Kisumu Bridge and Huruma. These downstream sections are exposed to significant anthropogenic activities, including industrial effluent discharge, urban waste, and agricultural runoff. Although seasonal variation was observed, with lower densities during the wet season likely due to increased flow and organism displacement, pollution remained the dominant factor influencing nematode distribution.

The analysis of physico-chemical parameters revealed significant spatial and temporal variation along the river. Temperature increased downstream due to reduced riparian cover and higher solar exposure, while dissolved oxygen declined in polluted sections, reflecting increased organic loading. Turbidity and total suspended solids increased downstream, particularly during the wet season, due to enhanced runoff and sediment transport. Electrical conductivity also showed an increasing trend downstream, indicating rising ionic concentrations associated with pollution inputs. Variations in pH were observed along the river, influenced by a combination of natural factors such as geology and anthropogenic inputs, including industrial and municipal discharges. These findings confirm the existence of a distinct pollution gradient from upstream to downstream sections of River Sosiani.

The study further demonstrated a strong relationship between nematode abundance and selected physico-chemical parameters. Higher nematode densities were associated with increased turbidity, total suspended solids, and electrical conductivity, as well as reduced dissolved oxygen levels in polluted sites. This indicates that nematodes respond to cumulative environmental stress and can effectively reflect changes in water quality. The findings therefore confirm the suitability of nematodes as reliable bioindicators for assessing pollution and ecological condition in freshwater systems.

5.2 Recommendation

There is a need to integrate nematode-based biological assessments with conventional physico-chemical monitoring approaches. While physico-chemical parameters provide immediate measurements of water quality, nematode communities reflect cumulative and long-term ecological conditions. Integrating these approaches will enhance the accuracy and effectiveness of water quality monitoring in River Sosiani and similar freshwater systems.

Continuous monitoring of River Sosiani should be implemented to track pollution trends and assess the effectiveness of management interventions. Nematodes can be incorporated as biological indicators in routine monitoring programs to provide early warning of ecological changes and pollution events.

Further research should focus on species-level identification of nematodes to improve the precision of biological monitoring. Identifying indicator species will support the development of locally relevant biotic indices for freshwater systems in Kenya.

Additional studies are needed to investigate the effects of specific pollutants, including heavy metals and emerging contaminants, on nematode communities. Understanding these impacts will provide deeper insight into pollution dynamics and support the development of targeted management strategies. Future research should also integrate turbidity measurements with particle size distribution, sediment chemistry, and microbial analysis to better understand contaminant transport and associated health risks.

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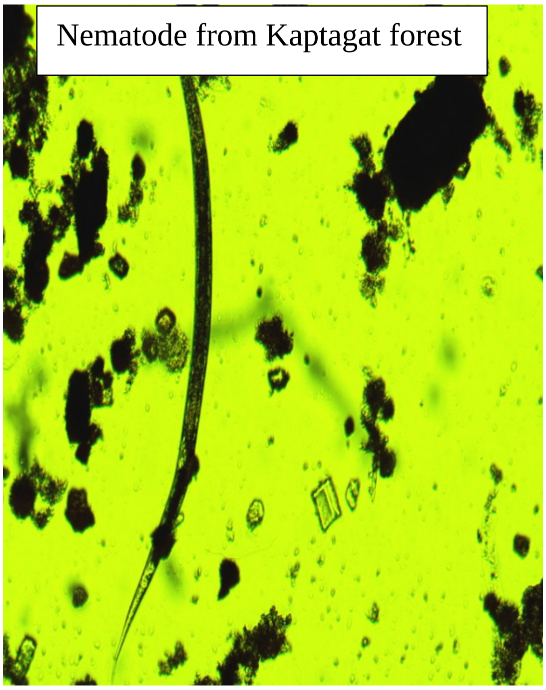
APPENDIX I NEMATODES SAMPLED FROM DIFFERENT SAMPLING POINTS ALONG RIVER SOSIANI

Nematode from Kisumu Bridge



Nematode from Kaptagat forest

Nematode from Huruma

Nematode from Kipkorgot