

**ASSESSMENT OF MICROBIAL QUALITY AND  
PHYSICOCHEMICAL PARAMETERS OF SHALLOW  
WELL WATER IN MOIBEN SUB-COUNTY, UASIN GISHU  
COUNTY, KENYA**

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**A Thesis Submitted in Partial Fulfillment of the Requirement for Conferment of  
the Degree of Master of Science in Sanitation of Meru University of Science and  
Technology**

**2025**

**DECLARATION**

This thesis is my original work and has not been presented for a degree in any other institution

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## **DEDICATION**

With lots of appreciation for their patience, understanding, and love. I dedicate this to my Children Acelynn and Ainslee, brothers, sisters, Mum and Dad, who always encouraged me, nourished my soul, and empowered my spirit.

**God bless!**

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## TABLE OF CONTENTS

<b>DECLARATION</b> .....	<b>ii</b>
<b>DEDICATION</b> .....	<b>iii</b>
<b>ACKNOWLEDGEMENT</b> .....	<b>iv</b>
<b>LIST OF TABLES</b> .....	<b>viii</b>
<b>LIST OF FIGURES</b> .....	<b>ix</b>
<b>LIST OF APPENDICES</b> .....	<b>x</b>
<b>OPERATIONAL DEFINITION OF TERMS</b> .....	<b>xi</b>
<b>ABBREVIATIONS AND ACRONYMS</b> .....	<b>xiii</b>
<b>ABSTRACT</b> .....	<b>xiv</b>
<b>CHAPTER ONE: INTRODUCTION</b> .....	<b>1</b>
1.1 Background Information .....	1
1.2 Problem Statement .....	4
1.3 Purpose of the Study .....	5
1.4 Objectives of the Study .....	6
1.4.1 General Objective.....	6
1.4.2 Specific Objectives.....	6
1.5 Research Questions .....	6
1.6 Justification of the Study.....	7
1.7 Limitations of the Study.....	8
1.8 Assumptions.....	8
<b>CHAPTER TWO: LITERATURE REVIEW</b> .....	<b>9</b>
2.0 Introduction.....	9
2.1 Global Water Quality Perspectives .....	9
2.1.1 Water Quality Determinants.....	9
2.1.2 Contamination Mechanisms.....	9
2.1.3 Health Implications .....	10
2.2 WHO Guidelines for Drinking Water Quality .....	10
2.2.1 Overview of WHO Guidelines.....	10
2.2.2 Microbiological Parameters.....	10
2.2.3 Chemical parameters .....	12
2.2.4 Physical parameters .....	12
2.2.5 Safety distances and protection measures .....	13
2.2.6 Monitoring requirements .....	13
2.2.7 Water safety plans .....	13
2.3 Microbial Quality of Water.....	14
2.3.1 Total coliforms, fecal coliform and <i>E. coli</i> .....	14
2.4 Physicochemical Parameters.....	16
2.5 Well-Latrine Distance Relationships .....	18
2.6 Knowledge Gaps .....	21
2.7 Theoretical Framework .....	23
2.8 Conceptual Framework .....	24
<b>CHAPTER THREE: METHODOLOGY</b> .....	<b>27</b>
3.0 Introduction .....	27

3.1 Study Design .....	27
3.2 Study Area.....	27
3.3 Sampling Technique and Sample Size.....	27
3.4 Inclusion Criteria.....	32
3.5 Exclusion Criteria.....	32
3.6 Data Collection.....	32
3.6.1 Shallow wells water sample collection .....	32
3.6.2 Determination of coliforms in water using the multiple tube technique.....	32
3.6.3 Confirmatory test - fecal coliform test .....	33
3.6.4 <i>E. coli</i> test.....	33
3.6.5 pH determination in water (electrometric method).....	33
3.6.6 Total dissolved solids (TDS) and electrical conductivity determination (Electrometric Method).....	33
3.6.7 Turbidity determination by absorptiometric method .....	34
3.6.8 Ammonia Determination by Spectrophotometric Method (Salicylate Method).....	34
3.6.9 Nitrate and nitrite determination by spectrophotometric methods.....	34
3.7 Quality Control Measures .....	34
3.7.1 Physicochemical parameters .....	34
3.7.2 Microbiological parameters.....	35
3.8 Data Analysis .....	35
3.9 Ethical Considerations .....	36
<b>CHAPTER FOUR: RESULTS .....</b>	<b>38</b>
4.0 Introduction.....	38
4.1 Microbial Analysis of Water samples .....	38
4.1.1 Total Coliforms .....	44
4.1.2 Fecal coliforms.....	45
4.1.3 <i>E. coli</i> .....	46
4.2 Analysis of Physiochemical Parameters .....	47
4.2.1 Ammonia.....	47
4.2.2 Nitrates .....	51
4.2.3 Nitrites.....	54
4.2.4 pH.....	58
4.2.5 Electrical conductivity.....	58
4.2.6 Total dissolved solids.....	58
4.2.7 Turbidity.....	59
4.3 Relationship Between Well Water Contamination and the Distance from Pit-Latrines.....	61
4.3.1 Total coliforms and the distance of the well from pit - latrine.....	62
4.3.2 Fecal coliform and the distance of the well from pit - latrine.....	63
4.3.3 <i>E. coli</i> and the distance of the well from pit - latrine.....	64
4.3.4 Ammonia and the distance of the well from pit – latrine.....	65
4.3.5 Nitrates and the distance of the well from pit – latrine.....	66
4.3.6 Nitrites and the distance of the well from pit – latrine.....	67
4.3.7 pH and the distance of the well from pit – latrine.....	68

4.3.8 Electrical conductivity and the distance of the well from pit – latrine .....	69
4.3.9 Total dissolved solids and the distance of the well from pit – latrine .....	70
4.3.10 Turbidity and the distance of the well from pit – latrine.....	71
4.3.12 ANOVA results for well distance and microbial contamination .....	72
4.3.14 ANOVA Results for Well Distance and Chemical Parameters .....	77
<b>CHAPTER FIVE: DISCUSSION .....</b>	<b>80</b>
5.0 Introduction .....	80
5.1 Microbial Contamination Levels in Shallow Wells .....	80
5.2 Physiochemical Parameters in Shallow Wells .....	82
5.3 Relationship Between Well Water Contamination and Distance from Pit Latrines	84
5.3.1 Total coliforms, fecal coliforms and E. coli and their relationship to well distances from pit-latrines .....	84
5.3.2 pH, electrical conductivity, total dissolved solids, turbidity and their relationship to well distances from pit-latrines .....	87
5.3.3 pH.....	87
5.3.4 Electrical conductivity.....	88
5.3.5 Total dissolved solids .....	88
5.3.6 Turbidity.....	89
5.3.7 Ammonia, Nitrates, Nitrites, and Their Relationship to Well Distances from Pit-Latrines .....	90
<b>CHAPTER SIX: CONCLUSION, RECOMMENDATIONS AND PUBLICATION</b>	<b>91</b>
6.0 Introduction .....	91
6.1 Summary of Key Findings .....	91
6.1.1 Microbial Contamination Levels in Shallow Wells .....	91
6.1.2 Physiochemical Parameters of Well Water .....	92
6.1.3 Relationship Between Well Water Contamination and Pit Latrine Distance....	92
6.2 Conclusion .....	93
6.3 Recommendations .....	93
6.4 Suggestions for Further Research .....	94
6.5 Publication .....	95
<b>REFERENCES .....</b>	<b>96</b>
<b>APPENDICES.....</b>	<b>105</b>

## LIST OF TABLES

Table 2. 1 Microbiological limits for potable water .....	11
Table 3. 1 Sampling frame.....	28
Table 4. 1 Total coliforms, Fecal Coliforms and Escherichia coli .....	39
Table 4. 2 Concentration of Ammonia in water samples tested .....	49
Table 4. 3 Concentration of Nitrates in mg/L for the samples tested .....	53
Table 4. 4 Concentration of nitrites in mg/L .....	56
Table 4. 5 pH electrical conductivity, total dissolved solids and turbidity.....	60
Table 4. 6 Model Fitness for Well Distance and Microbial Contamination.....	73
Table 4. 7 ANOVA for Well Distance and Microbial Contamination .....	73
Table 4. 8 Coefficients for Well Distance and Microbial Contamination .....	74
Table 4. 9 Model Fitness for Well Distance and Physical Parameters .....	75
Table 4. 10 ANOVA for Well Distance and Physical Parameters .....	75
Table 4. 11 Coefficients for Well Distance and Physical Contamination .....	76
Table 4. 12 Model Fitness for Well Distance and Chemical Parameters .....	77
Table 4. 13 ANOVA for Well Distance and Chemical Parameters .....	78
Table 4. 14 Coefficients for Well Distance and Chemical Parameters .....	79

## LIST OF FIGURES

Figure 3.1 Map of Moiben Sub-County .....	30
Figure 3.2 Map of Kenya.....	31
Figure 4.1 Most probable number count reference ranges .....	39
Figure 4.2 Samples showing presence of gas .....	44
Figure 4.3 Incubation of samples for 24 Hrs at 440C.....	45
Figure 4.4 Gas presence after incubation of the positive samples with brilliant green bile lactose broth.....	46
Figure 4. 5 Indole production confirming presence of E.coli.....	47
Figure 4.6 Formation of green color indicates presence of Ammonia in the samples tested	48
Figure 4.7 Calibration curve of absorbance versus ammonia concentration.....	49
Figure 4.8 Formation of amber-colored azo dye .....	51
Figure 4.9 Calibration curve of absorbance versus Nitrate concentration.....	53
Figure 4. 10 Formation of Pink Colour .....	55
Figure 4.11 Calibration curve of absorbance versus Nitrite concentration .....	57
Figure 4.12 Relationship between Total Coliform and the Distance of the well from the pit- latrine.....	62
Figure 4.13 Relationship between fecal Coliform and the distance of the well from pit-latrines.....	63
Figure 4.14 Relationship between E. coli and the distances of the well from Pit- latrines ...	64
Figure 4.15 Relationship between Ammonia concentration and the distance from wells to pit-latrines .....	66
Figure 4.16 Relationship between Nitrates and the well distance from the pit- latrines .....	67
Figure 4.17 Relationship between Nitrite Concentration and the well distance from the pit-latrine.....	68
Figure 4. 18 Relationship between pH and distance of well from pit latrine .....	69
Figure 4.19 Relationship between Electrical conductivity and distance of well from pit latrine .....	70
Figure 4.20 Relationship between Total dissolved solids and distance of well from pit latrine .....	71
Figure 4.21 Relationship between turbidity and distance of well from pit latrine	4.3.11
Inferential Analysis.....	72

## LIST OF APPENDICES

Appendix A: Informed Consent .....	105
Appendix B: Chemical Reagents used in the laboratory .....	106
Appendix C: Tabulation of pH, EC, TDS and turbidity .....	109
Appendix D: Ethical Approval, NACOSTI Research License .....	110
Appendix E: Publication .....	111
Appendix F: Plagiarism Report.....	112

## OPERATIONAL DEFINITION OF TERMS

Ammonia (NH <sub>3</sub> )	A compound of nitrogen and hydrogen that is found in water, soil, and air. It is produced naturally through the decomposition of organic matter, including plant and animal waste
Coliform	are a broad class of bacteria found in the environment, including the feces of humans and other warm-blooded animals and are used as an indicator organism to assess the sanitary quality of water and the potential presence of pathogens
<i>Escherichia coli</i> ( <i>E. coli</i> )	is a specific species within the coliform group. Most strains are harmless and are part of the normal flora of the human gut and are often used as a specific indicator of fecal contamination in water
Fecal coliforms	are a subset of total coliform bacteria that originate specifically from the intestines of warm-blooded animals. They are more precise indicators of fecal pollution and potential pathogen
Nitrates (NO <sub>3</sub> <sup>-</sup> )	are compounds that consist of nitrogen and oxygen, commonly found in fertilizers and can enter water sources through agricultural runoff, wastewater discharge, and septic systems
Nitrites (NO <sub>2</sub> <sup>-</sup> )	are intermediate products in the nitrogen cycle, formed by the oxidation of ammonia and further oxidation to nitrates. They are less stable than nitrates and can be toxic to humans and animals if ingested in large amounts
Population	a universal set of all people involved in a real or hypothetical group of

people, events or objects to which the research wants to generalize the result after finding

Physiochemical parameters refer to the various chemical components and characteristics of water that are measured to assess its quality. These parameters in the study include ammonia, nitrates, nitrites, pH, Electrical conductivity, total dissolved solids and turbidity

## ABBREVIATIONS AND ACRONYMS

AOPs	Advanced Oxidation Processes
<i>E. coli</i>	<i>Escherichia coli</i>
EC	Electrical Conductivity
ELDOWAS	Eldoret Water and Sanitation Company
KNBS	Kenya National Bureau of Standards
MDG	Millennium Development Goal
MPN	Most Probable Number
NACOSTI	National Commission for Science, Technology, and Innovation
NH <sub>3</sub>	Ammonia
NO <sub>2</sub> <sup>-2</sup>	Nitrites
NO <sub>3</sub> <sup>-3</sup>	Nitrates
SDG's	Sustainable Development Goals
SPSS	Statistical Package for Social Sciences
TDS	Total Dissolved Solids.
WASH	Wash, Sanitation, and Hygiene

## ABSTRACT

Informal settlements in urban areas of sub-Saharan Africa often rely heavily on shallow dug wells for their water supply. However, these wells are susceptible to contamination from various sources due to a lack of protection. This study aimed to assess the microbial quality and physicochemical parameters of shallow wells in Moiben Sub-County, Uasin Gishu County. Specifically, the study sought to: (i) determine the level of microbial contamination in shallow wells, (ii) analyze the physicochemical parameters of the water, and (iii) establish the relationship between shallow well water contamination and the distance of the wells from nearby pit latrines. The study population was 62 shallow wells in five zones of the sub-county. Stratified sampling technique was utilized in proportionally sampling wells for examination. Laboratory analysis was conducted to measure microbial indicators like fecal coliforms, *E. coli*, and total coliforms, and physicochemical parameters like pH, TDS, electrical conductivity, turbidity, nitrates, nitrites, and ammonia. Observational method was utilized to measure the distance of pit latrines from wells. Data was analyzed inferentially through ANOVA, while microbial contamination was quantified using the Most Probable Number (MPN) technique. Findings indicated that there was a significant correlation between distance from the well and microbial contamination ( $p < 0.001$ ), and 72.8% of microbial contamination was accounted for by distance. Likewise, 98.7% of physicochemical parameter contamination was accounted for by distance. The results point out that shallow wells closer to latrines have greater levels of contamination, above WHO's safe drinking water guidelines. The research emphasizes maintaining a minimum distance of 50 meters between pit latrines and groundwater sources to avert fecal contamination. The final beneficiaries of these results are policymakers, members of the community, and local health administrators, who can use the data to improve public health, sanitation facilities, and water quality in the region

## CHAPTER ONE: INTRODUCTION

### 1.1 Background Information

Water scarcity and quality remain critical global challenges, with the World Health Organization reporting that over 1 billion people lack access to safe drinking water and more than 2 billion people have insufficient access to sanitation facilities (World Health Organization, 2022). In developing countries, a significant portion of the population relies on untreated groundwater sources, including drilled boreholes, dug wells, and springs. While groundwater is generally considered of better quality than surface water sources, it remains vulnerable to contamination, particularly from on-site sanitation systems (Das et al., 2023).

The WHO emphasizes that potable water must meet specific standards in terms of physical features, chemical composition, bacteriological content, and general acceptability to ensure it's safe for consumption and cooking (WHO, 2021). The focus extends beyond meeting minimum standards to maintaining the highest possible level of drinking water quality through ongoing monitoring, management, and improvement of water sources.

Chemical contamination can lead to both acute effects like nausea and skin rashes, and chronic issues including liver damage, nervous system disorders, and birth defects (Li et al., 2021). Additionally, waterborne diseases such as diarrhea, cholera, and typhoid severely impact health and livelihoods, particularly in developing regions (Rahman, Kunwar, & Bohara, 2021). These health impacts are especially severe in areas where water treatment facilities fall short of meeting community needs due to issues like corruption, inadequate maintenance, or rapidly growing populations.

In Kenya, sustainability in water and sanitation remains a challenge despite its inclusion in Vision 2030 (Onyango, 2023). Water scarcity has been exacerbated by the rising population,

successive droughts, climate change, and poor management of available water resources. As much as 80% of all hospitalizations in Kenya up to 2018 were due to avoidable diseases and 50% were water, sanitation, and hygiene-related (Rahman et al., 2021).

Water quality is regulated by natural and anthropogenic factors consisting of geological, hydrological, and climatic conditions (Nourani et al., 2024). These are particularly important where water is limited and increased salinity is a potential outcome, most notably in coastal and arid regions. The health issues vary for developing and developed countries, the developing nations primarily experiencing gastrointestinal infections while the developed nations experience issues like organic load and eutrophication (Luvhimbi et al., 2022).

Studies in various parts of Kenya have shown serious water quality problems. A study in Langas, Eldoret, illustrated a high rate of contamination in shallow water wells beyond WHO levels, caused primarily by the location of pit latrines (Kiptum, Ndambuki, & Engineering, 2015).

In the Kwale District, a study established *E. coli* contamination in various sources of water rendering them unsuitable for human consumption (Tole, 2017).

Contamination of the water source often occurs through the entry of sewage from septic tanks or pit latrines and also surface runoff with soiled soil (Ogolla et al., 2020). During water collection, lifting equipment also disperses additional contamination when spilled water seeps back into the sources (Aju et al., 2024). This is mostly an issue in urban settlements with high population densities and on-site sanitation control (Singh et al., 2022).

The problem of microbial contamination extends beyond the source, occurring during and after collection, even when the water sources themselves are uncontaminated. This post-source contamination can significantly compromise water quality in storage vessels within

homes, potentially undermining the health benefits of newly installed water sources (Giri, 2021).

In Moiben Sub-County, Uasin Gishu County, approximately 40% of the population relies on piped water from Eldoret Water and Sanitation (ELDOWAS). However, due to high water prices, distance to water kiosks, low pressure, and irregular supply, many residents supplement their water needs with groundwater from shallow wells. The prevalence of shallow wells in the area is attributed to the high-water table.

The growing population in Moiben has led to increased reliance on shallow wells, often constructed alongside pit latrines and septic tanks without proper lining. Most wells are either uncovered or partially covered, making them susceptible to contamination through spillage and surface runoff. The residential areas exhibit poor sanitation practices, with limited enforcement of environmental sanitation laws.

The Kenyan Ministry of Public Health recommends a distance of at least 30 meters between wells and septic tanks or pit latrines. However, the transport of microbes from pit latrine waste to groundwater is highly dependent on the hydrology and soil in the area (Agyemang, 2023). This is particularly concerning given that pit latrines are widespread in poor countries as the primary human waste management system.

In response to these challenges, coupled interventions such as efficient waste management, improved sanitation practices, and additional water treatment plants are needed. This is also in accordance with the Sustainable Development Goal 6 of access to clean water and sanitation for all through sustainable management, with the vision of having universal access to safe and affordable drinking water by 2030 (Mulwa & Fangninou, 2021).

These issues raise the imperative need to establish the impacts of pit latrine leakage on shallow wells in Moiben Sub-County because little attention has been accorded to site sanitation conditions, particularly the impacts of pit latrines and septic tanks. The study seeks to examine groundwater quality from shallow wells in the region through geospatial technologies for a combined water quality assessment and its relationship with sanitation infrastructure.

## **1.2 Problem Statement**

In developing countries such as Kenya, most homes have no access to clean and safe water and drink untreated surface water or shallow and unprotected groundwater, where fecal contamination is a serious risk to public health (WHO, 2022). In the world, the lack of proper supply of safe water, basic sanitation, and hygiene results in about 2 million deaths due to diarrhea every year, where 0.5 million are children. Furthermore, approximately 1,000 children lose their lives every day due to preventable sanitation-related illnesses like diarrhea, Salmonellosis, and cholera (WHO, 2022).

Moiben Sub-County, one of six sub-counties in Uasin Gishu County, is unique in issues of water quality compared to its counterparts. While other sub-counties like Turbo and Ainabkoi are better served by piped water systems, Moiben Sub-County has a high population density of shallow wells, and approximately 60% of all households in the region use the wells for water supplies. The sub-county has a high population density of pit latrines. Moiben Sub-County's shallow wells, which are predominantly found in Merewet, Kimumu, and Sergoit wards, are at the highest risk of getting contaminated due to their proximity to the pit latrines. Out of an initial survey, over 70% of the wells fall within less than 20 meters from pit latrines, which is below the 30-meter minimum safe distance as laid down by the

Ministry of Health. This is compounded by the high water table in the area (15-20 meters average depth from ground) and dominant sandy-loam type of soil that is prone to fast contaminant transport.

Though they supply about 45,335 homes in Moiben Sub-County with domestic water, these open shallow wells are not regularly checked for quality. Increasing numbers of pit latrine constructions very close to the wells, as well as the geological condition of the region, make it a strong necessity to verify the extent of potential contamination and its public health implication.

### **1.3 Purpose of the Study**

The purpose of this study is to evaluate the quality of water obtained from shallow wells in Moiben Sub-County, Uasin Gishu County. Specifically, the study seeks to analyze both microbial and physicochemical parameters of well water in order to determine its safety for domestic use. Given that shallow wells are the primary water source for most households in the area, the study intends to provide evidence on the extent of contamination and its potential risks to human health.

In addition, the study aims to establish the relationship between water quality and the distance of shallow wells from nearby pit latrines. Since a majority of wells in Moiben Sub-County are located less than the recommended safe distance from pit latrines, the findings will be critical in informing public health interventions, guiding policy enforcement on sanitation practices, and raising community awareness on the need for proper water protection and treatment.

## **1.4 Objectives of the Study**

This study aim is to evaluate water quality parameters in shallow wells and their relationship to nearby pit latrines, providing crucial data for public health interventions and water safety management in Moiben Sub-County.

### **1.4.1 General Objective**

To assess the levels of microbial quality and physiochemical parameters of shallow wells Moiben Sub-County, Uasin- Gishu County.

### **1.4.2 Specific Objectives**

The following specific objectives were formulated to achieve the general objective:

- i. To determine the level of microbial contamination in shallow wells in Moiben Sub-County, Uasin Gishu County.
- ii. To determine the physiochemical parameters in shallow wells in Moiben Sub-County, Uasin Gishu County.
- iii. To establish the relationship between shallow well water contamination and the distance of the well from pit- latrines at Moiben Sub-County, Uasin Gishu County.

## **1.5 Research Questions**

- i. What is the level of microbial contamination in shallow wells in Moiben Sub-County, Uasin Gishu County?
- ii. What are the physiochemical parameters in shallow wells in Moiben Sub- County, Uasin Gishu County?
- iii. What is the relationship between shallow well water contamination and the distance of the well from pit- latrines at Moiben Sub-County, Uasin Gishu County?

## **1.6 Justification of the Study**

This study addresses several critical knowledge gaps in understanding shallow well water quality in Moiben Sub-County. While previous studies in Kenya have examined groundwater contamination from waste dump sites and general pit latrine effects, none have specifically investigated the combined impact of physicochemical parameters and microbial quality in relation to well-pit latrine proximity in areas with high water tables like Moiben. Additionally, there is limited understanding of how the unique soil composition and hydrogeological characteristics of Moiben Sub-County influence contaminant transport between pit latrines and shallow wells.

The selection of Moiben Sub-County as the study area is justified by the accessibility and prevalence of shallow wells: The area has numerous shallow wells that serve as primary water sources for domestic use due to the limited coverage of piped water systems. The sub-county presents a combination of residential areas, small-scale farming, and communal spaces, providing an opportunity to study water quality under varied human activity influences. Representative case study: As one of the rapidly developing sub-counties in Uasin Gishu County, Moiben exemplifies the challenges faced by many rural-urban transition areas in Kenya regarding water access and sanitation infrastructure. Limited previous research: While studies have been conducted on water quality in other parts of Uasin Gishu County, there is a notable gap in comprehensive water quality assessment specifically in Moiben Sub-County.

The findings from this study will contribute significantly to developing evidence-based intervention strategies to mitigate fecal contamination in shallow well waters. Informing policy formulation regarding safe distances between wells and pit latrines in areas with high

water tables. Establishing baseline data for long-term monitoring of groundwater quality in similar hydrogeological settings, creating location-specific guidelines for well construction and protection in Moiben Sub-County, Supporting the achievement of SDG 6 objectives at the local level through improved understanding of water quality challenges and solutions

The study's outcomes will benefit both local communities and policymakers by providing scientific evidence for improving water safety practices and informing public health interventions. This research will also establish a methodological framework for assessing shallow well water quality in similar geological settings across Kenya.

### **1.7 Limitations of the Study**

The study faced several constraints that may have influenced the research outcomes such as Seasonal variations where data collection was limited to one season, which may not fully represent annual water quality variations and technical constraints where laboratory analysis was limited to selected parameters due to equipment availability and analytical capabilities.

### **1.8 Assumptions**

The study was carried out under the following assumptions; a) the sampled wells were representative of the general shallow well conditions in Moiben Sub-County b) Household practices regarding well maintenance and pit latrine usage remained consistent during the study period c) Environmental conditions affecting groundwater movement remained stable during the sampling period.

## **CHAPTER TWO: LITERATURE REVIEW**

### **2.0 Introduction**

This chapter captures and evaluates reviewed relevant literature on levels of microbial quality, and physiochemical parameters of shallow wells in relation to their proximity to pit-latrines.

### **2.1 Global Water Quality Perspectives**

#### **2.1.1 Water Quality Determinants**

Water quality is a result of an intricate interaction between natural environmental processes and human action. Geological characteristics, such as rock type and mineral composition, influence water chemistry naturally. Hydrological processes, such as groundwater flow systems and aquifer dynamics, strongly influence contaminant transport (Nourani et al., 2024). Climatic changes influence water sources by altering the precipitation levels, temperature, and evaporation. Additionally, land use patterns ranging from agriculture to urbanization emit various pollutants into water sources. Sanitation facilities play a crucial role in water quality levels, and their lack has a direct impact on water safety.

#### **2.1.2 Contamination Mechanisms**

Groundwater contamination is achieved through several interconnected pathways. Infiltration of sewerage from on-site sanitation systems is a significant pathway of contamination, whereby poorly designed pit latrines and septic tanks allow an opportunity for infiltration of wastes into the groundwater. Surface runoff carries contaminants from agricultural lands, industries, and households, where chemical and biological contaminants are discharged into waters. Poor storage and collection of water can also result in additional contamination, particularly where there is inadequate infrastructure (Ogolla et al., 2020).

Poor well construction and maintenance also have the potential to contaminate by creating direct pathways for contaminants into water (Singh et al., 2022).

### **2.1.3 Health Implications**

Water contamination has various health implications with both short-term and long-term consequences. Acute effects appear in the form of skin diseases and gastrointestinal infections, with direct health implications. Chronic effects involve possible liver injury and neurologic illness, which can arise with long-term exposure to contaminated water (Luvhimbi et al., 2022). The highest risk of exposure exists in less-developed countries where water treatment facilities are lacking, and this forms a vicious cycle of disease that disproportionately targets vulnerable populations. These health risks underscore the critical need for integrated water quality management and proper sanitation.

## **2.2 WHO Guidelines for Drinking Water Quality**

### **2.2.1 Overview of WHO Guidelines**

The World Health Organization (WHO) produced comprehensive guidelines for drinking water quality that have served as the global reference point for drinking water safety standards. The guidelines have the objective of protecting public health through the provision of the scientific basis for national regulation and standards development (WHO, 2022). The guidelines address microbiological, chemical, and physical drinking water quality parameters and operational practices in ensuring the safety of water supplies.

### **2.2.2 Microbiological Parameters**

According to WHO Guidelines for Drinking-water Quality, Fourth Edition (2022), *Escherichia coli* (*E. coli*) or thermotolerant coliforms: Must not be detectable in any 100 mL

sample, Total coliforms: Must not be detectable in any 100 mL sample immediately after disinfection and Heterotrophic plate count: Less than 500 colony-forming units per milliliter

Table 2.1 summarizes the recommended limits for potable water.

**Table 2. 1**

*Microbiological Limits for Portable Water*

<b>S/No.</b>	<b>Type of micro-organism</b>	<b>Potable water</b>	<b>Method of test</b>
i)	Total viable counts at 22 °C, in mL, max.	100	
	Total viable counts at 37 °C, in mL, max	50	ISO 6222
ii)	Total Coliforms in 100 mL	Absent	ISO 4832
iii)	<i>E. coli</i> in 100 mL	Absent	ISO 9308-1
iv)	<i>Staphylococcus aureus</i> in 100 mL	Absent	ISO 6888-1
v)	Sulphite reducing anaerobes in 100 mL	Absent	ISO 6461-2
vi)	<i>Pseudomonas aeruginosa</i> fluorescence in 100 mL	Absent	ISO 16266

vii)	<i>Streptococcus fecalis</i> in 100mL	Absent	ISO 7899-2
viii)	<i>Shigella</i> in 100 mL	absent	ISO 21567
ix)	<i>Salmonella</i> in 100 mL	Absent	ISO 6785

*Source: WHO, 2022*

This parameter is for monitoring the system at source. Total time before analysis should be not more than 6 h at 4 °C. Determination of total viable counts shall start within 12 h after collection of the potable water sample.

During the bacteriological quality control for different types of water supply, refer to Annex A.

### **2.2.3 Chemical parameters**

The WHO has established guideline values for various chemical parameters based on the World Health Organization (2022) guideline version. These includes; pH: 6.5-8.5, Total Dissolved Solids (TDS): Less than 1000 mg/L, Nitrate (NO<sub>3</sub><sup>-</sup>): 50 mg/L (acute exposure), Nitrite (NO<sub>2</sub><sup>-</sup>): 3 mg/L (acute exposure), Ammonia: No health-based guideline value, but can affect taste and odor, Chloride: 250 mg/L, Fluoride: 1.5 mg/L, Iron 0.3 mg/L and Manganese: 0.1 mg/L.

### **2.2.4 Physical parameters**

The guidelines specify physical parameters that affect water quality and acceptability. These includes; Turbidity: Less than 5 NTU, ideally below 1 NTU for effective disinfection, Color: 15 True Color Units (TCU), Electrical Conductivity: Less than 2500 µS/cm at 20°C,

Temperature: No specific guideline value, but should be acceptable to consumers and Taste and Odor: Should be acceptable to consumers

### **2.2.5 Safety distances and protection measures**

The WHO recommends minimum safety distances between water sources and potential contamination sources. These includes; pit latrines in fine soils (clay): minimum 15 meters, Pit latrines in medium soils: minimum 25 meters, pit latrines in coarse soils (sand, gravel): minimum 30 meters and Additional distance may be required based on: local hydrogeological conditions, groundwater flow direction, water table depth and soil permeability.

### **2.2.6 Monitoring requirements**

The WHO emphasizes the importance of regular monitoring. This is done by microbial testing frequency based on population served, more frequent monitoring during: Rainy seasons, Flood events and Disease outbreaks, immediate investigation required when parameters exceed guidelines, verification monitoring to ensure compliance with water quality targets and operational monitoring to ensure control measures are functioning efficiently.

### **2.2.7 Water safety plans**

The WHO promotes a comprehensive risk assessment and risk management approach through Water Safety Plans (WSPs) that include system assessment, operational monitoring, management plans, documentation, validation and verification and regular review and updates. These guidelines provide a framework for ensuring drinking water safety while recognizing that the guidelines must be adapted to local or national environmental, social, economic, and cultural circumstances. The WHO emphasizes that these guidelines should be

used alongside proper sanitation, hygiene practices, and protection of water sources to ensure comprehensive water safety.

## **2.3 Microbial Quality of Water**

### **2.3.1 Total coliforms, fecal coliform and *E. coli***

Total coliforms, fecal coliforms, and *Escherichia coli* are important indicators of water quality and potential contamination by pathogenic microorganisms. These bacteria are used in general for water quality testing to assess the safety of drinking water and the efficiency of wastewater treatment processes (Zarić et al., 2023). Total coliforms are a general group of bacteria found in the soil, water, and on vegetation. Though not all coliforms are pathogenic, the presence of coliform bacteria in water indicates possible routes of contamination that may introduce pathogenic organisms into the water supply (Ogolla et al., 2020).

The presence of total coliforms mostly indicates that further investigation may be necessary to find the source and extent of the contamination. This is according to Hatam (2020). The study noted that, while the total coliforms themselves may not cause diseases, they are useful indicators of the effectiveness of water treatment and distribution system integrity. Fecal coliforms, a subset of total coliforms, are more specific indicators of fecal contamination. These bacteria are found in the intestines of warm-blooded animals, including humans, and their presence in water indicates that the water may be contaminated with pathogens from fecal sources.

Fecal coliforms are better indicators of recent fecal pollution than total coliforms. The close relationship between the rate of fecal coliform detection and the infection rate of the gastrointestinal diseases for communities using grossly contaminated sources was established during a previous study. Kanoti et al. (2019), in their paper, showed that fecal

coliform testing is really important in assessing water bodies for safety in recreational use. They found that increased fecal coliform levels produced increased incidence of gastrointestinal ailments within a population of bathers-a positive correlation which underlined the potential public health hazards from fecal contamination.

*E. coli* is a pathogenic bacterium which can provoke serious diseases such as diarrhea, urinary tract infection, and even kidney failure. In fact, a study by Rath (2021) postulates that *E. coli* testing offers a reliable measure of fecal contamination and the potential health hazards. Their findings in rural India indicated that *E. coli* was commonly detected in drinking water supplies, with high incidences of waterborne diseases within the area. This paper pinpoints the need for regular monitoring and efficient treatment of water supplies to make the water safe to drink.

A wide-ranging study by Rahman et al. (2021) involved the comparison of different water testing methods and arrived at the conclusion that *E. coli* testing plays a vital role in drinking water and recreational water monitoring. They concluded that rapid *E. coli* detection methods could greatly enhance public health protection through faster responses to contamination events. Technological development has advanced the detection and monitoring of these bacterial indicators. Recent innovations in molecular techniques have increased the sensitivity and specificity of water testing. These sophisticated methods are chosen, and it has been documented by Maurya et al. (2020), as giving rapid and accurate detection of coliforms and *E. coli*, hence timely intervention for protection of public health. Most coliform bacteria in water are innocuous; however, the presence of certain bacteria, such as fecal coliforms or *E. coli*, indicates fecal or sewage contamination.

This usually carries pathogenic agents of diseases. Ingestion of these pathogens through water results in waterborne diseases, which are a common cause of illness and death throughout the world (WHO, 2021). Outbreaks of such diseases are commonly linked to the absence of potable water in many developing countries. Diseases such as diarrhea are mainly caused by unsafe water, inadequate sanitation, and poor hygiene practices both at personal and community levels, especially where there is a common source of water supply. Policy and regulatory frameworks ensure the safety of water through monitoring coliforms and *E. coli*. The WHO has, in 2022, set guidelines and standards for acceptable levels of these bacteria in drinking water and recreational waters. These regulations are based on extensive research and aim to minimize the risks of waterborne diseases. Compliance with these standards requires regular testing, proper maintenance of water treatment and distribution systems, and effective management of wastewater and stormwater. Kanoti et al., (2019), showed that 85% of the borehole water samples were contaminated with both fecal coliforms and total coliforms in Kisumu. The occurrence of microbial contaminants, inclusive of pathogenic bacteria, relates to some variables such as drilling practices, maintenance, proximity to sanitary facilities, and the handling and storage of water.

#### **2.4 Physicochemical Parameters**

The physicochemical parameters are very important for determining the quality and safety of water regarding human consumption. These parameters of pH, TDS, electrical conductivity, turbidity, and nitrogen compounds are included in some very important indicators of water quality and contamination. Such understanding is indispensable for effective water management and public health protection.

The pH is a basic parameter controlling the course of many chemical and biological processes in water. According to Saalidong et al. (2022), pH in the range from 6.5 to 8.5 provides conditions of water that can be safe and efficiently consumed in agriculture and industries. Any deviations can facilitate heavy metal mobility, changes in solubility and bioavailability in aquatic ecosystems, thus being capable of harming either human health or even aquatic organisms themselves.

Total Dissolved Solids, or TDS, is the sum of inorganic and organic substances in water, which are mainly of natural mineral origin but may be affected by agricultural runoff and industrial discharges. In their research, Jiang et al. (2021) illustrated that TDS, if at a higher concentration, seriously degrades the quality of water regarding its taste, hardness, and possibly leading to kidney stone disease and cardiovascular diseases if continuously consumed over time. High levels of TDS in industries can cause scaling in boilers and cooling towers, reducing their efficiency.

Electrical conductivity is a very important parameter of water quality, especially in agricultural applications. Batarseh et al. (2021) indicated that the measurement of EC is an important component of irrigation water quality monitoring, since high values of EC lead to soil degradation and poor agricultural productivity. Their study focused on the regular monitoring of EC in order to prevent soil salinization and provide ideal conditions for crops.

Turbidity or water clarity has been an issue not only in the water treatment processes but also in the aspect of public health. The research by Garay et al. (2021) presented that high turbidity levels may protect the pathogens from disinfection and result in high public health risks. It can affect aquatic life because increased turbidity would decrease the amount of light entering the water body, impacting the photosynthesis process.

Nitrogenous compounds, notably nitrates, nitrites, and ammonia are also important predictors of contamination. In most situations these are characterized by intensive agriculture. Lee et al. (2020) comments that, nitrate concentration values higher than those recommended by WHO, that is above 50 mg/L are likely to cause harm to general health. According to Bradley et al. (2023), nitrite contamination is much greater in wells owned by individuals that are sited in country parts that lack specific installations for the purification of water. Cui et al. (2022) indicated that increased agricultural activities and inefficient treatment of wastewater have contributed to higher levels of ammonia in water bodies and called for better management strategies. This forms a complex web of the dynamics of water quality parameters. Tsaridou and Karabelas (2021) noted that satisfactory water quality management will involve an integrated approach considering such interrelatedness of the parameters. Their study showed that one parameter changing often has a cascading effect on others, and thus requires a holistic approach in monitoring and management. This is very important to know in a wide variety of contexts, from ensuring drinking water supplies are safe to providing water of appropriate quality for agriculture and industry.

## **2.5 Well-Latrine Distance Relationships**

The spatial relationship between water sources and sanitation facilities is an important factor in ensuring safe drinking water, especially for communities using groundwater. According to the World Health Organization, the distance between wells and any potential sources of contamination should be adequate to safeguard public health (WHO, 2024). Understanding these relationships is crucial for developing effective water safety guidelines and preventing waterborne diseases.

At a broader scale, the risk of contamination from pit latrines to groundwater sources is determined by various environmental and geological factors. Zhan et al. (2023) asserted that local hydrogeological conditions, soil composition, and seasonal changes determine the transport of contaminants through soil layers. Their study indicated that general distance recommendations cannot take into consideration these site-specific factors and, therefore, a more specific approach to well placement is required.

According to Gwenzi et al. (2023), studies have found that pit latrines within a 10-meter radius from shallow wells can easily contaminate the supply with fecal coliforms like *E. coli*. This proximity provides a very easy path for the pathogens in human waste into the drinking water, increasing the risk of gastrointestinal diseases immensely. Rajkopal and Athukorala (2022), have supported this by indicating that a minimum distance of 30 meters can considerably reduce the incidence of microbial contamination.

Chemical contamination patterns also relate well with the distances between wells and latrines. As Kiptum et al. (2015) stated, "nitrate levels were significantly higher in wells within 15 m from pit latrines", posing health risks such as methemoglobinemia in infants to the consumers than wells located farther away. Other findings by Kanouo et al. (2023) have corroborated this assertion and added that the pit latrines increase nitrate levels in groundwater.

Local conditions are a very important determinant of safe separation distances. Indeed, Knee et al. (2021) in Mozambique showed that high rainfall and permeable soils were able to move contaminants far beyond the generally recommended distances. In Kenya, Tran et al. (2020) reported that during the rainy season, contaminants from latrines were affecting wells as far away as 50 meters.

Socioeconomic aspects play a highly influential role in safe separation distances. Agyemang (2023) further reiterated that lack of awareness and economic reasons most often made the people construct the pit latrine perilously closer to the water body. This fact was again corroborated by Jubayer et al. (2023), who recommended community education and involvement to increase their knowledge about risks associated with contamination and adherence to safe practices.

In situations where observing strict safe distances is difficult, technological innovations and policy interventions offer potential solutions. According to the WHO (2021), leaching is avoided by the construction of improved latrines with lined pits. In addition, a study by Tran et al. (2020) confirmed that lined pit latrines and other improved sanitation technologies reduce the movement of contaminants into groundwater.

The Ministry of Public Health, Kenya, recommends a minimum separation distance of 30 meters between wells and pit latrines or septic tanks. However, Molapo (2021) observed that the transport of microbes from pit latrine wastes into groundwater is strongly linked with local hydrological and soil conditions. This, therefore, calls for an alarm in areas where pit latrines are the primary means of disposing of human waste, like Moiben sub-county.

These findings collectively underscore that approaches for determining safe distances between wells and latrines need to be specific to context, taking into consideration local geological, environmental, and social conditions. The application of such guidelines involves technical understanding, community engagement, and appropriate policy frameworks for effective protection of groundwater resources.

## **2.6 Knowledge Gaps**

Regardless of the much research into the quality of water and its contamination, there are still some significant gaps in knowledge concerning the complex relations existing among shallow wells, pit latrines, and various parameters of water quality. Further research is called for to improve present understanding and pave the way for better management of water.

In this regard, there is a critical knowledge gap regarding the seasonal variability of the contamination patterns observed in shallow wells. Although research studies by Olonga et al. (2015) and Onyango et al. (2018) identified higher levels of contamination during rainy seasons, the exact mechanisms and magnitudes of the seasonal influence on the individual contaminants are poorly understood. This knowledge gap is exceptionally high for regional sectors with different geological and climatic settings, where seasonal patterns could be considerably different from those described in literature.

The effects of emerging contaminants on water quality and public health are mostly long-term and not well documented. According to Taonameso et al. (2019), shallow wells with existing pharmaceuticals and personal care products introduce a new dimension into the already precarious situation, but very few comprehensive studies on their long-term impact and behavior in groundwater systems have not been conducted. This becomes increasingly significant with the rise of new types of contaminants due to urbanization and modern lifestyles.

The relationship between pit latrine design and the contamination of groundwater requires further research. While Gwenzi et al. (2023) established associations between proximity of pit latrines and levels of contamination, how different designs, construction materials, and maintenance practices affect patterns of contamination remains poorly understood. This will

be important in formulating efficient guidelines on sanitation infrastructure for shallow wells-dependent areas.

There is scant literature on the efficiency of community-based strategies for water management in the prevention of well contamination. Although water management projects that were unsuccessful due to inadequate community involvement have been documented Ombogoh et al (2022), and Kirori et al. (2022), comprehensive studies concerning successful community-driven initiatives and their long-term sustainability remain scant. This gap inhibits the development of effective, culturally appropriate solutions regarding water management.

Another important gap in knowledge has to do with the interplays of many contamination sources and their cumulative impacts on the quality of the water. Studies have explored some of the various sources through which contamination occurs, specifically Kiptum et al. (2015) and Leiter et al. (2013). However, they highlight that an effect brought about by combined sources of contamination with resultant synergism for water and health quality are not understood, with such understanding being pertinent towards the full scope of devising water protection strategies.

Besides, few studies have been done regarding the cost-effectiveness of various protection strategies for shallow wells. While WHO and UN (2021) recommend different types of protective measures, few detailed economic analyses have been done comparing options in various contexts. The absence of this information has implications for decision-making, especially in situations where resources are very limited.

While Corona et al. (2020) mentioned the influence of changing precipitation patterns on water quality, few studies have particularly addressed exactly how climate change could

influence mechanisms and patterns of groundwater contamination. This is very important in order to inform adaptive management at future scenarios.

These knowledge gaps further highlight that research efforts should be continued with the view to improving our understanding of the issues involved with water quality and, hence, management. These gaps need to be addressed through systematic research in order to improve water safety and public health, especially in communities' dependent upon shallow wells for their water supply.

## **2.7 Theoretical Framework**

The research is based on the theoretical underpinning of the Health Belief Model and Environmental Health Theory, which have given foundational understanding to analyzing issues related to water quality and impacts on public health. The Health Belief Model, first developed by social psychologists Hochbaum, Rosenstock, and Kegels in the 1950s, posits that peoples' beliefs about health problems, perceived benefits of action and barriers to action, and self-efficacy explain engagement or lack of engagement in health-promoting behavior (Green et al., 2020). In the context of shallow well water quality, HBM helps to explain how the communities perceive risks of contaminated water and their likelihood to adopt protective measures.

Environmental Health Theory adds to the HBM by focusing on the relationship between environmental factors and human health consequences. This theory postulates that environmental conditions, such as water quality and sanitation infrastructure, directly determine public health outcomes in a given environment (Motsinger-Reif et al., 2024). This theory helps explain how the proximity of pit latrines to water sources, coupled with various physicochemical parameters, creates environmental conditions that affect community health

in the case of shallow wells in Moiben Sub-County. The theory emphasizes the interconnectedness of environmental factors, and it is of particular relevance for understanding how various contaminants in well water interact and impact human health.

Both theories thus support the study of microbial contamination and physicochemical parameters in shallow wells. They offer a framework for analyzing how environmental conditions-distance from pit latrines, soil characteristics, and groundwater flow-combine with human behavior-well maintenance, water treatment practices, and sanitation habits-to affect water quality and, consequently, public health outcomes.

## **2.8 Conceptual Framework**

The conceptual framework in this study is intended to summarize how different factors interrelate to influence shallow well water quality within Moiben Sub-County. Its center identifies three key components: the sources of contamination, the mediating factors, and the resulting quality of the water. Major contamination sources are usually in pit latrines, surface runoff, and agriculture. The microbial and physicochemical quality attributes have contaminated total coliforms, fecal coliforms, and *E. coli*, with modifications in the well-water parameters, which are pH, electrical conductivity, total dissolved solids, turbidity, ammonia, nitrates, and nitrites to various extents, according to Abanyie et al., (2023).

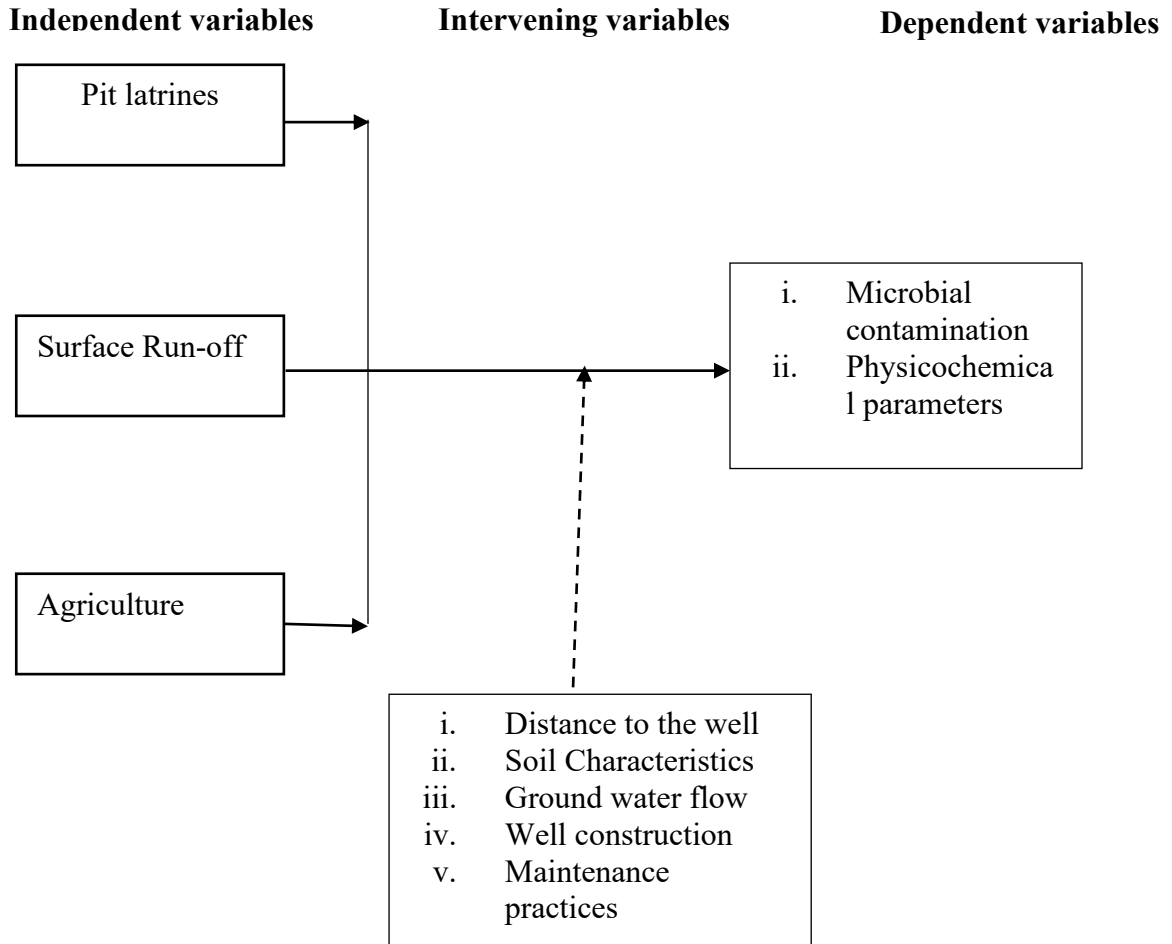
The mediating factors in the framework include distance between wells and pit latrines, soil characteristics, groundwater flow patterns, well construction methods, and maintenance practices. These act either to amplify or dampen the influence of the contamination sources on water quality. The framework realizes that the mediating factors do not exist independently but interact among themselves to affect the final resulting water quality outcomes.

The dependent variable in this framework is water quality outcomes, characterized by microbial contamination levels and physicochemical parameters. Contamination sources within this framework would directly have an effect on the aforementioned outcomes, while the modified factors act as mediators. It also recognizes that these particular outcomes relate to the public health, with possible waterborne diseases and other health impacts to the community.

This conceptual framework guides the study by highlighting the key variables to be measured and the relationships to be examined. It suggests that for effective water quality management, attention needs to be paid both to sources of contamination and mediating factors, while cognizant that these elements are interconnected within the greater environmental and social system of Moiben Sub-County. The framework places strong emphasis on the measurement of both microbial and physicochemical parameters to understand the outcomes of water quality. This is summarized in figure 2.1 below.

**Figure 2. 1**

*A Summary of Sources of Contaminants, Mediating Factors and Water Quality Outcomes*



*Source: researcher, (2024)*

## CHAPTER THREE: METHODOLOGY

### 3.0 Introduction

The following section describes how empirical data was obtained through experiments on microbial and physicochemical analysis of shallow well water obtained from named sites. The sample selection, collection, analysis, data analysis, reliability and validity, and ethical issues are discussed.

### 3.1 Study Design

The research design employed is a quasi-experimental involving laboratory experiments. Additionally, an observational method was implemented to determine the distance of boreholes from latrines. This was achieved by cross-referencing information with a checklist detailed

### 3.2 Study Area

The analysis samples were collected from Moiben sub-county in Uasin Gishu County. Moiben Constituency is divided into the following Wards: Moiben Ward, Sergoit Ward, Kimumu Ward, Tembelio ward and Karuna ward in the month of May. Moiben Sub-County covers a total land area of 769.8 Km<sup>2</sup>. It is about 330 km North West of Nairobi in Kenya. The Centre lies on latitude 0° 35' 20" N and longitude 35° 18' 21"E. The population of Moiben Sub- County was 181,338 persons and 45,335 households (KNBS, 2019).

### 3.3 Sampling Technique and Sample Size

A stratified sampling technique was used where sixty-two shallow wells were proportionately sampled from the five zones. This enabled analysis of fecal coliforms, *E. coli*, Total coliforms, pH; TDS, Electrical conductivity, turbidity nitrates, nitrites, and Ammonia. Simple random sampling was used to determine the shallow wells which were

sampled at the ward level. Further, lateral distance from the shallow wells to pit latrines was also established.

Table 3.1 indicates the number of households per ward and the number of sampled wells in each ward in Moiben sub-county

**Table 3. 1**

*Sampling Frame*

<b>Ward</b>	<b>No. of Households</b>	<b>Sampled wells</b>
Kimumu	15344	21
Moiben	10445	14
Sergoit	8103	11
Karuna	3374	4
Tembelio	8079	12
Total	45335	62

*(Source: KNBS, 2019).*

To determine an appropriate sample size that would be representative of the shallow wells used by these households, the Cochran formula was employed. This formula is particularly suitable when dealing with large populations and when seeking to achieve a specific level of precision.

The Cochran formula was applied as follows:

$$n = \frac{z^2 \times p(1-p)}{e^2} \quad (3.1)$$

Where;

$z^2$ = Test power for the level of confidence (95%)

n=sample size

p= expected proportion (0.2) (prevalence)

e= precision as 0.1

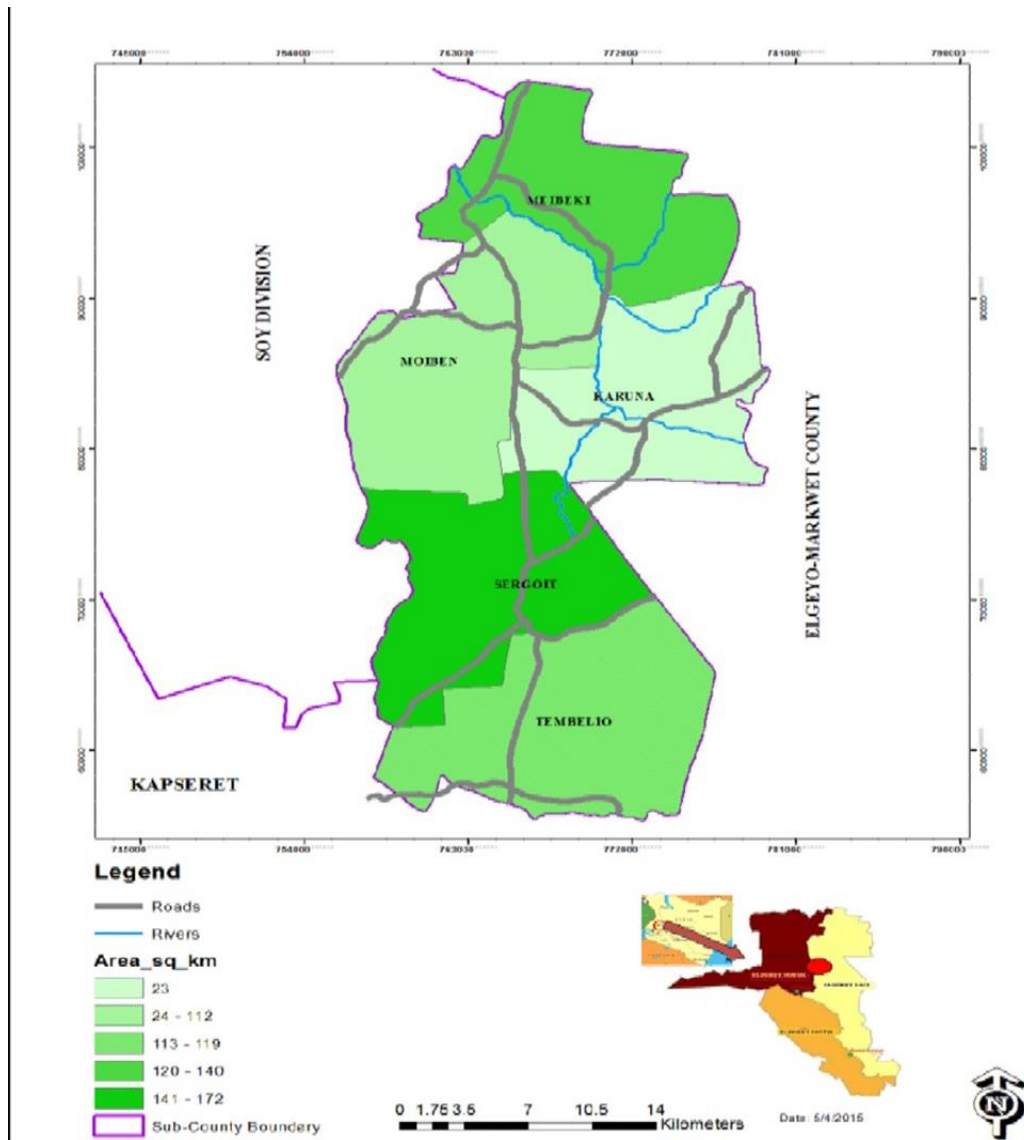
$$n = \frac{1.96 \times 1.96 \times 0.2(1-0.2)}{0.1 \times 0.1}$$

Sample size = 62 samples

The sample size of 62 shallow wells was determined to be adequate based on several key factors. First, the selected sample size provides a 95% confidence level, ensuring that the results represent the true population parameters with statistical reliability. Additionally, the precision level of 0.1 establishes an acceptable margin of error for water quality studies, aligning with standard research practices in environmental science. The expected proportion of 0.2 was strategically chosen based on previous studies conducted in similar geographical and demographic settings, providing a solid empirical foundation for the sampling approach. Furthermore, this sample size effectively accounts for the heterogeneous nature of well conditions observed across the different wards in the sub-county, ensuring comprehensive representation of varying environmental conditions and water quality characteristics.

**Figure 3. 1**

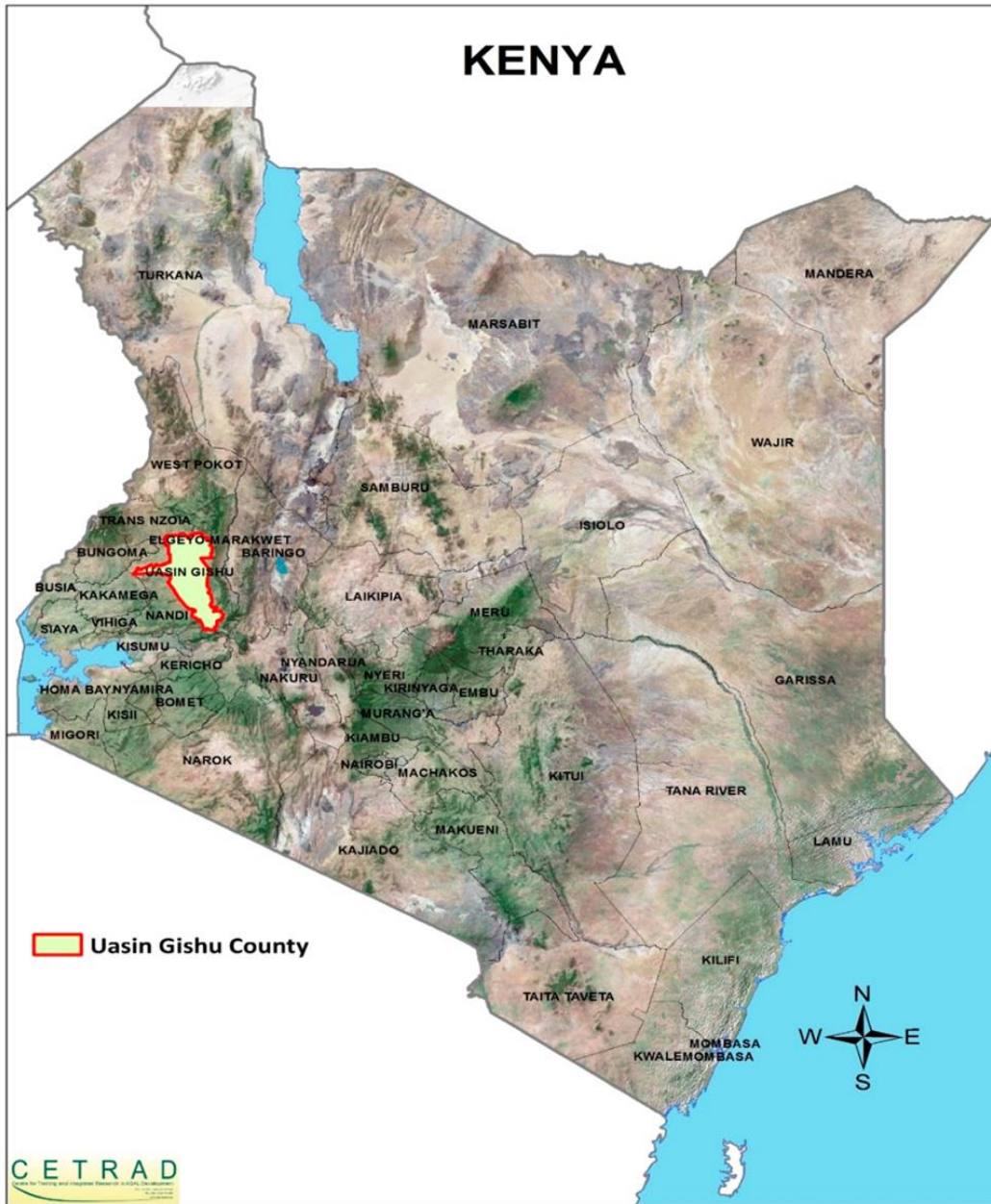
*Map of Moiben Sub-County*



*Source: City population .Kenya, 2024*

**Figure 3. 2**

*Map of Kenya*



*Source: Amazon.com, 2024*

### **3.4 Inclusion Criteria**

All shallow wells, which were being utilized, were sampled.

### **3.5 Exclusion Criteria**

Not all shallow wells, which were not being utilized, were sampled.

### **3.6 Data Collection**

The analysis included methods such as the most probable number (MPN), biochemical tests to detect *Escherichia coli*, total coliforms, and Fecal Coliform and physiochemical parameters to test for Nitrates, nitrites, ammonia, pH, turbidity and Electrical conductivity. Additionally, an observation method was utilized to determine the proximity of boreholes to latrines. This was done by verifying information from a checklist following the methodology outlined by Ribeiro (2020).

#### **3.6.1 Shallow wells water sample collection**

Water samples were collected using sterile 500 ml bottles, submerged to fill with the sample water. The bottles were labeled, capped, and stored in an ice-cold box until analysis, following Cui et al. (2022) guidelines.

#### **3.6.2 Determination of coliforms in water using the multiple tube technique**

The presumptive test began by inoculating water samples into tubes containing MacConkey broth. For media preparation, single strength MacConkey broth was made by dissolving 40g of MacConkey powder in 1000 ml distilled water, sterilized at 121°C for 15 minutes, and double strength was prepared with 80g in 1000 ml. After inoculation, the broth was incubated at 37°C for 24 hours, and gas production in Durham tubes confirmed the presence of coliforms, allowing the estimation of MPN as per the procedure in Figure 4.1.

### **3.6.3 Confirmatory test - fecal coliform test**

A 40g amount of Brilliant Green Bile Lactose Broth was dissolved in 1000 ml distilled water, sterilized at 121°C for 15 minutes, and used to inoculate cultures from the presumptive test. The culture was incubated at 44°C for 24 hours, and gas production confirmed fecal coliforms. The results were used to estimate MPN values of fecal coliforms as shown in Figure 4.1.

### **3.6.4 *E. coli* test**

Buffered peptone water was prepared by dissolving 10g in 500 ml distilled water and sterilizing it at 121°C for 15 minutes. A positive presumptive culture (10 ml) was transferred to peptone water, incubated at 44°C for 24 hours, and tested for *E. coli* by adding Kovac's reagent. Indole production, indicated by a red color, confirmed the presence of *E. coli*.

### **3.6.5 pH determination in water (electrometric method)**

A pH buffer tablet was dissolved in 100 ml distilled water to make a solution with a pH of 6.8 at 20°C. The Hach ion-selective meter was calibrated using buffers of pH 4, 7, and 10. The probe was rinsed between samples, and the pH and temperature of the sample were recorded.

### **3.6.6 Total dissolved solids (TDS) and electrical conductivity determination**

#### **(Electrometric Method)**

A 0.0005 mol/l concentration of potassium chloride (KCl) was prepared, with a conductivity of 74  $\mu\text{S}/\text{cm}$  at 25°C. The conductivity meter was calibrated with this solution, and after rinsing the probe, samples were tested. Conductivity and TDS readings were recorded directly from the meter.

### **3.6.7 Turbidity determination by absorptiometric method**

Formazin standards with turbidity values of 1000 NTU, 200 NTU, and 20 NTU were prepared. The turbidimeter was calibrated, and 15 ml of water samples were tested by inserting the sample cell into the turbidimeter and recording the turbidity value.

### **3.6.8 Ammonia Determination by Spectrophotometric Method (Salicylate Method)**

Calibration standards were prepared using a 10 mg/L ammonia solution. After adding ammonia salicylate reagent to 10 ml of sample, color change indicated ammonia presence. Absorbance was measured, and ammonia concentration was calculated using a calibration curve.

### **3.6.9 Nitrate and nitrite determination by spectrophotometric methods**

For nitrate-nitrogen, calibration standards were prepared and a nitrate reagent was added to the sample, followed by absorbance measurement. For nitrite, standards were prepared and analyzed using the diazotization method, with absorbance readings indicating nitrite concentration.

## **3.7 Quality Control Measures**

The following quality control measures were implemented across all analytical procedures to ensure data reliability and accuracy:

### **3.7.1 Physicochemical parameters**

These parameters include; pH Analysis where pH buffer of 6.86 was tested as the Hach ion selective meter was calibrated with buffer pH 4 and 7, achieving 96% recovery at test temperature, TDS and electrical conductivity where analysis of 50mg/L TDS using sodium chloride salt was conducted alongside samples with 96% recovery of the 74 uS/cm standard. Electrical Conductivity quality control achieved 95% recovery using 74uS/cm standard.

Standard formazin with 50 NTU was analyzed alongside samples, achieving 95% recovery on turbidity. Ammonia: Distilled water (blank) was used to zero the equipment, and standards were analyzed alongside samples, Nitrate-nitrogen: Distilled water blank was used to zero equipment, and 5mg/L NO<sub>3</sub>-N standard solution was analyzed with samples, Nitrite: Distilled water blank was used for equipment calibration, and 0.13mg/L NO<sub>2</sub>-N standard solution was analyzed alongside samples.

### **3.7.2 Microbiological parameters**

Sterile equipment and media were used throughout the analysis, reference cultures were maintained for quality control, positive and negative controls were included in each batch of analysis, all media were prepared according to manufacturer specifications and sterility checked and duplicate analyses were performed for verification of results

### **3.8 Data Analysis**

Microsoft Excel and Statistical Package for Social Sciences (SPSS) version 25 were used to analyze quantitative data both descriptively and inferentially. Descriptive statistics including means, standard deviations, frequencies, and percentages were calculated to summarize the water quality parameters. For inferential analysis, multiple linear regression models were employed to examine the relationships between the dependent variables (microbial contamination indicators) and independent variables (physicochemical parameters and well characteristics).

The general form of the multiple linear regression model used was:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \dots + \beta_n X_n + \varepsilon \quad (3.2)$$

Where:

Y = Dependent variable (Total coliforms, Fecal coliforms, or *E. coli* counts)

$\beta_0$  = Intercept (constant)

$\beta_1, \beta_2, \beta_3, \dots, \beta_n$  = Regression coefficients

$X_1, X_2, X_3, \dots, X_n$  = Independent variables (pH, TDS, EC, turbidity, nitrates, nitrites, ammonia, and distance from latrines)

$\varepsilon$  = Error term

The statistical analysis performed include; a) Tests for regression assumptions including normality, multi-collinearity, and homoscedasticity. b) Correlation analysis to assess relationships between variables. c) ANOVA to test the overall significance of the regression models. d) R-squared values to determine the model's explanatory power and P-values to test the significance of individual predictor variables ( $\alpha = 0.05$ )

Results were presented using tables, scatter plots, and charts to visualize relationships between variables and demonstrate trends in the data. The regression analysis helped identify which physicochemical parameters were significant predictors of microbial contamination in the shallow wells.

### **3.9 Ethical Considerations**

An introductory letter from Meru University of Science and Technology MIRERC (Meru University Institutional Research and Ethics Review Committee) was issued, which was submitted to NACOSTI for ethical approval. NACOSTI License issued (ref. No. 890401). Also consent to conduct the study was sought from the National Environment Management Authority (NEMA) that carries surveys on matters concerning the environment. The residents of Moiben sub-county in Uasin Gishu County were accorded utmost respect and confidentiality during the study period. The organisms isolated were deactivated before release to the environment.

Any data regarding that resident's personal or private lives was kept confidential. The residents of Moiben were given the assurance that no personally identifiable information about them was to be disclosed in any format.

## **CHAPTER FOUR: RESULTS**

### **4.0 Introduction**

This chapter presents the findings of the study based on the objectives of the study. Specifically, the section presents findings on microbial analysis of water samples, analysis of physiochemical parameters and relationship between well water contamination and the distance of the wells from pit- latrines. The data was also subjected to inferential analysis by use of Analysis of Variance (ANOVA) where the regression coefficients were generated.

### **4.1 Microbial Analysis of Water samples**

This section presents the first objective, which is to establish the level of microbial contamination in the shallow wells of Moiben Sub-County. Microbial indicators analyzed include Total Coliform and *E. coli*. These give insights into the prevalence of microbial pollution in the sampled wells and pinpoint the potential risks to public health.

Figure 4. 1

Most Probable Number Count Reference Ranges

MULTIPLE-TUBE FERMENTATION TECHNIQUE (9221)/Estimation of Bacterial Density

TABLE 9221-IV. MPN INDEX AND 95% CONFIDENCE LIMITS FOR VARIOUS COMBINATIONS OF POSITIVE RESULTS WHEN FIVE TUBES ARE USED PER DILUTION (10 mL, 1.0 mL, 0.1 mL)\*

9-71

Combination of Positives	MPN Index/100 mL	Confidence Limits		Combination of Positives	MPN Index/100 mL	Confidence Limits	
		Low	High			Low	High
0-0-0	<1.8	—	6.8	4-0-3	25	9.8	70
0-0-1	1.8	0.090	6.8	4-1-0	17	6.0	40
0-1-0	1.8	0.090	6.9	4-1-1	21	6.8	42
0-1-1	3.6	0.70	10	4-1-2	26	9.8	70
0-2-0	3.7	0.70	10	4-1-3	31	10	70
0-2-1	5.5	1.8	15	4-2-0	22	6.8	50
0-3-0	5.6	1.8	15	4-2-1	26	9.8	70
1-0-0	2.0	0.10	10	4-2-2	32	10	70
1-0-1	4.0	0.70	10	4-2-3	38	14	100
1-0-2	4.0	1.8	15	4-3-0	27	9.9	70
1-1-0	6.1	0.71	12	4-3-1	33	10	70
1-1-1	8.1	1.8	15	4-3-2	39	14	100
1-1-2	6.1	3.4	22	4-4-0	34	14	100
1-2-0	8.2	1.8	15	4-4-1	40	14	100
1-2-1	6.1	3.4	22	4-4-2	47	15	120
1-3-0	8.3	3.4	22	4-5-0	41	14	100
1-3-1	10	3.5	22	4-5-1	48	15	120
1-4-0	10	3.5	22	5-0-0	23	6.8	70
2-0-0	4.5	0.79	15	5-0-1	31	10	70
2-0-1	6.8	1.8	15	5-0-2	43	14	100
2-0-2	9.1	3.4	22	5-0-3	58	22	150
2-1-0	6.8	1.8	17	5-1-0	33	10	100
2-1-1	9.2	3.4	22	5-1-1	46	14	120
2-1-2	12	4.1	26	5-1-2	63	22	150
2-2-0	9.3	3.4	22	5-1-3	84	34	220
2-2-1	12	4.1	26	5-2-0	49	15	150
2-2-2	14	5.9	36	5-2-1	70	22	170
2-3-0	12	4.1	26	5-2-2	120	34	230
2-3-1	14	5.9	36	5-2-3	150	58	400
2-4-0	15	5.9	36	5-2-4	94	34	230
3-0-0	7.8	2.1	22	5-3-0	79	22	220
3-0-1	11	3.5	23	5-3-1	110	34	250
3-0-2	13	5.6	35	5-3-2	140	52	400
3-1-0	11	3.5	26	5-3-3	170	70	400
3-1-1	14	5.6	36	5-3-4	210	70	400
3-1-2	17	6.0	36	5-4-0	130	36	400
3-2-0	14	5.7	36	5-4-1	170	58	400
3-2-1	17	6.8	40	5-4-2	220	70	440
3-2-2	17	6.8	40	5-4-3	280	100	710
3-3-0	20	6.8	40	5-4-4	350	100	710
3-3-1	17	6.8	40	5-4-5	430	150	1100
3-3-2	21	9.8	70	5-5-0	240	70	710
3-4-0	24	6.8	40	5-5-1	350	100	1100
3-4-1	21	9.8	70	5-5-2	540	150	1700
3-5-0	24	9.8	70	5-5-3	920	220	2600
4-0-0	25	4.1	35	5-5-4	1600	400	4600
4-0-1	13	5.9	36	5-5-5	>1600	700	—
4-0-2	17	6.8	40				
	21						

\* Results to two significant figures.

where:

- $j$  = a dilution,
- $s$  = the highest dilution with at least one positive tube,
- $x_s$  = the number of positive tubes in the  $s$ th dilution,
- $n_j$  = the number of tubes in the  $j$ th dilution,
- $v_j$  = the amount of the original sample inoculated into each tube in the  $j$ th dilution,

$z_s$  = the amount of the original sample inoculated into each tube of the  $s$ th dilution, and

$K$  = the number of dilutions.

For example, in the series x-x-3-0-0, where the third dilution level ( $z_3$ ) equals 0.1 mL,  $x_3 z_3 = 0.3$ , and  $\sum n_j v_j = 0.555$ . Thus, the calculated MPN = 7800/100 mL.

Source: (Lipps et al.,2023)

The figure 4.1 is a Most Probable Number Probability Table. It serves as the calibration table for determining the MPN counts.

Table 4.1 indicates the distances of the wells from pit latrines and the most probable number of total coliforms, fecal coliforms and *Escherichia coli*.

**Table 4. 1***Total Coliforms, Fecal Coliforms and Escherichia coli*

Well no.	Distance of the pit latrines from well (metres)	Most probable number		
		Total coliform	Fecal Coliform	<i>E. coli</i>
		mg/L	mg/L	mg/L
Well 1	86	40	22	26
Well 2	16	1600	1600	1600
Well 3	14	1600	1600	1600
Well 4	32	920	920	540
Well 5	22	1600	1600	1600
Well 6	17	1600	1600	1600
Well 7	31	920	1600	920
Well 8	49	540	540	920
Well 9	55	170	240	220
Well 10	37	920	920	920
Well 11	44	540	540	350
Well 12	30	920	920	540
Well 13	35	920	920	920
Well 14	41	540	350	540
Well 15	31	920	920	920
Well 16	25	1600	1600	1600
Well 17	16	1600	1600	1600

Well no.	Distance of the pit latrines from well (metres)	Most probable number		
		Total coliform	Fecal Coliform	<i>E. coli</i>
		mg/L	mg/L	mg/L
Well 18	18	1600	920	1600
Well 19	20	920	920	1600
Well 20	30	920	920	540
Well 21	70	22	23	26
Well 22	65	70	79	94
Well 23	14	1600	1600	1600
Well 24	10	1600	1600	1600
Well 25	15	1600	1600	1600
Well 26	50	140	170	220
Well 27	32	540	920	540
Well 28	28	920	920	540
Well 29	33	920	350	350
Well 30	36	350	430	430
Well 31	21	1600	920	540
Well 32	11	1600	1600	1600
Well 33	10	1600	1600	1600
Well 34	22	920	1600	1600
Well 35	11	1600	920	1600
Well 36	39	430	350	240

Well no.	Distance of the pit latrines from well (metres)	Most probable number		
		Total coliform	Fecal Coliform	<i>E. coli</i>
		mg/L	mg/L	mg/L
Well 37	48	210	140	210
Well 38	67	70	79	110
Well 39	48	140	210	210
Well 40	17	1600	920	540
Well 41	13	1600	1600	1600
Well 42	15	920	1600	1600
Well 43	24	920	540	920
Well 44	35	350	220	540
Well 45	43	350	280	220
Well 46	74	33	70	40
Well 47	37	540	350	540
Well 48	31	140	140	140
Well 49	72	43	40	33
Well 50	62	58	49	70
Well 51	53	170	110	140
Well 52	31	540	350	540
Well 53	40	350	210	280
Well 54	47	350	280	350
Well 55	16	1600	1600	1600

Well no.	Distance of the pit latrines from well (metres)	Most probable number		
		Total coliform	Fecal Coliform	<i>E. coli</i>
		mg/L	mg/L	mg/L
Well 56	13	1600	920	1600
Well 57	33	540	540	540
Well 58	30	920	540	920
Well 59	43	540	350	280
Well 60	15	1600	1600	920
Well 61	42	220	210	350
Well 62	46	350	350	540

*Source: Researcher, 2024*

Table 4.1 presents the results for microbial contamination of well for the 62 samples. The results are shown here as the most probable number of MPN of the total coliforms, fecal coliforms, and *E. coli* in one milliliter of water from each well and are highly differing. Most cases exhibited a very high degree of contamination compared to NEMA-recommended values for safe drinking water.

Water samples were analyzed within 24 hours of sampling for total coliforms, Fecal Coliforms and *E. coli* by the Most Probable method. The outcome indicates the wells were highly contaminated with Total coliforms, Fecal Coliform and *E. coli* with the levels of total coliforms well above the NEMA recommended values of 0MPN/100ml

#### 4.1.1 Total Coliforms

The test aimed to assess the contamination levels of well water using. All the samples formed gas as shown in figure 4.2 and results analyzed using MPN probability table in Figure 4.1.

**Figure 4. 2**

*Samples Showing Presence of Gas*



*Source: Researcher, 2024*

The tubes that produced gases were counted in each group after incubation with MacConkey broth for 24hrs were analyzed using the Most Probable Number (MPN) table. The World Health Organization (WHO) and National Environmental Management Authority (NEMA) standard guidelines stipulate that potable water should contain 0 MPN/100 ml. However, the total coliform in the tested samples ranged from 33 MPN/100ml to 1600 MPN/100 ml. /100 ml. The detailed results for the Most Probable Number. This is evident in the results tabulated in table 4.1.

#### 4.1.2 Fecal coliforms

A small volume of the culture from the presumptive test which was transferred to bottles containing brilliant green bile lactose broth as soon as gas formation was observed. This was incubated for 24 hours at 44 °C-produced gas as shown below in figure 4.3.

**Figure 4. 3**

*Incubation of Samples for 24 Hours at 44°C*



*Source: Researcher, 2024*

The presence of gas indicates a positive test for fecal coliforms. The test results revealed significant contamination in the well water samples. The total coliform counts ranged from 22MPN/100ml to over 1600MPN/100ml.

#### **Figure 4. 4**

*Gas Presence After Incubation of the Positive Samples with Brilliant Green Bile Lactose Broth*



*Source: Researcher, 2024*

The presence of fecal coliforms in well water is a critical indicator of water quality and potential health risks. The high levels of coliforms detected in this study, with some samples exceeding 1600MPN/100 ml, far surpass the WHO and NEMA guidelines for safe drinking water, which stipulate 0 MPN/100 ml (WHO, 2022)

#### **4.1.3 *E. coli***

The tubes that were positive in presumptive test were inoculated in peptone water. This was to test for the presence of *E. coli* and incubated for 24hrs at 44° C as shown in Figure 4.3.

After the incubation period, a confirmatory test was done using Kovac's Reagent and tested positive as shown in figure 4.4 above by formation of red colour in the upper layer.

**Figure 4. 5**

*Indole Production Confirming Presence of E. coli*



*Source: Researcher, 2024*

## **4.2 Analysis of Physicochemical Parameters**

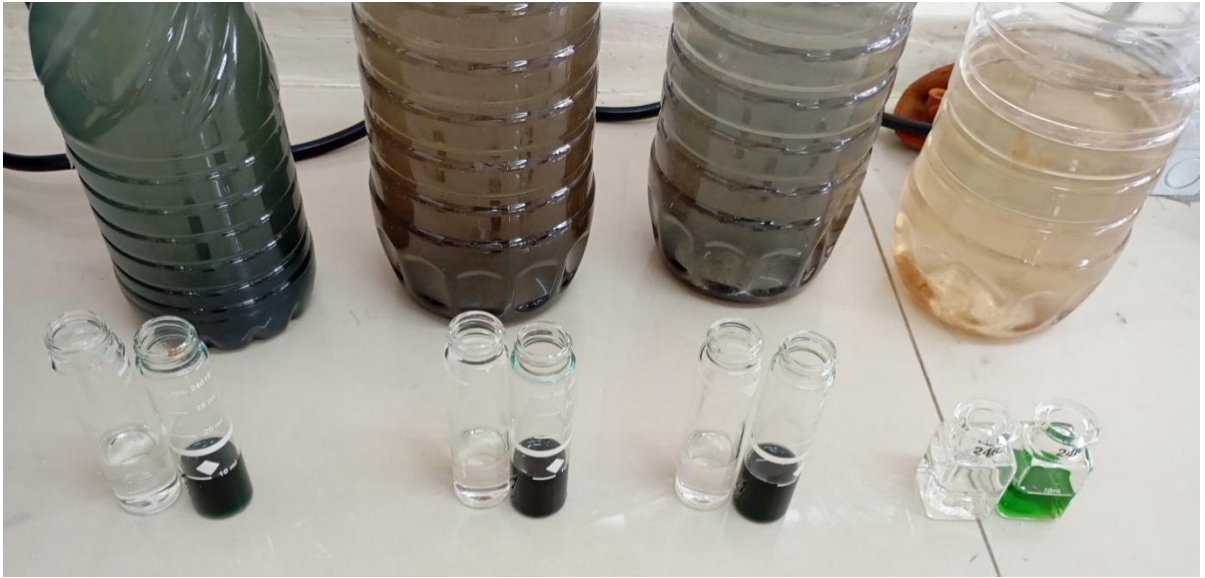
This section focuses on the second objective, which was to determine the physicochemical parameters of shallow wells in Moiben Sub-County. Parameters including pH, turbidity, electrical conductivity (EC), and total dissolved solids (TDS) were measured to evaluate water quality.

### **4.2.1 Ammonia**

Salicylate method is a widely used technique for detecting ammonia in water. Colorimetric method involves the reaction of ammonia with salicylate and hypochlorite under alkaline conditions to form a green-colored complex that can be measured spectrophotometrically. This indicates presence of ammonia in the water sample as shown in figure 4.6.

**Figure 4. 6**

*Formation of Green Color Indicates Presence of Ammonia in the Samples Tested*

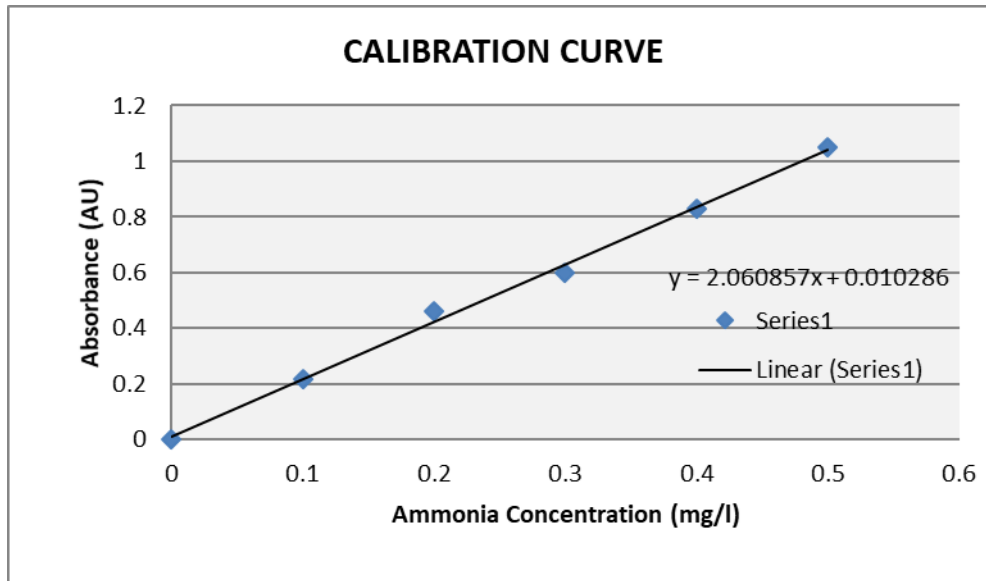


*Source: Researcher, 2024*

The test results indicated varying levels of ammonia contamination across the sampled wells. The concentration of ammonia in the well water samples ranged from 0.061 mg/L to 1.0 mg/L. Notably, several samples exceeded the World Health Organization (WHO) recommended maximum limit of 0.5 mg/L for drinking water (WHO, 2022) as shown in table 4.7 below especially those whose distances of the well from pit Latrines were very minimal.

**Figure 4. 7**

*Calibration Curve of Absorbance Versus Ammonia Concentration*



*Source: Researcher, 2024*

The figure 4.7 shows the calibration curve of absorbance versus ammonia concentration.

This enables the determination of accurate ammonia levels based on the absorbance.

Table 4.2 shows concentration of ammonia in water samples tested indicating the well distances from the pit latrine

**Table 4. 2***Concentration of Ammonia in Water Samples Tested*

<b>Wells in numbers</b>	<b>Distance of the well from the pit-latrine (m)</b>	<b>Concentration of Ammonia in mg/L</b>	<b>Well in numbers</b>	<b>Distance of the well from the pit-latrine (m)</b>	<b>Concentration of Ammonia in mg/L</b>
Well 1	10	0.985	Well 32	29	0.22
Well 2	10	0.981	Well 33	30	0.20
Well 3	11	0.525	Well 34	30	0.20
Well 4	11	0.956	Well 35	30	0.20
Well 5	14	0.906	Well 36	32	0.16
Well 6	15	0.902	Well 37	32	0.15
Well 7	15	0.84	Well 38	33	0.15
Well 8	16	0.834	Well 39	33	0.14
Well 9	16	0.83	Well 40	33	0.14
Well 10	16	0.821	Well 41	34	0.14
Well 11	16	0.809	Well 42	35	0.13
Well 12	17	0.804	Well 43	35	0.13
Well 13	17	0.786	Well 44	37	0.13
Well 14	17	0.781	Well 45	37	0.12
Well 15	18	0.756	Well 46	37	0.11
Well 16	18	0.734	Well 47	38	0.11
Well 17	19	0.721	Well 48	39	0.10
Well 18	19	0.702	Well 49	39	0.10
Well 19	20	0.687	Well 50	40	0.10
Well 20	20	0.250	Well 51	41	0.090
Well 21	21	0.32	Well 52	41	0.087
Well 22	22	0.31	Well 53	43	0.079
Well 23	22	0.31	Well 54	43	0.078
Well 24	23	0.29	Well 55	48	0.065
Well 25	24	0.28	Well 56	48	0.061
Well 26	25	0.27	Well 57	53	0.05
Well 27	25	0.26	Well 58	55	0.046
Well 28	26	0.25	Well 59	67	0.031
Well 29	26	0.24	Well 60	70	0.029
Well 30	27	0.24	Well 61	72	0.026
Well 31	28	0.23	Well 62	80	0.023

*Source: Researcher, 2024*

Table 4.2 displays the ammonia concentrations in the water samples from 62 wells, measured in milligrams per liter (mg/L). Several wells exceed the World Health Organization (WHO) recommended limit of 0.5 mg/L for drinking water. Wells situated closer to pit latrines showed higher ammonia concentrations, indicating potential contamination from human or animal waste.

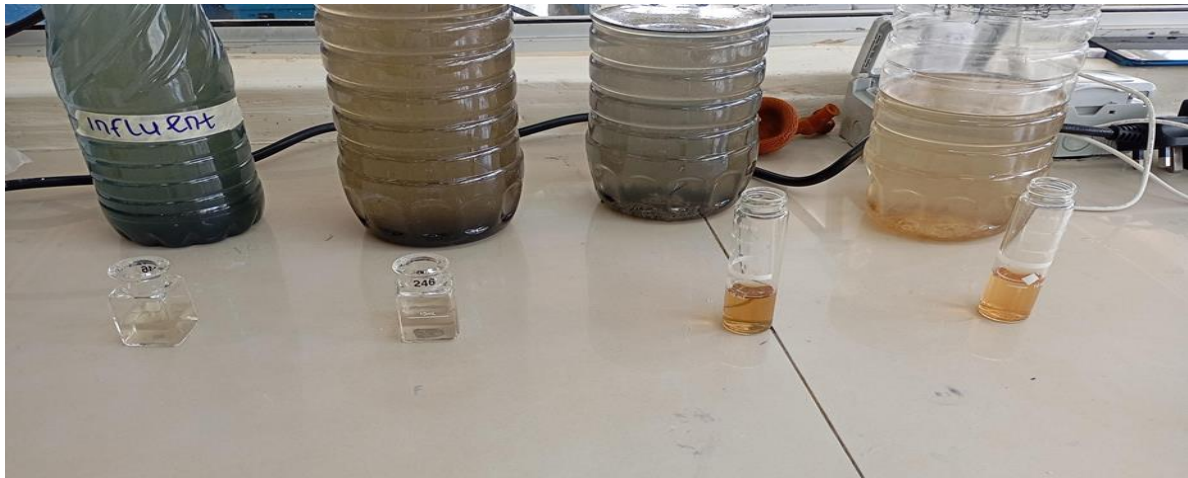
Ammonia concentration between 0.5 mg/L and 1.0 mg/L, suggests moderate contamination likely from agricultural runoff or domestic wastewater since most are large scale farmers.

#### 4.2.2 Nitrates

This method involves reducing nitrate to nitrite using a cadmium column, followed by a colorimetric determination of nitrite. Samples treated with sulfanilamide and N-(1-naphthyl) ethylenediamine dihydrochloride formed an amber-colored azo dye as shown in figure 4.8.

**Figure 4. 8**

*Formation of Amber-Colored Azo Dye*



*Source: Researcher, 2024*

The absorbance of the colored solution was measured using a spectrophotometer at a wavelength of 540 nm. The intensity of the color developed is directly proportional to the concentration of nitrate-nitrogen in the sample.

The test results indicated varying levels of nitrate-nitrogen contamination across the sampled wells. The concentration of nitrate-nitrogen in the well water samples ranged from 1 to 7 mg/L, with several samples not exceeding the World Health Organization (WHO) recommended maximum limit of 10 mg/L for drinking water as shown in table 4.2.

This table presents the nitrate concentrations in well water samples, measured in milligrams per liter (mg/L). The nitrate levels ranged from 1.0 mg/L to 7.0 mg/L, with most samples falling within the WHO recommended maximum limit of 10 mg/L for drinking water. However, some wells, particularly those closer to pit latrines, showed higher nitrate levels, which could be linked to contamination from agricultural runoff or wastewater.

Table 4.3 indicates concentration of Nitrates on the samples tested and the distances of the well from pit latrine

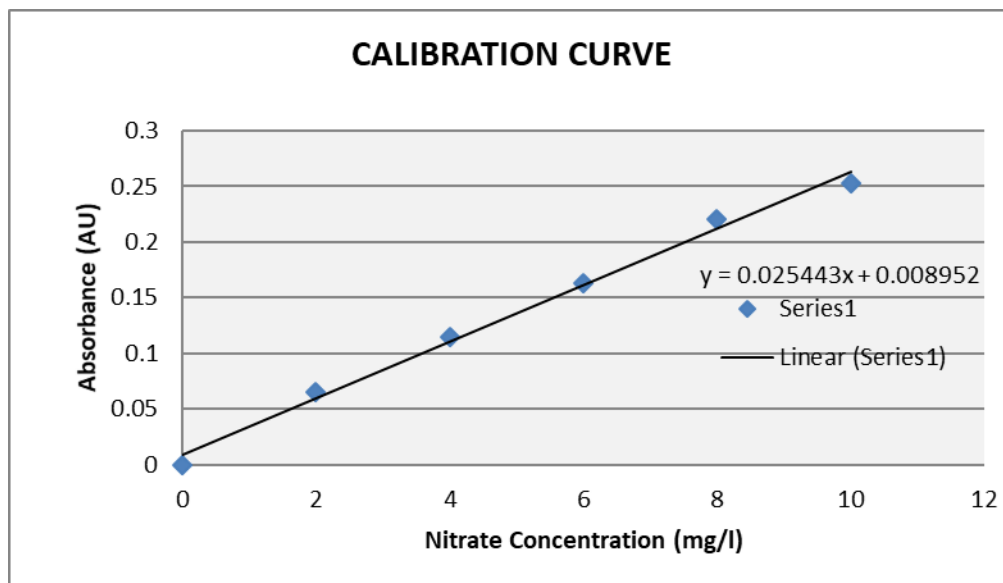
**Table 4. 3***Concentration of Nitrates in mg/L for the Samples Tested*

<b>Wells in numbers</b>	<b>Distance of the well from the pit-latrine (m)</b>	<b>Concentration of Nitrates in mg/L</b>	<b>Well in numbers</b>	<b>Distance of the well from the pit-latrine (m)</b>	<b>Concentration of Nitrates in mg/L</b>
Well 1	10	7.06	Well 32	29	1.847
Well 2	10	7.17	Well 33	30	2.00
Well 3	11	6.7	Well 34	30	1.84
Well 4	11	6.6	Well 35	30	1.76
Well 5	14	4.9	Well 36	32	1.45
Well 6	15	4.5	Well 37	32	1.41
Well 7	15	4.4	Well 38	33	1.33
Well 8	16	4.1	Well 39	33	1.14
Well 9	16	4.1	Well 40	33	1.14
Well 10	16	3.6	Well 41	34	1.10
Well 11	16	3.6	Well 42	35	1.10
Well 12	17	3.5	Well 43	35	1.06
Well 13	17	3.5	Well 44	37	1.06
Well 14	17	3.4	Well 45	37	1.02
Well 15	18	3.3	Well 46	37	1.10
Well 16	18	3.2	Well 47	38	0.98
Well 17	19	3.1	Well 48	39	1.06
Well 18	19	3.26	Well 49	39	0.94
Well 19	20	3.2	Well 50	40	0.90
Well 20	20	2.9	Well 51	41	0.86
Well 21	21	3.0	Well 52	41	0.82
Well 22	22	2.8	Well 53	43	0.79
Well 23	22	2.7	Well 54	43	0.63
Well 24	23	2.6	Well 55	48	0.63
Well 25	24	2.2	Well 56	48	0.59
Well 26	25	2.3	Well 57	53	0.51
Well 27	25	2.0	Well 58	55	0.32
Well 28	26	2.0	Well 59	67	0.36
Well 29	26	1.9	Well 60	70	0.28
Well 30	27	1.9	Well 61	72	0.24
Well 31	28	1.9	Well 62	80	1.847

*Source: Researcher, 2024*

**Figure 4. 9**

*Calibration Curve of Absorbance Versus Nitrate Concentration*



*Source: Researcher, 2024*

The figure 4.9 shows the Calibration curve of absorbance versus Nitrate concentration. This enabled the determination of accurate nitrate levels based on the absorbance.

### 4.2.3 Nitrites

This method involves the reaction of nitrite with an aromatic amine (usually sulfanilamide) to form a diazonium salt, which is then coupled with another compound (N-(1-naphthyl) ethylene diamine dihydrochloride) to form a pink-colored azo dye. The intensity of the color is directly proportional to the concentration of nitrite in the sample and is measured using a spectrophotometer as shown in figure 4.10.

**Figure 4. 10**

*Formation of Pink Colour*



*Source: Researcher, 2024*

The test results indicated varying levels of nitrite-nitrogen contamination across the sampled wells. The concentration of nitrite-nitrogen in the well water samples ranged from 0.004 mg/L to 0.2 mg/L, with several samples exceeding the World Health Organization (WHO) recommended maximum limit of 0.1 mg/L for drinking water. This is because most of the residents are large scale farmers as shown in table 4.4.

This table presents the concentration of nitrites in water samples from various wells at different distances from the pit latrine. The data indicates that the concentration of nitrites is highest in wells closer to the pit latrine (e.g., Well 1 and Well 2 at 10 meters), with values ranging from 0.199 mg/L to 0.200 mg/L. As the distance from the pit latrine increases, the nitrite concentrations decrease significantly, with values at 80 meters (Well 62) as low as

0.005 mg/L. This suggests that nitrite contamination decreases with increasing distance from the pit latrine.

Table 4.4 indicates concentration of nitrites and distances of well from the pit latrine

**Table 4. 4**

*Concentration of Nitrites in mg/L*

<b>Wells in numbers</b>	<b>Distance of the well from the pit-latraine (m)</b>	<b>Concentration of Nitrites in mg/L</b>	<b>Well in numbers</b>	<b>Distance of the well from the pit-latraine (m)</b>	<b>Concentration of Nitrites in mg/L</b>
Well 1	10	0.199	Well 32	29	0.05
Well 2	10	0.200	Well 33	30	0.051
Well 3	11	0.199	Well 34	30	0.051
Well 4	11	0.197	Well 35	30	0.050
Well 5	14	0.194	Well 36	32	0.044
Well 6	15	0.175	Well 37	32	0.037
Well 7	15	0.177	Well 38	33	0.032
Well 8	16	0.175	Well 39	33	0.032
Well 9	16	0.159	Well 40	33	0.031
Well 10	16	0.157	Well 41	34	0.027
Well 11	16	0.147	Well 42	35	0.023
Well 12	17	0.146	Well 43	35	0.022
Well 13	17	0.144	Well 44	37	0.022
Well 14	17	0.138	Well 45	37	0.019
Well 15	18	0.137	Well 46	37	0.019
Well 16	18	0.135	Well 47	38	0.022
Well 17	19	0.132	Well 48	39	0.018
Well 18	19	0.13	Well 49	39	0.018
Well 19	20	0.13	Well 50	40	0.018
Well 20	20	0.13	Well 51	41	0.017
Well 21	21	0.11	Well 52	41	0.014
Well 22	22	0.11	Well 53	43	0.013
Well 23	22	0.08	Well 54	43	0.012
Well 24	23	0.08	Well 55	48	0.012
Well 25	24	0.07	Well 56	48	0.008
Well 26	25	0.07	Well 57	53	0.007
Well 27	25	0.07	Well 58	55	0.006
Well 28	26	0.07	Well 59	67	0.006

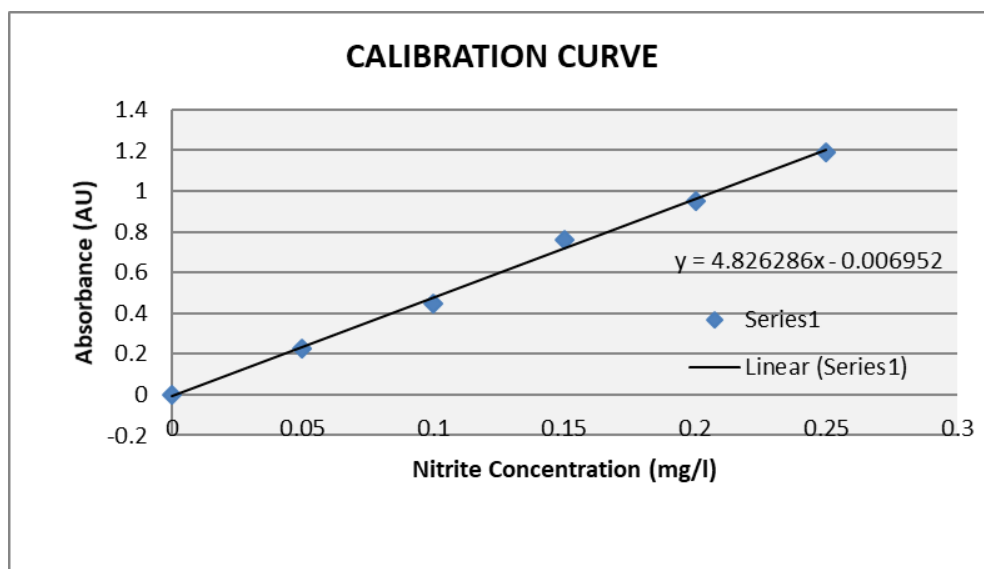
Wells in numbers	Distance of the well from the pit-latrine (m)	Concentration of Nitrites in mg/L	Wells in numbers	Distance of the well from the pit-latrine (m)	Concentration of Nitrites in mg/L
Well 29	26	0.06	Well 60	70	0.005
Well 30	27	0.06	Well 61	72	0.004
Well 31	28	0.199	Well 62	80	0.005

Source: Researcher, 2024

A significant number of samples exhibited nitrite-nitrogen concentrations between 0.1 mg/L and 1.0 mg/L, suggesting moderate contamination likely from agricultural runoff or domestic wastewater. Only one well had nitrite-nitrogen levels exceeding 2.0 mg/L, pointing contamination possibly due to industrial discharge or extensive agricultural activity.

**Figure 4. 11**

*Calibration Curve of Absorbance Versus Nitrite Concentration*



Source: Researcher, 2024

The figure 4.11 shows the Calibration curve of absorbance versus Nitrite concentration. This enabled the determination of accurate nitrate levels based on the absorbance.

#### **4.2.4 pH**

In the data, closer distances to the pit latrine (10-20 meters) show lower pH values, indicating more acidic conditions. This is likely due to the leaching of acidic compounds from the pit latrine into the shallow well water. As the distance from the pit latrine increases, pH values gradually rise towards neutral (7.0), indicating that the influence of acidic leachates diminishes with distance. For example, at 10 meters, the pH is around 5.5, while at 80 meters, it stabilizes at 8.5, reflecting a neutral to slightly alkaline environment. This is shown in table 4.5 below

#### **4.2.5 Electrical conductivity**

The data shows high EC values at closer distances, with 1500  $\mu\text{S}/\text{cm}$  at 10 meters, decreasing steadily with distance. By 80 meters, EC drops to 150  $\mu\text{S}/\text{cm}$ . This trend indicates that the concentration of dissolved ions is significantly higher near the pit latrine, likely due to the leaching of electrolytes from the latrine into the groundwater. As the distance increases, the impact of these contaminants lessens, resulting in lower EC values. This is shown in table 4.5 below

#### **4.2.6 Total dissolved solids**

Total Dissolved Solids represent the combined content of all inorganic and organic substances dissolved in water. The observed trend shows higher TDS levels near the pit latrine, with values around 1000 mg/L at 10 meters, decreasing to 150 mg/L at 80 meters. This pattern mirrors the EC data, as TDS is directly related to the concentration of dissolved ions in the water. High TDS levels near the pit latrine suggest substantial leaching of various soluble compounds, including nitrates, phosphates, and organic matter, from the latrine into the groundwater. This is shown in table 4.5 below

#### **4.2.7 Turbidity**

The data shows that turbidity is highest near the pit latrine, with values around 40 NTU at 10 meters, and decreases to 7 NTU at 80 meters. High turbidity near the latrine is likely due to the infiltration of particulate matter from the latrine's waste, including organic and inorganic particles. As the distance from the latrine increases, the turbidity decreases significantly, indicating a reduction in the concentration of suspended particles. This is shown in table 4.5 below.

This table summarizes the pH, electrical conductivity (EC), total dissolved solids (TDS), and turbidity of water samples from various wells at varying distances from the pit latrine. The data shows a clear trend where the pH, EC, TDS, and turbidity values decrease with increasing distance from the pit latrine. Wells closer to the pit latrine (e.g., Well 1 at 10 meters) exhibit lower pH (5.5), high EC (1500  $\mu\text{S}/\text{cm}$ ), high TDS (1000 mg/L), and high turbidity (40 NTU), indicating significant contamination. As the distance increases, these values gradually approach more neutral and lower values, with wells located farther than 50 meters showing significantly reduced contamination levels.

Table 4.5 indicates electrical conductivity, total dissolved and turbidity in relation to well distance from pit latrine

**Table 4. 5***pH, Electrical Conductivity, Total Dissolved Solids and Turbidity*

<b>Wells in numbers</b>	<b>Distance of the well from the pit-latrine (m)</b>	<b>pH</b>	<b>EC (<math>\mu</math>S/cm)</b>	<b>TDS (mg/L)</b>	<b>Turbidity (NTU)</b>
Well 1	10	5.5	1500	1000	40
Well 2	10	5.5	1500	1000	40
Well 3	11	5.6	1400	950	39
Well 4	11	5.6	1400	950	39
Well 5	14	5.7	1300	900	38
Well 6	15	5.7	1300	900	38
Well 7	15	5.7	1300	900	38
Well 8	16	5.8	1200	850	37
Well 9	16	5.8	1200	850	37
Well 10	16	5.8	1200	850	37
Well 11	16	5.8	1200	850	37
Well 12	17	5.9	1100	800	36
Well 13	17	5.9	1100	800	36
Well 14	17	5.9	1100	800	36
Well 15	18	5.9	1100	800	36
Well 16	18	5.9	1100	800	36
Well 17	19	6.0	1000	750	35
Well 18	19	6.0	1000	750	35
Well 19	20	6.0	1000	750	35
Well 20	20	6.0	1000	750	35
Well 21	21	6.1	950	700	34
Well 22	22	6.1	950	700	34
Well 23	22	6.1	950	700	34
Well 24	23	6.1	900	680	33
Well 25	24	6.2	900	680	33
Well 26	25	6.2	850	650	32
Well 27	25	6.2	850	650	32
Well 28	26	6.3	800	600	31
Well 29	26	7.3	800	600	31
Well 30	27	6.3	750	580	30
Well 31	28	6.3	750	580	30
Well 32	29	6.4	700	550	29
Well 33	30	6.4	700	550	29
Well 34	30	6.4	700	550	29

Wells in numbers	Distance of the well from the pit-latrine (m)	pH	EC ( $\mu\text{S}/\text{cm}$ )	TDS (mg/L)	Turbidity (NTU)
Well 35	30	6.4	700	550	29
Well 36	32	6.5	650	500	28
Well 37	32	6.5	650	500	28
Well 38	33	6.5	600	500	28
Well 39	33	6.5	550	500	28
Well 40	33	6.5	550	500	28
Well 41	34	6.6	600	450	27
Well 42	35	6.6	600	450	27
Well 43	35	6.6	600	450	27
Well 44	37	6.6	550	400	26
Well 45	37	6.6	550	400	26
Well 46	37	6.6	550	400	26
Well 47	38	6.7	500	380	25
Well 48	39	6.7	500	380	25
Well 49	39	6.7	500	380	25
Well 50	40	6.7	450	350	24
Well 51	41	6.8	450	350	24
Well 52	41	6.8	450	350	24
Well 53	43	6.8	400	300	23
Well 54	43	6.8	400	300	23
Well 55	48	6.9	350	280	22
Well 56	48	6.9	350	280	22
Well 57	53	7.0	300	250	21
Well 58	55	7.1	300	250	21
Well 59	67	8.0	250	200	15
Well 60	70	8.2	200	180	11
Well 61	72	8.2	200	180	8
Well 62	80	8.5	150	150	7

*Source: Researcher, 2024*

### **4.3 Relationship Between Well Water Contamination and the Distance from Pit-Latrines**

This section addresses the third objective, which was to establish the relationship between shallow well water contamination and the distance of wells from pit latrines. Using both

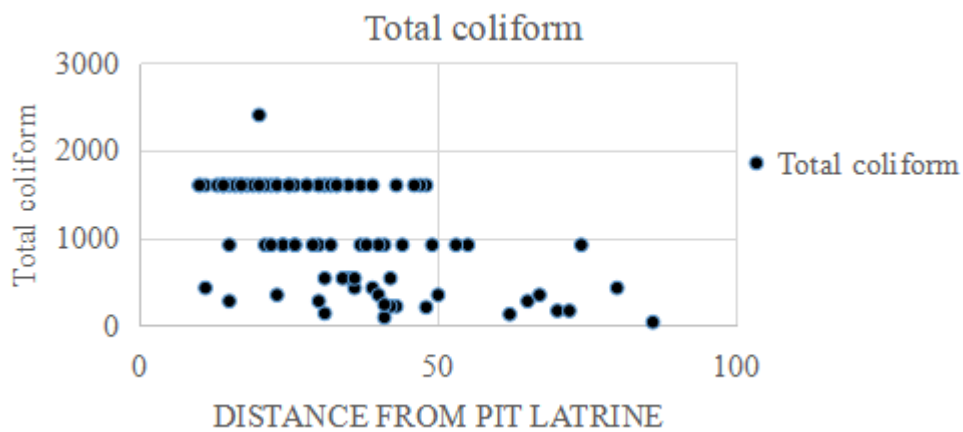
descriptive and regression analyses, the study evaluated microbial, chemical, and physical parameters to determine how proximity to latrines influences water quality. The results highlight key correlations and underline the impact of pit latrine placement on contamination levels.

#### 4.3.1 Total coliforms and the distance of the well from pit - latrine

Contamination of well water by total coliforms, can lead to serious health problems. The presence of total coliforms in the water samples assessed using the Most Probable Number (MPN) method showed that wells that had a minimal distance of distances range 10 m- 30 m had the highest number of total coliforms as shown below in figure 4.12.

**Figure 4. 12**

*Relationship Between Total Coliform and the Distance of the Well from the Pit- Latrine*



*Source: Researcher, 2024*

These wells showed the highest levels of total coliforms, with counts ranging from 540 to 1600 MPN/100ml, indicating significant contamination. Such high levels far exceed WHO guidelines (WHO, 2022) and suggest direct contamination from nearby pit latrines. The wells that were far away from the pit- latrines at a distance range of 30 to 50 m showed less

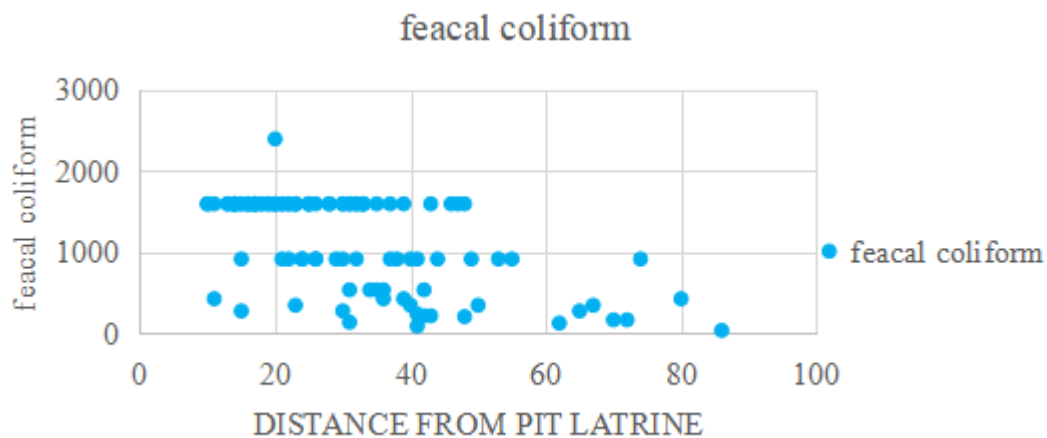
number of total Coliforms. These wells had moderate levels of total coliforms suggesting that distance reduces but does not eliminate contamination risk. Wells more than 50 meters from pit latrines exhibited the lowest levels of total coliforms ranging from 22 to 70 MPN/100ml. Some wells within this distance met WHO standards (WHO, 2022) indicating that a greater distance from pit latrines significantly reduces the risk of contamination.

#### 4.3.2 Fecal coliform and the distance of the well from pit - latrine

The presence of Fecal Coliform in the water samples assessed using the Most Probable Number (MPN) method showed that wells that had a minimal distance of distances range 10 - 30 m had the highest number of fecal coliforms as shown below in figure 4.13.

**Figure 4. 13**

*Relationship Between Fecal Coliform and the Distance of the Well from Pit- Latrines*



*Source: Researcher, 2024*

These wells showed the highest levels of total coliforms, with counts ranging from 340 to 1600 MPN/100ml, indicating significant contamination. Such high levels far exceed WHO guidelines and suggest direct contamination from nearby pit latrines.

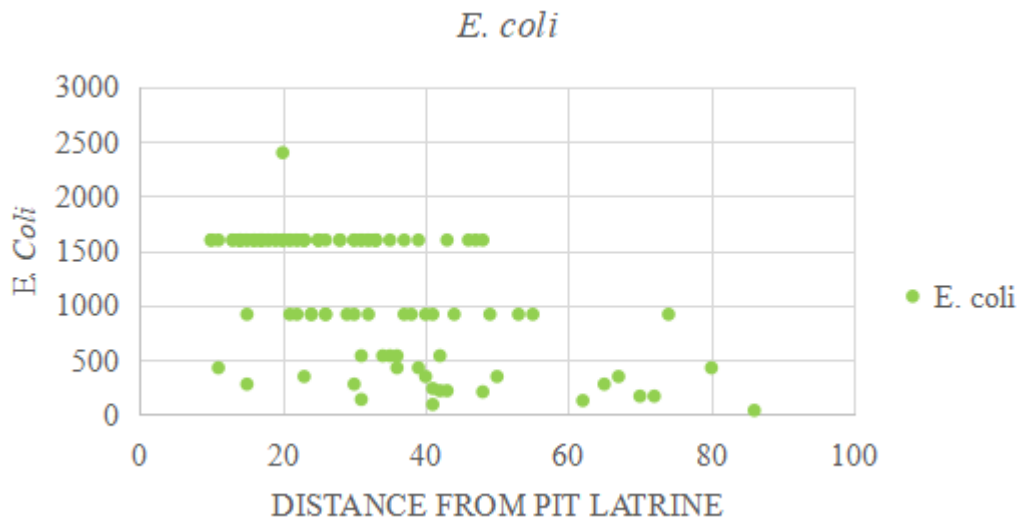
The wells that were far away from the pit- latrines at a distance range of 30 to 50 m showed less number of Fecal Coliforms. These wells had moderate levels of Fecal coliforms suggesting that distance reduces but does not eliminate contamination risk. Wells more than 50 m from pit latrines exhibited the lowest levels of Fecal Coliforms, with counts ranging from 20 to 70 MPN/100ml as shown in figure 4.13 above. Some wells within this distance met WHO standards, indicating that a greater distance from pit latrines significantly reduces the risk of contamination.

**4.3.3 *E. coli* and the distance of the well from pit - latrine**

The presence of *E. coli* in the water samples assessed using the Most Probable Number (MPN) method showed that wells that had a minimal distance of distances range 10 - 30m had the highest number of *E. coli* as shown below in Figure 4.14.

**Figure 4. 14**

*Relationship Between E. coli and the Distances of the Well from Pit- Latrines*



Source: Researcher, 2024

These wells showed the highest levels of *E. coli* ranging from 540 to 1600 MPN/100ml, indicating significant contamination. Such high levels far exceed WHO guidelines and suggest direct contamination from nearby pit latrines.

The wells that were far away from the pit- latrines at a distance range of 30 to 50 m showed less number of *E. coli*. These wells had moderate levels of *E. coli* suggesting that distance reduces but does not eliminate contamination risk.

Wells more than 50 meters from pit latrines exhibited the lowest levels of *E. coli* ranging from 20 to 70 MPN/100ml as shown in table 4.14 above. Some wells within this distance met WHO standards, indicating that a greater distance from pit latrines significantly reduces the risk of contamination.

#### **4.3.4 Ammonia and the distance of the well from pit – latrine**

The presence of ammonia in the water samples was assessed using the salicylate method. This showed that wells with distance range between 10 to 30 metres from Pit Latrines exhibited the highest levels of ammonia. Their concentrations ranging 0.061 to 1.0 mg/L. Notably, several samples exceeded the World Health Organization (WHO) recommended maximum limit of 0.5 mg/L for drinking water, especially those whose distances is less than 30 metres from the pit latrines. Such levels suggest significant contamination.

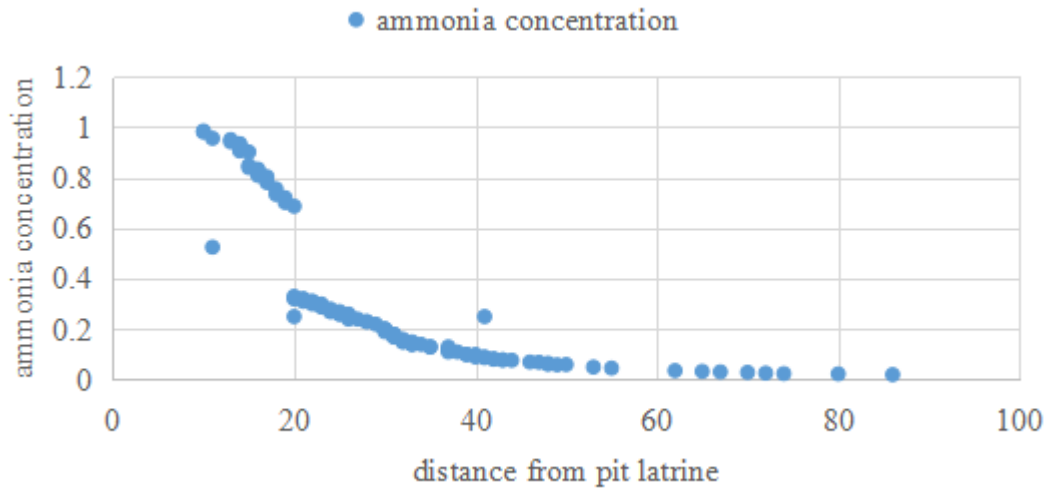
Wells located 30-50 metres from pit latrines showed moderate levels of ammonia, with concentrations ranging from 0.5 to 1.0 mg/L. Although, the contamination levels were lower than those in wells closer to the pit latrines, they still indicated a notable impact of the latrines on water quality.

Wells more than 50 meters from pit latrines had the lowest levels of ammonia, with concentrations generally below 0.5 mg/L. Some wells within this distance met WHO

standards for minimal ammonia levels, suggesting that a greater distance from pit latrines significantly reduces the risk of contamination. This is shown in Figure 4.15.

**Figure 4. 15**

*Relationship Between Ammonia Concentration and the Distance from Wells to Pit-Latrines*



*Source: Researcher, 2024*

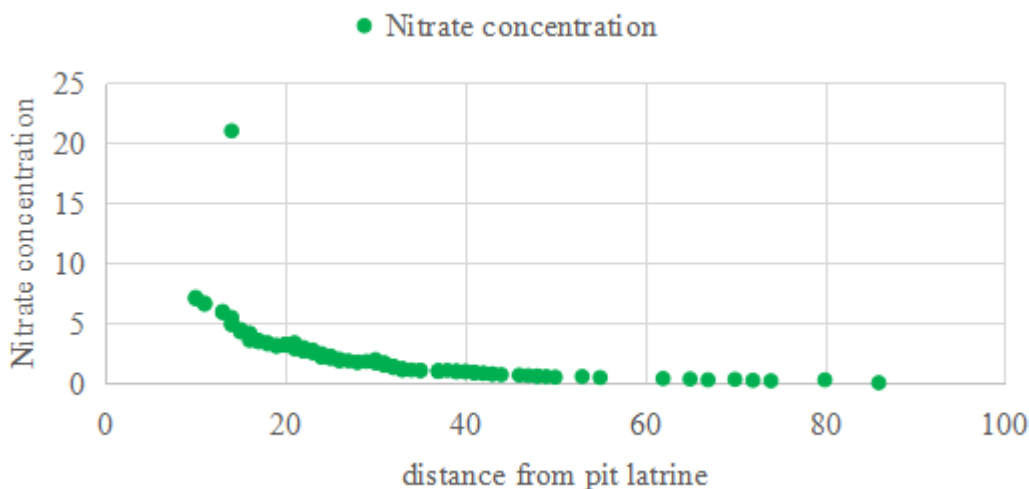
#### **4.3.5 Nitrates and the distance of the well from pit – latrine**

The assessment of nitrates levels in the water samples was conducted by cadmium reduction spectrophotometric method. The results indicated that wells situated within a distance range of 10 to 30 meters from pit latrines exhibited the highest Nitrate concentrations, ranging from 4 to 7 mg/L. Samples were within the World Health Organization's (WHO) recommended maximum limit of 10.0 mg/L for drinking water. Wells located 30 to 50 meters from pit latrines showed moderate nitrate levels, with concentrations ranging from 3.0 to 6.0 mg/L. Wells situated more than 50 meters away from pit latrines had the lowest ammonia levels range between 1mg/L- 3mg/L. These wells met WHO standards for minimal

ammonia levels, indicating that a greater distance from pit latrines the less the Nitrate concentration as shown in figure 4.16.

**Figure 4. 16**

*Relationship Between Nitrates and the Well Distance from the Pit- Latrines*



*Source: Researcher, 2024*

#### **4.3.6 Nitrites and the distance of the well from pit – latrine**

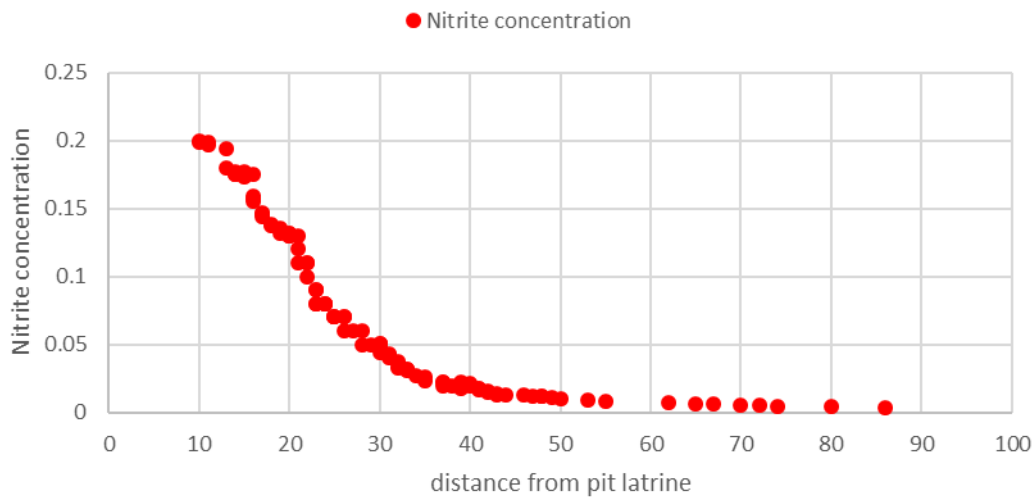
Nitrites in the water samples was assessed using diazotization method. This showed that Wells with distance range between 10 to 30 metres from Pit Latrines exhibited the highest levels of Nitrite concentration. Their concentrations ranging 0.005- 0.2 mg/L which exceeded the World Health Organization (WHO) recommended maximum limit of 0.1mg/L for drinking water

Wells located 30-50 meters from pit latrines showed moderate levels of ammonia, with concentrations ranging from 0.5 to 1.0 mg/L. Although the contamination levels were lower than those in wells closer to the pit latrines, they still indicated a notable impact of the latrines on water quality.

Wells more than 50 meters from pit latrines had the lowest levels of ammonia, with concentrations generally below 0.5 mg/L. These wells within this distance met WHO standards for minimal ammonia levels, suggesting that a greater distance from pit latrines the less the levels of Nitrites. This is shown in Figure 4.17

**Figure 4. 17**

*Relationship Between Nitrite Concentration and the Well Distance from the Pit-Latrine*



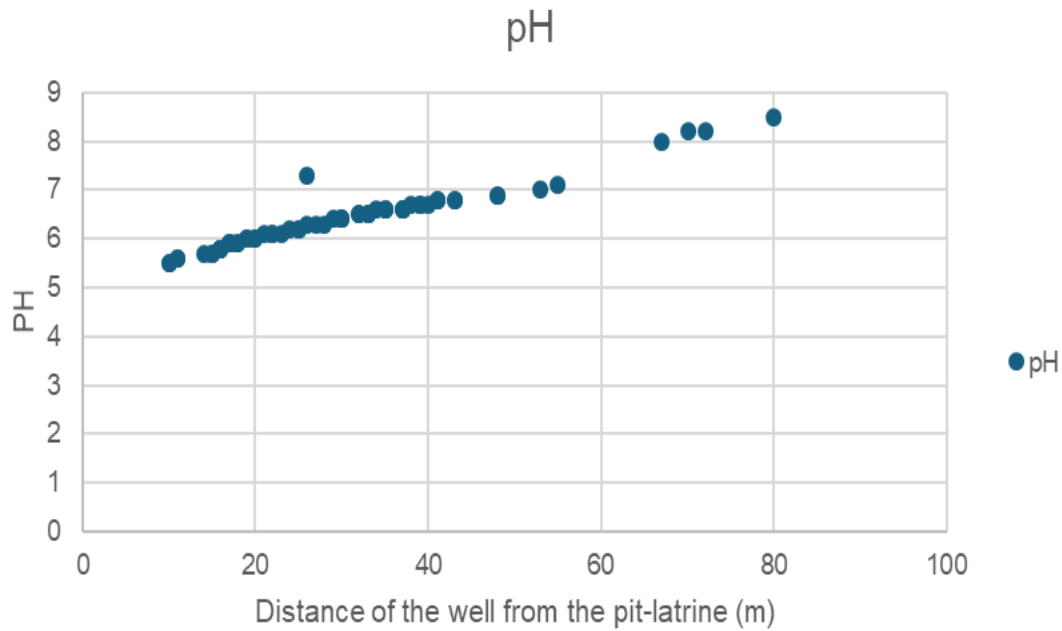
*Source: Researcher, 2024*

### 4.3.7 pH and the distance of the well from pit – latrine

Closer distances to the pit latrine (10-20 meters) show lower pH values, indicating more acidic conditions while those that has a distance between 30m-50 m shows neutral pH values and those whose well distance from the pit latrine had higher pH values upto 8.5 which is within the recommended WHO standard.(WHO, 2021) of 6.5-8.5. The relationship between pH and distance of well from pit latrine is shown in figure 4.18.

**Figure 4. 18**

*Relationship Between pH and Distance of Well from Pit Latrine*



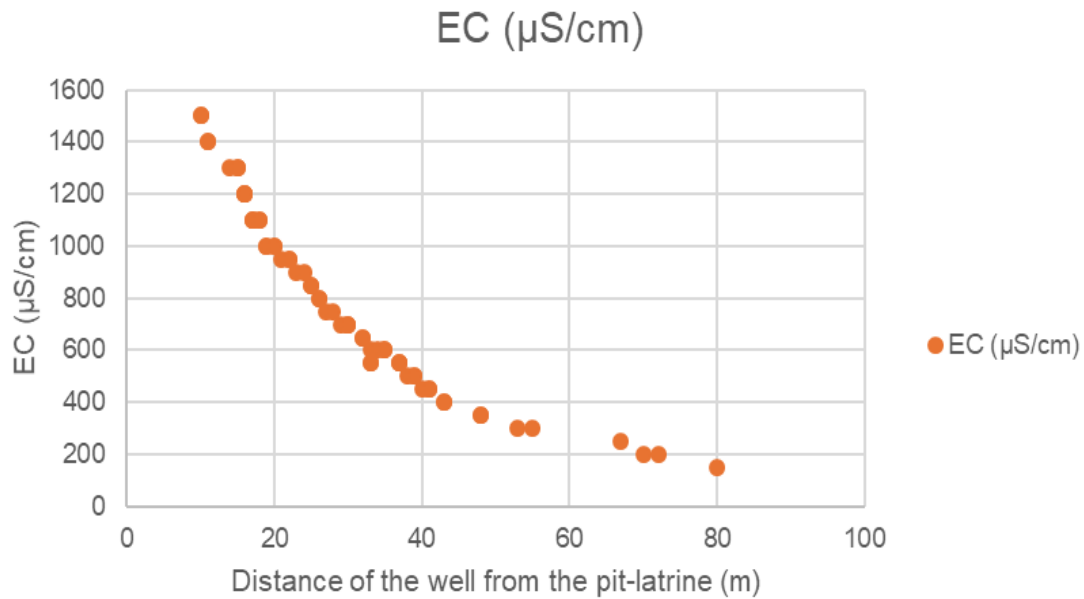
*Source: Researcher, 2024*

#### **4.3.8 Electrical conductivity and the distance of the well from pit – latrine**

High Electrical conductivity values at closer distances, with 1500  $\mu\text{S}/\text{cm}$  at 10 meters, decreasing steadily with distance. Distances between 30m- 50 m have values ranging between 750 -450  $\mu\text{S}/\text{cm}$ . By 80 meters, Electrical conductivity drops to 150  $\mu\text{S}/\text{cm}$ . This trend indicates that the concentration of dissolved ions is significantly higher near the pit latrine. This relationship is shown in figure 4.19 below.

**Figure 4. 19**

*Relationship Between Electrical Conductivity and Distance of Well from Pit Latrine*



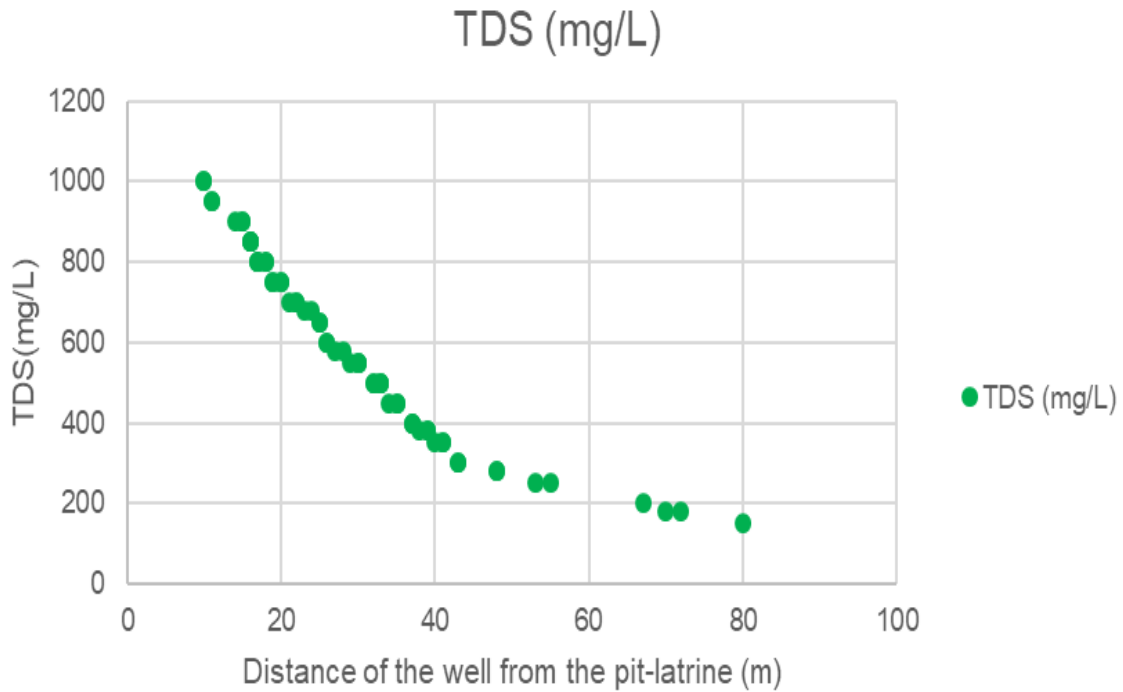
*Source: Researcher, 2024*

#### **4.3.9 Total dissolved solids and the distance of the well from pit – latrine**

Higher TDS levels are seen near the pit latrine, with values around 1000 mg/L at 10 meters, decreasing to 150 mg/L at 80 meters. The closer the well is to the pit latrine the higher the dissolved solids while those wells whose distances were far away from the pit latrine had low numbers of dissolved solids. This is shown in figure 4.20 below.

**Figure 4. 20**

*Relationship Between Total Dissolved Solids and Distance of Well from Pit Latrine*



*Source: Researcher, 2024*

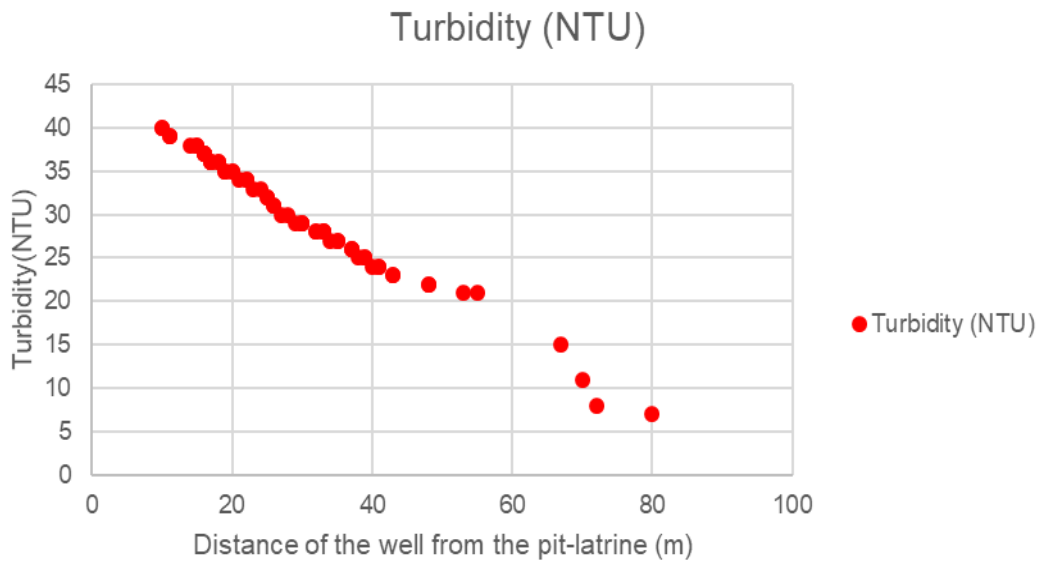
#### **4.3.10 Turbidity and the distance of the well from pit – latrine**

Turbidity is highest near the pit latrine, with values around 40 NTU at 10 meters, and decreases to 7 NTU at 80 meters. As the distance from the latrine increases, the turbidity decreases significantly while turbidity is high in wells that are closer to the pit –latrine. This is evident in figure 4.21 below.

**Figure 4. 21**

*Relationship Between Turbidity and Distance of Well from Pit Latrine 4.3.11 Inferential*

*Analysis*



*Source: Researcher, 2024*

The data relating to microbial and physicochemical was subjected to regression analysis by use of ANOVA. A simple linear regression model and multiple linear regression models were applied in the analysis. The results are presented in form of model fitness, ANOVA and regression coefficients for each test.

#### **4.3.12 ANOVA results for well distance and microbial contamination**

The results for the Model fitness are presented in Table 4.6.

Table 4.6 shows model for fitness of well distance and microbial contamination

**Table 4. 6**

*Model Fitness for Well Distance and Microbial Contamination*

<b>Model</b>	<b>R</b>	<b>R Square</b>	<b>Adjusted R Square</b>	<b>Std. Error of the Estimate</b>
	.853 <sup>a</sup>	.728	.714	8.33789

*Source: Researcher, 2024*

a. Predictors: (Constant), *E Coli*, Total Coliform, Fecal Coliform

The results for R = 0.853 implies that the model is a good measure of the relationship between well distance and level of microbial contamination. The R squared (0.728) implies the well distance is able to explain 72.8% of the level of microbial contamination.

Table 4.7 shows ANOVA for well distance and microbial contamination

**Table 4. 7**

*ANOVA for Well Distance and Microbial Contamination*

<b>Model</b>	<b>Sum of Squares</b>	<b>Df</b>	<b>Mean Square</b>	<b>F</b>	<b>Sig.</b>
Regression	10772.527	3	3590.842	51.652	.000 <sup>b</sup>
Residual	4032.183	58	69.520		
Total	14804.710	61			

*Source: Researcher, 2024*

a. Dependent Variable: Distance from the toilet

b. Predictors: (Constant), *E Coli*, Total Coliform, Fecal Coliform

The ANOVA results show a significance of 0.000 implying that the relationship between the well distance and level of microbial contamination is significant.

Having established the significance of the relationship, the data was analyzed for the regression coefficients.

Table 4.8 indicates coefficients for well distance and microbial contamination

**Table 4. 8**

*Coefficients for Well Distance and Microbial Contamination*

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	49.701	1.864		26.670	.000
Total Coliform	-.016	.004	-.611	-3.713	.000
Fecal Coliform	-.002	.005	-.069	-.392	.696
E Coli	-.005	.004	-.198	-1.202	.234

*Source: Researcher, 2024*

a. Dependent Variable: Distance from the toilet

The regression results for microbial contamination (Table 4.8) reveal that Total Coliform contamination has a significant inverse relationship with well distance ( $\beta = -0.611$ ,  $p = 0.000$ ), suggesting that wells located closer to latrines are more contaminated with Total Coliform. In contrast, Fecal Coliform and *E. coli* contamination were not found to have statistically significant relationships with well distance ( $p = 0.696$  and  $p = 0.234$ , respectively), aligning with the earlier descriptive statistics, which indicated that while contamination levels vary, they do not necessarily correlate strongly with distance from the toilet.

Table 4.9 indicates ANOVA results for Well Distance and Physical Parameters

**Table 4. 9**

*Model Fitness for Well Distance and Physical Parameters*

<b>Model R</b>	<b>R Square</b>	<b>Adjusted R Square</b>	<b>Std. Error of the Estimate</b>
.994 <sup>a</sup>	.987	.987	1.80510

*Source: Researcher, 2024*

a. Predictors: (Constant), Turbidity, EC, pH, TDS

The results for R = 0.994 implies that the model is a good measure of the relationship between well distance and level of physical contamination. The R squared (0.987) implies the well distance is able to explain 98.7% of the level of contamination.

Table 4.10 shows the results for ANOVA for well distances and physical parameters

**Table 4. 10**

*ANOVA for Well Distance and Physical Parameters*

<b>Model</b>	<b>Sum of Squares</b>	<b>Df</b>	<b>Mean Square</b>	<b>F</b>	<b>Sig.</b>
Regression	14618.982	4	3654.746	1121.648	.000 b
Residual	185.727	57	3.258		
Total	14804.710	61			

*Source: Researcher, 2024*

a. Dependent Variable: Distance from the toilet

b. Predictors: (Constant), Turbidity, EC, pH, TDS

The ANOVA results show a significance of 0.000 implying that the relationship between the well distance and level of contamination is significant.

Having established the significance of the relationship, the data was analyzed for the regression coefficients.

Table 4.11 indicates coefficients for well distance and physical contamination

**Table 4. 11**

*Coefficients for Well Distance and Physical Contamination*

Model	Unstandardized		Standardized		t	Sig.
	Coefficients		Coefficients			
	B	Std. Error	Beta			
(Constant)	76.721	14.117			5.435	.000
pH	1.930	1.550	.079		1.246	.218
EC	.013	.006	.299		2.099	.040
TDS	-.018	.011	-.264		-1.614	.112
Turbidity	-1.986	.196	-.946		-10.130	.000

*Source: Researcher, 2024*

a. Dependent Variable: Distance from the toilet

The results in Table 4.11 show that Turbidity is the only physical parameter significantly related to well distance ( $\beta = -0.946$ ,  $p = 0.000$ ), while Electrical Conductivity (EC), pH, and Total Dissolved Solids (TDS) do not show statistical significance ( $p$ -values  $> 0.05$ ). Specifically, Turbidity exhibits a strong negative relationship, suggesting that wells located farther from latrines have lower turbidity, consistent with the descriptive analysis that identified higher turbidity levels in wells closer to latrines, indicating physical contamination. The positive relationship observed for EC ( $\beta = 0.299$ ,  $p = 0.040$ ) in the descriptive analysis contrasts with its lack of significance in the regression, which raises concerns about the reliability of the findings for EC, pH, and TDS.

Potential reasons for this include insufficient variation in these parameters, multicollinearity among variables, or a smaller sample size that increases the risk of Type II errors. Although the model's high  $R^2$  value (0.987) suggests a good fit, it may be overly influenced by the

significant Turbidity coefficient. Thus, while the results confirm a reliable relationship between Turbidity and well distance, the lack of significance for other parameters warrants caution and further investigation, such as expanding the sample size or using alternative modeling techniques to explore these relationships more accurately.

#### 4.3.14 ANOVA Results for Well Distance and Chemical Parameters

Table 4.12 shows the results for the Model fitness

**Table 4. 12**

*Model Fitness for Well Distance and Chemical Parameters*

<b>Model R</b>	<b>R Square</b>	<b>Adjusted R Square</b>	<b>Std. Error of the Estimate</b>
.821 <sup>a</sup>	.674	.657	9.12312

a. Predictors: (Constant), Nitrites, Ammonia, Nitrates

The results for  $R = 0.821$  implies that the model is a good measure of the relationship between well distance and level of chemical contamination. The R squared (0.674) implies the well distance is able to explain 67.4% of the level of contamination.

Table 4.13 shows results for ANOVA for well distance and chemical parameters

**Table 4. 13**

*ANOVA for Well Distance and Chemical Parameters*

<b>Model</b>	<b>Sum of Squares</b>	<b>Df</b>	<b>Mean Square</b>	<b>F</b>	<b>Sig.</b>
Regression	9977.296	3	3325.765	39.958	.000 <sup>b</sup>
Residual	4827.414	58	83.231		
Total	14804.710	61			

*Source: Researcher, 2024*

a. Dependent Variable: Distance from the toilet

b. Predictors: (Constant), Nitrites, Ammonia, Nitrates

The ANOVA results show a significance of 0.000 implying that the relationship between the well distance and level of contamination is significant.

This confirms that the model effectively captures the variance in well distance based on chemical parameters such as Nitrites, Ammonia, and Nitrates. The significant result aligns with the earlier descriptive analysis, which indicated that well proximity to latrines is associated with varying levels of contamination. In particular, Nitrites were found to have a significant inverse relationship with well distance, reinforcing the ANOVA findings.

Having established the significance of the relationship, the data was analyzed for the regression coefficients.

Table 4.14 shows the results of coefficient for well distance and chemical parameters

**Table 4. 14***Coefficients for Well Distance and Chemical Parameters*

<b>Model</b>	<b>Unstandardized Coefficients</b>		<b>Standardized Coefficients</b>	<b>T</b>	<b>Sig.</b>
	<b>B</b>	<b>Std. Error</b>	<b>Beta</b>		
1 (Constant)	46.212	1.982		23.320	.000
Ammonia	-8.445	9.548	-.173	-.885	.380
Nitrates	-.972	1.826	-.106	-.532	.597
Nitrites	-131.655	52.722	-.560	-2.497	.015

*Source: Researcher, 2024*

a. Dependent Variable: Distance from the toilet

The results for regression coefficients show the relationship between well distance and Nitrites of beta = 0.-0.560 with a p value of 0.015 which is significant as the p value is below the threshold of 0.05. The rest of the coefficients were not significant as the p values (0.380 and 0.597) were above the acceptable limits of p=0.05.

## CHAPTER FIVE: DISCUSSION

### 5.0 Introduction

This chapter presents the discussion of the study findings, giving analysis on microbial contamination levels and physicochemical parameters of shallow wells in Moiben Sub-County, Uasin Gishu County. The findings are considered with regard to proximity to pit latrines of these wells, emphasizing the well distance-water quality relationship. Key activities pertain to Total Coliforms, Fecal Coliforms, *Escherichia coli* (*E. coli*), pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Turbidity, Ammonia, Nitrates, and Nitrites. This chapter endeavors to show the complete understanding of the impacts of sanitation on water quality and health status in the public.

### 5.1 Microbial Contamination Levels in Shallow Wells

The microbial contamination of shallow wells in the Moiben Sub-County was found to be high, hence posing a serious threat to water quality and public health. A total of 62 wells were sampled for three key microbial indicators: total coliforms, fecal coliforms, and *E. coli*. All samples showed contamination levels that exceeded the National Environmental Management Authority and World Health Organization recommended value of 0 MPN/100ml for safe drinking water.

The total coliform counts for the sampled wells varied from 33 MPN/100ml to 1600 MPN/100ml. Since coliforms were present in every sampled well, it suggests the wide prevalence of bacterial contamination within the entire study area. Presence of gas after incubation of samples in MacConkey broth for a period of 24 hours, indicated definite evidence for the presence of coliforms. These results are especially important because they

delineate that not one of the wells sampled were within the minimum standards of safety for drinking water.

Fecal coliform tests had equally alarming results as their levels of contamination ranged between 22 MPN/100ml and 1600 MPN/100ml. The presence of the fecal coliforms was confirmed by the gas formation in brilliant green bile lactose broth incubated at 44°C after 24 hours, as recorded in tables 4.1.2.0 and 4.1.2.1. This is very alarming because the presence of fecal coliforms in all the sampled wells indicates specific fecal contamination, hence potential health risks to the consumers.

The detection of *E. coli* by indole production using Kovac's Reagent indicated contamination ranging from 26 MPN/100ml to 1600 MPN/100ml. The red color formation in the upper layer after testing, as illustrated in Figure 4.1.3, gave positive confirmation for *E. coli*. The detection of *E. coli* in all sampled wells is of special significance since it is a specific indicator of fecal contamination and indicates the probable presence of other pathogenic organisms.

These findings denote that all the wells in Moiben Sub-County had severe microbial contamination, and therefore none of the water sources met the standards for safe drinking water. The presence of all three types of microbial indicators-total coliforms, fecal coliforms, and *E. coli* consistently above the recommended limits indicates the severity of the health risk the current sources pose to the community. This broad assessment of microbial contamination provides important background information on the quality of well water in the region and strongly underlines the urgent need for intervention measures to improve water quality and public health.

## 5.2 Physiochemical Parameters in Shallow Wells

The analysis of physiochemical parameters in shallow wells within Moiben Sub-County showed that the water quality indicators such as ammonia, nitrates, nitrites, pH, electrical conductivity, total dissolved solids, and turbidity were significantly different. These parameters are important in giving insight into the chemical and physical characteristics of well waters.

The ammonia concentrations ranged from 0.023 mg/L to 0.985 mg/L in the wells sampled, with several wells exceeding the WHO recommended maximum limit of 0.5 mg/L for drinking water. Ammonia was confirmed by the salicylate method, where a green-colored complex was observed upon testing. This would suggest that there is potential organic contamination, probably arising from agricultural activities in the area, since most residents are large-scale farmers.

The nitrate levels in the well water samples ranged from 0.24 mg/L to 7.17 mg/L, still within the WHO recommended maximum limit of 10 mg/L for drinking water. The nitrate levels were determined by cadmium reduction followed by colorimetric determination of the produced amber-colored azo dye. These moderate levels of nitrate indicate the presence of oxidized nitrogen compounds, although not at levels that are usually associated with severe contamination.

Nitrite analysis gave values between 0.004 and 0.200 mg/L, with some samples showing values above the WHO recommended limit of a maximum of 0.1 mg/L for drinking water. The presence of nitrites was confirmed by the development of a pink-colored azo dye due to the presence of intermediate nitrogen compounds. The variations in nitrite levels would,

therefore, seem to indicate that nitrogen transformation processes are continuously occurring within the groundwater system.

All values fall within the wide limit of pH ranges from 5.5 to 8.5, thus showing a wide variation throughout the study area. Different acidic conditions in most of the studied wells, represented by a lower pH of 7.0 against the post-7.0 alkalinity records, represent great geological diversity that may further face or, if any, certain anthropogenic responses in changing their chemical nature.

The electrical conductivity ranged from 150  $\mu\text{S}/\text{cm}$  to 1500  $\mu\text{S}/\text{cm}$  between different wells. These values correspond to high levels of total ion content dissolved in well water. The high values of EC reveal the substantial mineralization of groundwater in some areas of the region of study. Among these sampled wells, TDS was generally between 150 to 1000 mg/liter, indicating a high quantity of the mobile charged ions present within water, in correspondence to the noted electrical conductivity.

The turbidities ranged from 7 NTU to 40 NTU in the wells. Such a variation in range, demonstrates that the water contained suspended material of every size. Turbidity indicates organic and inorganic suspended matter in the well waters as clarity and in some cases affects their potability.

Comprehensive analysis of these physicochemical parameters indeed shows great fluctuation in the quality of water in all sampled wells from Moiben Sub-County. Higher levels of some parameters, particularly ammonia and nitrites above WHO guidelines, do indeed call for some remedial action regarding the management of the quality of this well water. These results will further contribute to important basic data about the chemical and

physical qualities of well waters in the area that shall be useful for the planning of water quality management.

### **5.3 Relationship Between Well Water Contamination and Distance from Pit Latrines**

The analysis of the relationship between well water contamination and pit latrine distance in Moiben Sub-County revealed significant spatial patterns in both microbial and physiochemical contamination levels.

#### **5.3.1 Total coliforms, fecal coliforms and *E. coli* and their relationship to well distances from pit-latrines**

The total coliform in the samples ranged from 33 to 1600MPN/100ml of water. Of the 62 samples tested, 55 samples were having high coliform ranging from 50 MPN/100ml to 1600 MPN/100ml; this sums it up that 88% of the samples were contaminated. The R squared in ANOVA was 0.728, which implied that 72.8% contamination of the well water tested due to microbial contaminant, exceeded the standard set by World Health Organization. The closer the distance between the wells and the pit latrine the higher the contamination. According to WHO guidelines, coliform levels should not exceed 0 MPN/100ml of water (WHO, 2022) values above this threshold necessitate treatment before the water is considered safe for consumption. The recorded values in this study surpass the accepted limits for drinking water, rendering it unfit for human consumption.

Fecal Coliform test results showed heavy contamination in well water samples. The total coliform counts ranged from 22MPN/100ml to over 1600MPN/100ml. Fecal coliforms in well water are considered a critical indicator of water quality and health risk. These high levels, with some samples reaching 1600MPN/100 ml, far exceed the WHO and NEMA guidelines for safe drinking water, which recommend 0 MPN/100 ml. *E. coli* ranged from

16MPN/100ml to 1600MPN/100ml. The variation of the well distances from the pit latrines was also reflected in the amount of contamination, with those wells far away from the pit latrines having minimal contamination.

A similar study, conducted in several communities in South-Western Nigeria, found that 85% of these wells had coliform counts above 0 MPN/100 mL, the maximum permissible for drinking water. Poor sanitation practices, inadequate waste disposal, and proximity of wells to latrines/refuse dumps were attributed to high levels of contamination. The study thus emphasized the improvement in sanitation infrastructure with education on public health for reducing risks of contamination. A similar incidence of contamination was recorded for Southwest Nigeria. Ganiyu et al. 2021 recorded bacteriological contamination and heavy metals in shallow hand-dug wells around Ona River, while the most ecologically risky heavy metal was cadmium. Anthropogenic activities were pinpointed as the major source, and the non-carcinogenic risk was highest in infants. The study called emphatically for improved hygiene, pre-treatment of water, and access to potable water.

A study by Osiemo, Ogendi, & M' Erimba, 2019, determined the microbiological quality of shallow well water in the Nairobi Metropolitan Area. The study revealed that 60% of the wells tested positive for fecal coliforms, with counts exceeding the WHO permissible limit of 0 CFU/100 mL for drinking water. These were exacerbated by other major sources of contamination such as poor sanitation including the use of pit latrines close to the wells, in addition to faulty waste disposal systems. Umeh in 2020, in a study conducted in South-Western Nigeria reported that as high as 85% of the shallow wells analyzed were contaminated by total coliforms above the permissible limit set by WHO. This level of

contamination is alarming and seems to be posing serious public health risks through drinking water via shallow wells in the region.

Similarly, Petculescu et al., 2022 noted significant seasonal and spatial variation in total coliform and *E. coli* contamination in private wells across Ontario. Using information from more than 253,000 wells in the study, it was indicated that static TC thresholds are not efficient, since during summer and autumn, higher contamination rates were recorded compared to other seasons. The authors called for dynamic evidence-based thresholds and noted that NEC: *E. coli* ratios may help infer the mechanism of groundwater contamination, hence calling for tailored water quality guidelines.

Lyons et al. 2021 investigated the effects of surface water intrusion, land use, and bacterial community composition on shallow groundwater well water quality in a rural area in Finland. Results indicated that surface water intrusion in the wells was inversely related to bacterial alpha diversity. Water quality was generally adequate, although several wells showed impaired water quality due to high turbidity, heterotrophic bacteria, or iron levels. Several wells contained coliform bacteria and fecal indicators, reflecting potential contamination from adjacent land use activities, including agriculture and road deicing. The study outlined the complexity of the microbial community in groundwater and the need for further monitoring and research into surface water intrusion as a potential vector for ground water contamination, as it relates to outbreaks of waterborne diseases.

### **5.3.2 pH, electrical conductivity, total dissolved solids, turbidity and their relationship to well distances from pit-latrines**

These parameters are crucial in determining water quality as they reflect the amount of dissolved ions, organic matter, and suspended particles that may render the water not conducive for consumption.

### **5.3.3 pH**

The study indicates that distances closer to the pit latrine ranging between 10-20 meters have lower pH values of 5.5-6.4 indicating more acidic conditions.

This is likely due to the leaching of acidic compounds from the pit latrine into the groundwater. With increasing distance from the pit latrine, pH values rise steadily toward neutral-7.0-indicating that the influence of acidic leachates decreases with increased distance. For example, at 10 meters, the pH is about 5.5, while at 80 meters, it stabilizes at 8.5, reflecting a neutral to slightly alkaline environment. This trend indicates that good distance between the pit latrine and wells is imperative for maintaining water pH in acceptable and safe limits for consumption and other uses. Distance to the pit latrines has been observed to be a determinant factor in water pH in the Kenyan studies.

The proximity often leads to more acidic conditions resulting from the leaching of organic matter and nitrates from the latrines. According to Kaponda (2019), a study revealed that pH values generally tended to decrease with decreasing distance to pit latrines, probably because of increased levels of contamination. This same trend was also clear from a study in rural Kenya where the pH values were relatively lower in wells closer to latrines, hence showing increased levels of organic and microbial contamination (Ngatia, 2022).

#### **5.3.4 Electrical conductivity**

According to the study, the wells whose distance to the pit-latrine is closer show high EC values, being 1500  $\mu\text{S}/\text{cm}$  at 10 meters, reducing linearly with distance. At 80 meters, the values drop to 150  $\mu\text{S}/\text{cm}$ . The trend from this shows that the amount of dissolved ions in water close to the pit latrine is high, maybe due to the leaching of electrolytes from the latrine into the groundwater. As the distance increases, the effects of these contaminants become minimal; hence, the reduced values of EC. This decreasing nature of EC with distance proves that increased separation is effective in reducing ionized contaminants from pit latrines to make water safer for drinking and agricultural use. Research by (Gokçekuş et al., 2020) indicated a clear increase in EC values in wells closer to pit latrines, which is attributed to the seepage of salts and minerals from human waste. This trend is supported by various studies that reported significantly higher levels of EC in groundwater samples near pit latrines than those that were further away, reflecting the influence of latrine leachate on groundwater quality (Kisi et al., 2022).

#### **5.3.5 Total dissolved solids**

The trend from the study also indicates higher values of TDS close to the pit latrine, with values at about 1000 mg/L at 10 meters reducing to 150 mg/L at 80 meters. This reproduces the trend seen in the EC data since TDS is directly proportional to the amount of ions dissolved in water. The high TDS values close to the pit latrine point to intense leaching of many soluble components, such as nitrates, phosphates, and organic matter, from the latrine into the groundwater. The gradual decrease in TDS with the increase in the distance shows a dilution effect and attenuation of these contaminants due to their wide nature through soil and groundwater, hence the proper placement of wells away from potential sources of

contamination. A study by Lutterodt et al. (2023) reported that the TDS levels were significantly higher in wells within 20 meters of pit latrines, evidenced by significant leaching of both organic and inorganic materials from the latrines into the groundwater. This agrees with findings around the world on the association of proximity to sanitation facilities with increased TDS levels in groundwater (Cui et al., 2022).

### **5.3.6 Turbidity**

From the study, it is observable that the turbidity of wells closer to the pit latrine is the highest, about 40 NTU at 10 meters, while it diminishes to 7 NTU at 80 meters.

High turbidity close to the latrine is most probably due to the infiltration of particulate matter from the latrine waste, both organic and inorganic. With increased distance from the latrine, turbidity decreases significantly, indicating that with increased distance, the concentration of suspended particulates is reduced. This trend supports the natural filtration process occurring within the soil matrix whereby particulates are removed as water moves further away from a contaminant source.

A lower turbidity can be maintained to keep water safer for drinking because high turbidity may protect harmful microorganisms and interfere with disinfection. In Kenya, studies have indicated that wells nearer to pit latrines usually show higher turbidity levels. For example, the study by Ochiba 2020 established that the level of turbidity significantly increased in wells within 15 meters of pit latrines, showing suspended solids and microbial contamination from latrine effluent. This is supported by the conclusion of other related studies, in which proximity to pit latrines also emerged as strong predictors of increased turbidity in the groundwater (Kanouo et al., 2023).

### **5.3.7 Ammonia, Nitrates, Nitrites, and Their Relationship to Well Distances from Pit-Latrines**

From the test conducted, the result showed that levels of ammonia contamination varied among sampled wells. The ammonia level in the well water samples ranged from 0.061 mg/L to 1.0 mg/L; several samples exceeded the recommended maximum limit set by the WHO (2020), of 0.5 mg/L for drinking water. This was quite significant especially in wells whose distances from pit Latrines were very small. The nitrite concentrations in the well water samples ranged from 0.004 to 0.2 mg/L, and several samples had levels above the World Health Organization's recommended maximum limit of 0.1 mg/L in drinking water. The concentration of nitrates in the well water samples ranged from 1 mg/L to 7 mg/L, with several samples not exceeding the World Health Organization (WHO) recommended maximum limit of 10 mg/L for drinking water.

## **CHAPTER SIX: CONCLUSION, RECOMMENDATIONS AND PUBLICATION**

### **6.0 Introduction**

This chapter presents the conclusion and recommendations of the study on microbial quality and physicochemical parameters of shallow well water in Moiben Sub-County, Uasin Gishu County. The research systematically surveyed well water quality in relation to their proximity to pit latrines using both microbial contamination levels and physicochemical parameters among 62 shallow wells within the locality.

These were guided in the study by three major objectives: to determine the level of microbial contamination of shallow wells; analyze physicochemical parameters of well water; and establish the relationship between contamination of well water and distance to pit latrines. Extensive laboratory analysis and field observations to obtain meaningful insight into the current state of water quality with respect to its consequences on the public health of Moiben Sub-County were carried out.

The conclusion and recommendations stand on the empirical evidence obtained from the quasi-experimental design and observation methods undertaken in this study. These findings will contribute significantly to informing water resource management, public health policy, and community well-being in Moiben Sub-County and other areas that experience challenging situations about water quality and sanitation infrastructure.

### **6.1 Summary of Key Findings**

#### **6.1.1 Microbial Contamination Levels in Shallow Wells**

The study revealed pervasive microbial contamination across all sampled wells in Moiben Sub-County, with none meeting the WHO and NEMA standards for safe drinking water.

Key findings shows that total coliform contamination ranged from 33 to 1600 MPN/100ml, with 88% of samples showing high contamination levels between 50-1600 MPN/100ml.

Fecal coliform levels varied from 22 to 1600 MPN/100ml, indicating widespread fecal contamination, *E. coli* concentrations ranged from 26 to 1600 MPN/100ml, confirming the presence of fecal matter in all sampled wells and Statistical analysis showed that 72.8% of water contamination could be attributed to microbial factors.

### **6.1.2 Physicochemical Parameters of Well Water**

Analysis of physicochemical parameters revealed significant variations across the sampled wells showing that Ammonia levels ranged from 0.023 to 0.985 mg/L, with several wells exceeding the WHO limit of 0.5 mg/L,

Nitrate concentrations varied from 0.24 to 7.17 mg/L, remaining within WHO guidelines of 10 mg/L, Nitrite levels ranged from 0.004 to 0.200 mg/L, with some wells exceeding the WHO limit of 0.1 mg/L,

pH values varied from 5.5 to 8.5, indicating both acidic and alkaline conditions, Electrical conductivity measurements ranged from 150 to 1500  $\mu$ S/cm, Total Dissolved Solids ranged from 150 to 1000 mg/L and Turbidity levels varied from 7 to 40 NTU.

### **6.1.3 Relationship Between Well Water Contamination and Pit Latrine Distance**

The study established a clear correlation between well distance from pit latrines and contamination levels. Wells located closer to pit latrines consistently showed higher levels of contamination. The relationship was particularly strong for microbial contamination indicators and the pattern of contamination aligned with findings from similar studies in other regions, including research from Nigeria, Bangladesh, and Nepal.

## **6.2 Conclusion**

Based on the specific objectives, the following conclusions were drawn:

All sampled wells in Moiben Sub-County are contaminated with levels of total coliforms, fecal coliforms, and E. coli that exceed safe drinking water standards. The universal presence of these microbial indicators suggests widespread fecal contamination of groundwater resources and current water sources pose significant health risks to the community

Several wells showed elevated levels of ammonia and nitrites above WHO guidelines. The variation in physicochemical parameters indicates diverse geological influences and anthropogenic impacts while some parameters remained within acceptable limits.

A clear inverse relationship exists between well distance from pit latrines and contamination levels. Proximity to pit latrines significantly influences both microbial and physicochemical water quality parameters. Current well placement practices may not adequately protect water sources from contamination.

## **6.3 Recommendations**

The first priority is given to improving the sanitation infrastructure by constructing well-engineered latrines and sewage systems. Efforts should be made to ensure that the distance between the pit latrines and groundwater sources is kept at 50 meters to avoid fecal contamination.

Ensuring shallow wells are protected and that proper maintenance is observed is the better way of preventing microbial contamination. Wells need to be properly constructed, sealed, and also maintained to avoid reaching surface contaminants into groundwater. This will

ensure monitoring of water quality periodically to identify possible contamination and swift measures taken towards it.

Community-based education and awareness programs should be provided to sensitize residents on the importance of water quality and associated risks with intake of contaminated water. Communities should be encouraged toward adoption of safe water practices-boiling or treating water before consumption-to reduce risks of waterborne diseases.

Investment should be made in improved sanitation infrastructure, including the building of well-engineered latrines and sewage systems, to avoid the leaching of contaminants into the groundwater sources. Efforts have to be done in order to promote proper waste disposal practices and proper distance between the wells and contamination sources.

Introduction of nitrates and other pollutants into groundwater could be reduced by the introduction of best agricultural practices, such as controlled application of fertilizers and buffer zones between agriculture and water sources. Agricultural extension services are at the helm in directing farmers to utilize sustainable farming techniques with reduced environmental impacts from agricultural activities.

#### **6.4 Suggestions for Further Research**

Based on the limitations and findings of this study, the following areas are recommended for future research:

Seasonal Variation Analysis; Further research should examine the temporal variations in well water quality across different seasons in Moiben Sub-County. This would provide insights into how rainfall patterns and seasonal changes affect both microbial contamination levels and physicochemical parameters in shallow wells.

Hydrogeological Assessment; A comprehensive study of the local hydrogeology, including groundwater flow patterns and soil characteristics, would enhance understanding of contaminant transport mechanisms between pit latrines and shallow wells. This would help in developing effective guidelines for well placement and protection.

Health Impact and Economic; Analysis Research investigating the relationship between water quality parameters and the prevalence of waterborne diseases in the community would be valuable. This should include analysis of healthcare costs and economic impacts associated with water contamination to guide policy interventions.

These suggested areas of research would address current knowledge gaps and contribute to improving water quality management strategies in Moiben Sub-County and similar regions.

## **6.5 Publication**

Wang'ondu, L., Mwangi, E., & Mberia, J. The assessment of shallow well water quality in relation to well distance from the pit latrine: a case study of Moiben Sub-county, Uasin – Gishu County. *African Journal of Science, Technology and Social Sciences*, 4(2), PAS 1–10.

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**APPENDICES**

**Appendix A: Informed Consent**

The importance of this study is to determine the levels of microbial quality and physiochemical parameters of shallow wells in relation their proximity to pit- latrines in Moiben Sub-County, Uasin- Gishu County. No third party will be able to access the collected data; it will only be used for academic purposes. Gaining an understanding on the level of microbial contamination and physiochemical parameters in shallow wells, and the relationship between well contamination and the distances of the wells from pit- latrines at Moiben Sub-County are the objectives. The solitary purpose of the researcher's study is to broaden your understanding on the levels of microbial quality of shallow wells in relation their proximity to pit- latrines by learning about your opinions on the subject. Please take note that participation in this study is completely voluntary; you are free to accept or reject it. It will be necessary for you to allow collection water samples from your wells and measure the distances of the well from the pit-larine.

Kindly indicate your stand in participating in this study by signing this consent form:

I grant you permission to enter my compound (tick where appropriate)

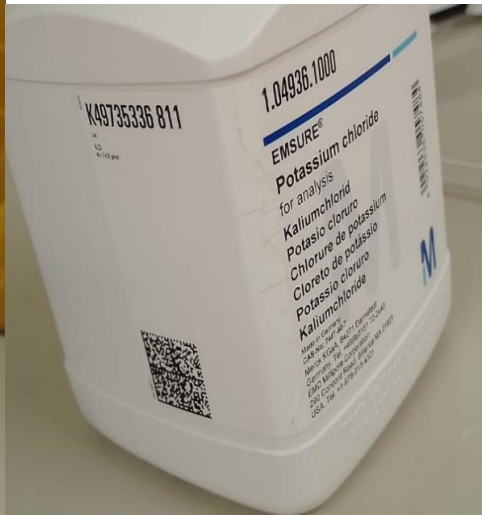
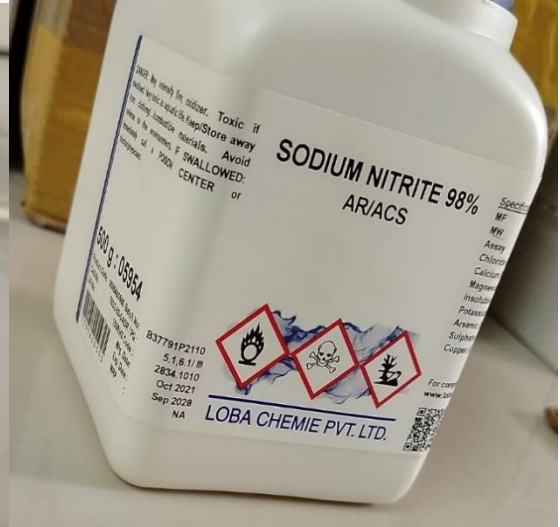
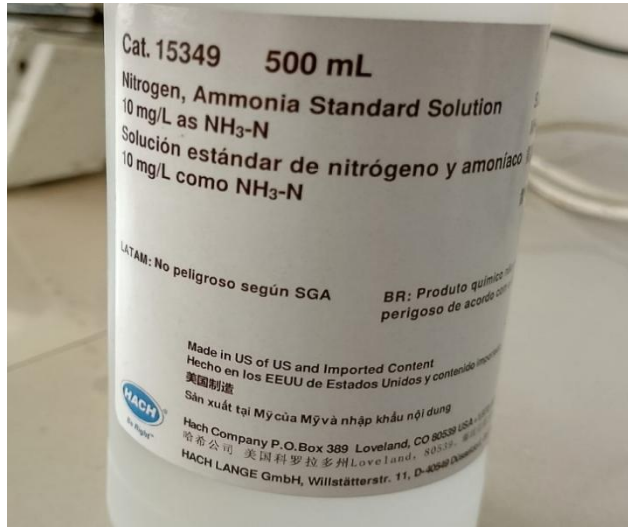
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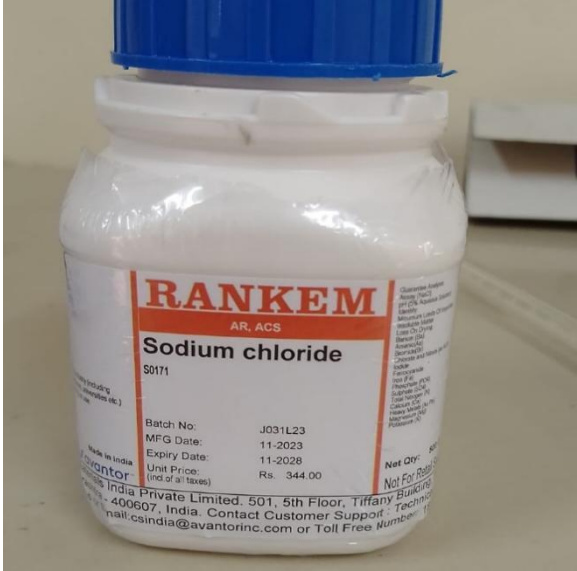
No [ ]

Name: .....

Signature: .....









### Appendix C: Tabulation of pH, EC, TDS and turbidity

pH	EC ( $\mu\text{S/cm}$ )	TDS (mg/L)	Turbidity (NTU)
Mean	6.414516	781.4516	29.5
Standard Error	0.081461	44.94891	0.94249
Median	6.4	725	29.5
Mode	6.6	1100	36
Standard Deviation	0.641424	353.9281	7.42117
Sample Variance	0.411425	125265.1	55.07377
Kurtosis	2.28512	-0.85937	1.2557
Skewness	1.315395	0.22542	-1.00716
Range	3	1350	33
Minimum	5.5	150	7
Maximum	8.5	1500	40
Sum	397.7	48450	1829
Count	62	62	62

**Appendix D: Ethical Approval, NACOSTI Research License**

  
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**This is to Certify that Miss.. Leah wangari Wang'odu of Meru University of Science and Technology, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Uasin-Gishu on the topic: ASSESSMENT OF MICROBIAL QUALITY OF SHALLOW WELLS IN MOIBEN SUB- COUNTY, UASIN-GISHU COUNTY. for the period ending : 24/June/2025.**

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## Appendix E: Publication



### Assessment of shallow well water quality in relation to well distance from the pit latrine a case study of Moiben Sub-county, Uasin-Gishu County

Leah Wangari Wang'ondy,<sup>1</sup> Erastus Mwangi<sup>1</sup> and Jane Mberia<sup>2</sup>

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#### ARTICLE INFO

#### ABSTRACT

##### KEY WORDS

Microbial contamination  
Water contamination  
Physicochemical parameters  
Shallow well  
Pit latrine

Sustainable Informal settlements in urban areas of sub-Saharan Africa often rely heavily on shallow dug wells for their water supply. However, these wells are susceptible to contamination from various sources due to a lack of protection. This study aimed to assess the microbial quality and physicochemical parameters of shallow wells in Moiben Sub-County, Uasin Gishu County. Specifically, the study sought to: (i) determine the level of microbial contamination in shallow wells, (ii) analyze the physicochemical parameters of the water, and (iii) establish the relationship between shallow well water contamination and the distance of the wells from nearby pit latrines. The study population was 62 shallow wells in five zones of the sub-county. Stratified sampling technique was utilized in proportionally sampling wells for examination. Laboratory analysis was conducted to measure microbial indicators like fecal coliforms, *E. coli*,

and total coliforms, and physicochemical parameters like pH, TDS, electrical conductivity, turbidity, nitrates, nitrites, and ammonia. Observational method was utilized to measure the distance of pit latrines from wells. Data was analyzed inferentially through ANOVA, while microbial contamination was quantified using the Most Probable Number (MPN) technique. Findings indicated that there was a significant correlation between distance from the well and microbial contamination ( $p < 0.001$ ), and 72.8% of microbial contamination was accounted for by distance. Likewise, 98.7% of physicochemical parameter contamination was accounted for by distance. The results point out that shallow wells closer to latrines have greater levels of contamination, above WHO's safe drinking water guidelines. The research emphasizes maintaining a minimum distance of 50 meters between pit latrines and groundwater sources to avert fecal contamination. The final beneficiaries of these results are policymakers, members of the community, and local health administrators, who can use the data to improve public health, sanitation facilities, and water quality in the region.

##### Introduction

Many developing countries rely on untreated groundwater, which can be contaminated by on-site sanitation systems (Li et al., 2021). The World Health Organization states that potable water

should meet standards in physical features, chemical composition, bacteriological content, and general acceptability to ensure safety for drinking and cooking (WHO, 2021). In urban areas with high

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# Appendix F: Plagiarism Report



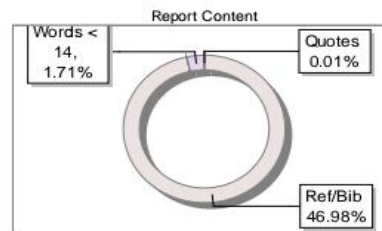
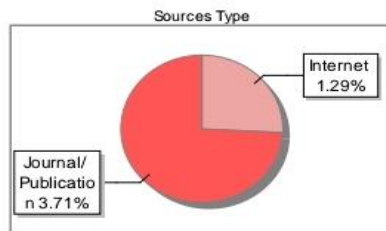
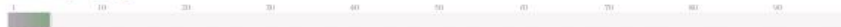
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