

**AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND
ENTREPRENEURIAL DEVELOPMENT**



**WASTEWATER TREATMENT AND REUSE FOR URBAN IRRIGATION: A
CASE STUDY AT KORLE-BU VEGETABLE FARM IN ACCRA, GHANA**

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**THESIS SUBMITTED TO THE GRADUATE SCHOOL, AKENTEN APPIAH-
MENKA UNIVERSITY OF SKILLS TRAINING AND ENTREPRENEURIAL
DEVELOPMENT IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF A MASTER OF PHILOSOPHY DEGREE IN
ENVIRONMENTAL AND OCCUPATIONAL HEALTH EDUCATION**

MAY, 2025

DECLARATION

STUDENT

I, Peter Dinko, declare that this thesis, except quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE

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SUPERVISORS

I hereby declare that the preparation and presentation of this work were supervised in accordance with the guidelines for supervision of thesis/dissertation/project as laid down by the Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development.

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ACKNOWLEDGMENT

I am grateful to my supervisors, Dr. Kofi Sekyere Boateng, Dr Joana Apenkwa and Ing. Prof. Isaac Monney for their unwavering support and encouragement throughout this thesis. I also thank Dr. Nii Kpakpo Adotey, head of environmental chemistry laboratory, Ghana Atomic Energy Commission for his guidance, support and encouragement throughout the sampling and laboratory analysis. I am grateful to Abraham Anyagre, a colleague staff of Accra school of hygiene for his support during sampling and setting up the treatment system.

DEDICATION

This thesis is specially dedicated to my Daddy, the holy spirit for the strength and inner peace granted me throughout this work even in the midst of certain turbulence in life. I also dedicate it to the mother of my daughter, my best pair, prayer partner and comrade Margeret Armah for her support and encouragement.

LIST OF ABBREVIATIONS

| | |
|-------------|---|
| ANTs..... | Anaerobic treatments |
| ATs..... | Aerobic treatments |
| BOD..... | Biochemical oxygen demand |
| COD..... | Chemical oxygen demand |
| TN..... | Total nitrogen |
| SDGs..... | Sustainable development goals |
| UV..... | Ultra violet |
| EU..... | European union |
| GSS..... | Ghana statistical service |
| TSS..... | Total suspended solids |
| TDS..... | Total dissolved solids |
| NTU..... | Nephelometric turbidity unit |
| WHO..... | World health organisation |
| BAF..... | Biologically aerated filter |
| EC..... | Electrocoagulation |
| MBRs..... | Membrane bioreactors |
| NF..... | Nanofiltration |
| RO..... | Reverse osmosis |
| GH-EPA..... | Ghana environmental protection agency |
| PSU..... | Practical salinity unit |
| KNUST..... | Kwame Nkrumah university of science and technology |

| | |
|------------|---|
| DO..... | Dissolved oxygen |
| SAR..... | Sodium adsorption ratio |
| PPCPs..... | Pharmaceutical and personal care products |
| TOC..... | Total organic carbon |
| TP..... | Total phosphate |
| MPN..... | Most probable number |
| CFU..... | Coliform forming unit |
| WSPs..... | Wastewater stabilization ponds |
| TH..... | Total hardness |

ABSTRACT

The use of untreated wastewater from open drains for irrigation in urban vegetable farms is increasing in Ghana due to high cost of treated water; meanwhile less than 50% of this wastewater undergoes prior treatment before disposal suggesting a potential health threat when used for irrigation. This research sought to develop a simple wastewater treatment system for reuse in irrigation. The mean chemical characteristics of wastewater were, Biochemical oxygen demand (325mg/l), Chemical oxygen demand (1072mg/l), Lead (0.35mg/l), As (1.6mg/l), Sodium absorption ratio (2.35meq/l). The recorded level of mercury was below detectable limit of 0.0005mg/l. Almost all parameters reduced by a significant percentage after treatment making it fit for use in irrigation. the mean difference in parameter of raw and treated wastewater were as follows; Electrical conductivity reduced by 79.6%, Total dissolved solids reduced by 40.81%, Total suspended solids reduced by 99.85%, S Turbidity reduced by 98.68%, Biochemical oxygen demand reduced by 99.65%, Chemical oxygen demand reduced by 89.04%, Lead reduced by 83.74%, Arsenic reduced by 99.16%, *Escherichia coli* reduced by 100% and Sodium absorption ratio reduced by 47.23%. At 95% confidence level ($\alpha=0.05$). A t-test showed significant difference between the treated and intreated wastewater. The reduction rate was significant since most parameters considered conformed to regulatory standards for irrigation of vegetable crops after treatment. It is recommended that vegetable crop farmers adapt the system to prevent the spread of diseases caused by irrigating crops with contaminated water sources of similar characteristics.

TABLE OF CONTENTS

| | |
|---|------|
| DECLARATION | iii |
| ACKNOWLEDGMENT | ii |
| DEDICATION | iii |
| LIST OF ABBREVIATIONS | iv |
| ABSTRACT | vi |
| TABLE OF CONTENTS | vii |
| LIST OF TABLES | xii |
| LIST OF FIGURES | xiii |
| | |
| CHAPTER ONE | 1 |
| INTRODUCTION | 1 |
| 1.1 Background to the study..... | 1 |
| 1.2 Problem Statement | 3 |
| 1.3 Main Objective of The Research..... | 4 |
| 1.3.1 Specific Objectives..... | 4 |
| 1.4 Research Questions | 4 |
| 1.5 Justification of the study | 5 |
| 1.6 Significance of the Study | 5 |
| 1.7 Scope of the study | 6 |
| 1.8 Limitation of the Research | 7 |
| | |
| CHAPTER TWO | 8 |
| LITERATURE REVIEW | 8 |
| 2.1 Characteristics of wastewater used for irrigation..... | 8 |
| 2.1.1 Physical characteristics of wastewater | 8 |
| 2.1.2 Impact of color on wastewater quality for irrigation..... | 8 |

| | |
|--|----|
| 2.1.3 Turbidity of wastewater used for irrigation..... | 9 |
| 2.1.4 Total Suspended Solids (TSS) of wastewater | 9 |
| 2.1.5 pH of wastewater..... | 10 |
| 2.1.6 Electrical Conductivity of wastewater | 12 |
| 2.1.7 Sodium Adsorption Ratio..... | 13 |
| 2.1.8 Odour of wastewater used for irrigation | 15 |
| 2.2 Chemical parameters of wastewater..... | 17 |
| 2.2.1 Mercury in wastewater..... | 25 |
| 2.2.2 Lead in wastewater used for irrigation..... | 27 |
| 2.2.3 Arsenic in wastewater | 28 |
| 2.2.4 Chemical oxygen demand in wastewater..... | 30 |
| 2.2.5 Total organic carbon in wastewater used for irrigation..... | 30 |
| 2.2.6 Total nitrogen in wastewater..... | 32 |
| 2.2.7 Total phosphate | 33 |
| 2.3 Biological characteristics of wastewater | 34 |
| 2.3.1 Pathogens | 34 |
| 2.3.2 Total coliform in wastewater..... | 35 |
| 2.3.3 Fecal coliform in wastewater | 36 |
| 2.3.5 <i>Escherichia coli</i> (<i>E. coli</i>)..... | 38 |
| 2.3.6 <i>Salmonella</i> spp in wastewater | 40 |
| 2.3.7 Enterococci in wastewater..... | 41 |
| 2.4 Technologies used to treat wastewater..... | 42 |
| 2.4.1 Wastewater stabilization ponds..... | 42 |
| 2.4.2 The use of constructed wetlands | 43 |
| 2.4.3 The use of rapid sand filtration for wastewater treatment..... | 45 |
| 2.4.4 The use of slow sand filters for wastewater treatment | 46 |
| 2.5 Regulatory requirements for water used for irrigation..... | 46 |

| | |
|--|----|
| CHAPTER THREE..... | 48 |
| METHODOLOGY..... | 48 |
| 3.0 Introduction..... | 48 |
| 3.1 Study site..... | 48 |
| 3.2 Sampling technique..... | 49 |
| 3.2.1 Research Design..... | 49 |
| 3.2.2 Sample size determination of raw wastewater..... | 49 |
| 3.3 Sample collection of raw wastewater..... | 49 |
| 3.3.1 Raw wastewater samples..... | 49 |
| 3.3.2 Treated Wastewater Samples..... | 50 |
| 3.4. Design of experimental scale system..... | 50 |
| 3.4.1 Preparation of sand..... | 50 |
| 3.4.2 Preparation of sawdust activated carbon..... | 51 |
| 3.4.3 Experimental setup..... | 51 |
| 3.4.4 Model of wastewater treatment system..... | 53 |
| 3.4.5 Size of Sedimentation Tank..... | 53 |
| 3.4.6 Overflow Velocity (Surface Loading Rate)..... | 55 |
| 3.4.7 Flow Through Velocity..... | 55 |
| 3.4.8 Inflow Rate..... | 55 |
| 3.4.9 Designing an experimental scale system..... | 56 |
| 3.4.10 Dimensions of Sedimentation Tank..... | 56 |
| 3.4.11 Filter Bed Depth..... | 56 |
| 3.4.12 Surface Area..... | 56 |
| 3.4.13 Determining the depth of filter bed..... | 56 |
| 3.4.14 Filter Medium..... | 57 |
| 3.4.15 Trial Studies..... | 57 |
| 3.5 Laboratory analysis..... | 58 |

| | |
|---|----|
| 3.5.1 Parameters to be determined | 58 |
| 3.5.2 pH..... | 58 |
| 3.5.3 Dissolved oxygen | 58 |
| 3.5.4 Biochemical oxygen demand | 59 |
| 3.5.5 Chemical oxygen demand..... | 59 |
| 3.5.6 Total suspended solids | 59 |
| 3.5.7 Total dissolved solids..... | 60 |
| 3.5.8 Electrical conductivity | 61 |
| 3.5.9 Salinity | 61 |
| 3.6.10 Total hardness | 61 |
| 3.5.11 Alkalinity | 62 |
| 3.5.12 Chlorine..... | 62 |
| 3.5.13 Sodium | 62 |
| 3.5.14 Calcium..... | 63 |
| 3.5.15 Magnesium..... | 63 |
| 3.5.16 Total phosphate | 63 |
| 3.5.17 Total nitrogen..... | 64 |
| 3.5.18 Mercury..... | 64 |
| 3.5.19 Lead..... | 65 |
| 3.5.20 Arsenic | 65 |
| 3.5.21 Total coliform..... | 65 |
| 3.5.22 Fecal coliform | 65 |
| 3.5.23 <i>Escherichia coli</i> | 66 |
| 3.5.24 <i>Salmonella spp</i> | 66 |
| 3.5.25 Turbidity..... | 66 |
| 3.6 Statistical Analysis..... | 67 |

| | |
|--|-----|
| CHAPTER FOUR..... | 68 |
| RESULTS AND DISCUSSION | 68 |
| 4.0 Introduction..... | 68 |
| 4.1 Results..... | 68 |
| 4.1.1 Physical Observation and Description of Wastewater | 68 |
| 4.1.2 Physical characteristics of wastewater | 70 |
| 4.1.3 Chemical characteristics of wastewater | 74 |
| 4.1.4 Microbial characteristics of wastewater..... | 82 |
| 4.1.5 Characteristics of raw and treated wastewater | 85 |
| 4.2 Discussion of Findings..... | 99 |
| 4.2.1 Physical characteristics of wastewater | 99 |
| 4.2.2 Chemical characteristics of wastewater | 101 |
| 4.2.3 Removal efficiency of contaminants..... | 104 |
| | |
| CHAPTER FIVE..... | 108 |
| CONCLUSIONS AND RECOMMENDATIONS..... | 108 |
| 5.0 Introduction..... | 108 |
| 5.1 Conclusions..... | 108 |
| 5.2 Recommendations | 110 |
| 5.2.1 Recommendation for policy decisions | 110 |
| 5.2.2 Recommendation for further research..... | 110 |
| 5.2.3 Recommendation for Farmers..... | 110 |
| | |
| REFERENCES..... | 112 |
| APPENDICES | 134 |

LIST OF TABLES

| | |
|---|----|
| Table 4.1: Physical characteristics of wastewater | 71 |
| Table 4.2 Chemical Parameters of Wastewater | 76 |
| Table 4.3 Microbial Analysis of Wastewater..... | 83 |
| Table 4.4: Parameters of raw and treated wastewater (Day one to day four) | 86 |
| Table 4.5: Parameters of raw and treated wastewater (Day-5 to Day-8) | 87 |
| Table 4.6: Percentage Difference in Treated and Raw Wastewater..... | 88 |
| Table 4.7: Statistical analysis of raw and treated wastewater characteristics | 98 |

LIST OF FIGURES

| | |
|---|----|
| Figure 2.1: Conceptual framework of wastewater treatment | 47 |
| Figure 3.1 sampling and laboratory analysis of wastewater | 50 |
| Figure 4.1: Picture of flow channel impoundment of wastewater | 69 |

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

As pressures on freshwater resources increase globally and new sources of supply become increasingly scarce, expensive, or politically contentious, it is crucial to identify new and innovative ways to meet present and future water needs. In other to do this coupled with the need to safeguard our environment, improved and environmentally friendly techniques must be used as alternatives for recovering water sources that were previously considered waste (Garrick *et al.*, 2020). Population growth has also necessitated the need to grow crops in the urban space compared to the indigenous way of overreliance on food from rural areas (Imathiu, 2021).

There is the need to develop more sustainable practices for the management and efficient use of water resources, as well as the need to protect the environmental ecosystems where these resources are located (Rousseau & Deschacht, 2020). However, despite increased awareness of the issues at stake, economic criteria and politically charged reasoning are still driving water resource development decisions at most local, regional, national and international levels (Yetim, 2023). Though the long-term benefits of an integrated approach to achieving sustainable water resources development have been cited in many of the global water conferences over the past decade, considerable time and change in policy will be required to implement such an approach. At present, best available practice and scientific knowledge are rarely adequately factored into decision-making or well represented when establishing water resource policy or implementing management practices. (Fu *et al.*, 2020).

The combination of both naturally occurring conditions and humanity's actions creates pressure on our water resources (Jain & Singh, 2023).

Climate change and natural variability in the distribution and occurrence of water are the natural driving forces that complicate the sustainable development of our water resources (Mishra, 2023). While many issues remain on how to deal with and alleviate the pressures on our water resources, the progress being made in some sectors is worth noting. Natural units, such as river basins and aquifer systems, are becoming institutionally recognized. Basin-oriented water resources assessment is increasingly being adopted by national and regional programmes and due consideration is given to the need to identify the critical volume and quality of water needed to maintain ecosystem resilience (Yazawa *et al.*, 2023). We are also seeing the emergence of highly detailed analyses of the processes involved as well as results-based diagnoses from catchment agencies, basin commissions and watershed and aquifer management authorities. These activities are being carried out globally in a variety of different economic and cultural settings and at different sizes and scales (Troell *et al.*, 2023).

Most of these organizations were created relatively recently for jurisdictions that correspond to physical hydrological limits rather than historically defined administrative boundaries (Zipper *et al.*, 2020).

The research also agrees with Ghana's environmental sanitation policy's principle of encouraging locally accepted ways of improving wastewater management (Brewer, 2022). This study will therefore help provide a simple and scientifically proven technique of safeguarding our freshwater resources while helping the agriculture industry to produce healthy vegetable crops even in the urban areas where wastewater is used for irrigation.

1.2 Problem Statement

The use of wastewater collected in open drains for irrigation in vegetable farms at urban centers is increasingly becoming dominant in Ghana (Gbedemah *et al.*, 2024a). This phenomenon is partly due to high cost of treated water, increased anthropogenic activities that leads to excessive pollution of surface water in the urban centers, release of harmful substances into water bodies and open drains by industries producing liquid effluents and the growing need of the population to acquire a sustainable supply of food to augment foodstuffs transported from rural areas. This makes the quality of municipal wastewater to keep deteriorating. Less than 50% of municipal wastewater from industries, institutions and other premises undergo treatment regime before disposed into open drains in Ghana (Awere, 2021).

In Accra, vegetable farms near Korle-Bu are important source of urban supplies of vegetables such as serve supplies vegetable such as lettuce, cabbage, carrot among others. These vegetable farms also rely largely on wastewater from the open drains (Osei *et al.*, 2021).

Municipal wastewater characteristics (physical, biological and chemical) are far above the standard for wastewater disposal and irrigation set by the World Health Organisation (WHO) and Environmental Protection Agency of Ghana (Drechsel *et al.*, 2022). In Ghana, majority of food joints use vegetables for preparation and garnishing. Some of these vegetables are produced from sources that use these wastewaters for irrigation (Gbedemah *et al.*, 2024a).

The utilization of wastewater for irrigation poses significant public health risks due to exposure to various pathogens, including Salmonella (Amahmid *et al.*, 2023). Studies have shown that wastewater used in agriculture can contain pathogenic parasites like Giardia, Ascaris, and Trichuris, which can contaminate soil and crops, leading to increased health risks for individuals exposed to these contaminated environments (Amahmid *et al.*, 2023).

Additionally, the presence of pathogenic microorganisms in wastewater, such as endocrine disruptors, pose serious biological risks to human health when used for irrigation purposes (Ozkay *et al.*, 2022). This study sought to develop a simple wastewater treatment system for reuse in vegetable crop irrigation with Korle-Bu vegetable farm as case study.

1.3 Main Objective of The Research

The aim of the research was to develop an environmentally friendly system for wastewater treatment and reuse for urban irrigation.

1.3.1 Specific Objectives

1. To determine the physical, chemical, and microbial characteristics of wastewater used for irrigation.
2. To develop a simple and innovative wastewater treatment system.
3. To assess the performance of the experimental scale wastewater treatment system.

1.4 Research Questions

1. Given the quantity of water required for irrigation, which treatment system is cost-effective and environmentally friendly for farmers at the Korle-Bu vegetable farm?
2. What is the quality of wastewater after treatment with the design system?
3. What is the quality (physicochemical and microbiological) of wastewater used for irrigation at the vegetable farm?

1.5 Justification of the study

Reliable and useful data and information on irrigation water characteristics in Ghana especially for urban centers where agriculture relies largely on wastewater for irrigation are scanty and this knowledge gap needs to be properly addressed in an attempt to settle on an appropriate economic, technical and engineering solution to treating wastewater of varying characteristic for reuse in irrigation. It is also important to settle on a scientifically accepted treatment regime which produces sustainably usable water for the agricultural industry given the variations in seasons and wastewater characteristics. This research is focused on producing relevant and informative data on the characteristics of wastewater used for irrigation in urban centers with Korle-Bu vegetable farm as a case study from existing literature and field studies.

It also explores several different ways of wastewater treatment and reuse for other purposes such as irrigation in order to come up with a more environmentally friendly, cost-effective, economically, and technically feasible mechanism of purifying wastewater. The research serves as a platform for piloting a simple and innovative wastewater treatment system in urban irrigation and a possible future scale-up. The research also agrees with Ghana's environmental sanitation policy which advocates that local knowledge, practices and approaches must be explored for effective wastewater management. This study will therefore gather in a single organised document the characteristics of wastewater used for irrigation and simple mechanisms of treating and purifying it to help the urban vegetable industry produce wholesome food crops.

1.6 Significance of the Study

There are three main attributes of water that makes it unique from any other resource. These attributes are; fresh water is vital to sustain life, for which there is no substitute.

This means that water has a (high) value to its users., Although water is a renewable resource, it is practically speaking finite. Many uses of water are therefore subtractable, meaning that the use by somebody may preclude the use by somebody else. Water is a fugitive resource. It is therefore difficult to assess the (variations in) stock and flow of the resource, and to define the boundaries of the resource. This complicates the planning and monitoring of withdrawals as well as the exclusion of those not entitled to abstract water. Its fugitive nature makes it also more costly to harness, requiring the construction of reservoirs (Sishekanu & Katati, 2022).

These three attributes of water make it handling and use a key aspect of our everyday life that cannot be overemphasized. It is very crucial to conserve water to sustain current and future lives. This makes it important to treat water after use to provide support for the future populations.

This wastewater is loaded with several microorganisms which are threats to public health. Some farmers also believe that this wastewater contains nutrient which helps to increase crop yield. Farmers are also not ready to adapt a wastewater treatment system that is relatively expensive (Pesewu *et al.*, 2017a).

The research will serve as a scientific bases for adapting to proper irrigation practices as well as promoting public health. The study can also be adopted by agencies that use wastewater of similar characteristics to ensure compliance to effluent standards.

1.7 Scope of the study

The research aimed to determine the physico-chemical and bacteriological characteristics of wastewater used for irrigation in urban centers of Ghana with Korle-bu vegetable farm as a case study.

It also aimed to design a cost-effective and environmentally friendly treatment system to purify wastewater to meet regulatory standards for irrigation. Additionally, the study aimed at comparing the treated and untreated wastewater to local and international water quality standards.

1.8 Limitation of the Research

The treatment system will only be effective for wastewater of similar characteristics to that of the study area since different contaminants require different treatment processes. Other characteristics of wastewater such as radiological did not form part of the parameters under study.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This part presents reviews of existing works relating to the research study from various journals, published and unpublished academic work and other internet sources. It identifies similarity and differences in result of similar research. This section also explores the most appropriate and cost-effective mechanism of treating wastewater for reuse given the socio-economic conditions of beneficiaries.

2.1 Characteristics of wastewater used for irrigation

2.1.1 Physical characteristics of wastewater

Water is a scarce resource, and its efficient use is necessary for sustainable development. Agriculture is one of the largest users of water globally, and there is a need to explore alternative water sources to meet the increasing water demand for irrigation (Osei *et al.*, 2021). Wastewater can be a viable source of water for irrigation purposes. However, before using wastewater for irrigation, it is necessary to ensure that it meets certain physical, chemical, and biological parameters (Hashem & Qi, 2021a). In this study, the physical parameters of wastewater that are relevant to its use in irrigation was considered.

2.1.2 Impact of color on wastewater quality for irrigation

Color is another important physical parameter that is used to assess the quality of wastewater. The color of wastewater can be an indicator of the presence of certain contaminants, such as heavy metals and organic matter (Reta & Mekonen, 2023).

High levels of organic matter in wastewater can lead to the growth of algae, which can reduce oxygen levels in the water and negatively impact plant growth (Ansar *et al.*, 2023).

Similarly, high levels of heavy metals in wastewater can accumulate in the soil and be taken up by the plants, leading to health concerns. It is necessary to monitor the colour of wastewater and treat it if necessary (Solayman *et al.*, 2023).

2.1.3 Turbidity of wastewater used for irrigation

Turbidity is a measure of the number of suspended particles in wastewater. High levels of turbidity can clog irrigation systems, reduce the effectiveness of fertilizers, and negatively affect plant growth. The recommended level of turbidity for irrigation water should not exceed 10 NTU for general crops and 5NTU for vegetable crops (Benameur *et al.*, 2022).

2.1.4 Total Suspended Solids (TSS) of wastewater

Total Suspended Solids (TSS) is a measure of the number of solids that are suspended in wastewater. High levels of TSS can cause clogging of irrigation systems and negatively affect plant growth (Shi *et al.*, 2022). The recommended level of TSS for irrigation water should not exceed 50 mg/L. Total suspended solids (TSS) are a measure of the number of solid particles present in wastewater that are large enough to be retained by a filter (Adjovu *et al.*, 2023).

TSS is an important parameter for assessing the quality of wastewater, as it can impact the performance of treatment processes and the suitability of the water for reuse (Shi *et al.*, 2022).

Wastewater typically contains a range of solid particles, including organic matter, food waste, and other debris.

These particles can be introduced into the wastewater from a variety of sources, such as human and animal feces, food waste, and cleaning products (Govind & Shrestha, 2022).

The TSS in wastewater can vary depending on a number of factors, such as the source of the wastewater, the time of day, and the activities taking place. The TSS in any wastewater is high compared to other forms of wastewater depending on the activity that produced it. This is because wastewater contains a larger amount of organic matter and other solid particles, which can be difficult to remove during the treatment process. For the use of wastewater in irrigation, the TSS level is an important parameter to consider. High TSS levels in irrigation water can lead to clogging of irrigation equipment and may negatively impact plant growth and yield (Anyango *et al.*, 2024). TSS can interfere with the absorption of nutrients and water by plant roots, reducing the efficiency of irrigation. To ensure wastewater is suitable for use in irrigation, it is important to properly treat the water to reduce the TSS level (Ashie *et al.*, 2024). Treatment processes such as sedimentation, filtration, and biological treatment can be used to remove solid particles and organic matter from the wastewater. Regular testing and monitoring of the TSS level in both the wastewater and the irrigation water can help to ensure that the water is suitable for its intended use.

2.1.5 pH of wastewater

pH is a measure of the acidity or alkalinity of wastewater. The pH level of wastewater can affect plant growth by influencing the availability of nutrients in the soil. The ideal pH range for irrigation water should be between 6.5 and 8.5 (Ofori *et al.*, 2024a). If the pH level of the wastewater is not within this range, it may need to be adjusted through treatment.

The pH of wastewater is an important parameter to consider when assessing its quality and suitability for various uses, including irrigation (Ofori *et al.*, 2024b). The pH is a measure of the acidity or alkalinity of the water, and is expressed on a scale of 0 to 14, with a pH of 7 considered neutral. The pH of wastewater can vary depending on a number of factors, such as the source of the water, the time of day, and the activities taking place (Rinne, 2024).

For example, the pH of wastewater generated from cleaning products or personal care products may be different from that generated from human waste. The pH of wastewater is slightly acidic, with a pH range of 5.5 to 7.5. This is due to the presence of organic acids, such as acetic acid, in the wastewater. However, the pH of wastewater can also be influenced by external factors, such as the pH of the water supply or the presence of acidic or alkaline substances in the wastewater (Villegas-Rodríguez *et al.*, 2024). The pH of wastewater can have an impact on its treatment and reuse potential. Wastewater treatment processes are often optimized for a specific pH range, and fluctuations in the pH can impact the performance of these processes. For example, a pH that is too low or too high can inhibit the growth of beneficial microorganisms in biological treatment processes, reducing the efficiency of the treatment process. The pH of wastewater can impact its suitability for use in irrigation. Most crops grow best in a pH range of 6.0 to 7.5, and water with a pH outside this range may negatively impact plant growth and yield (Amankwah-Yeboah *et al.*, 2023).

In some cases, the pH of wastewater may need to be adjusted before it can be used for irrigation, either through the use of chemical treatments or through blending with other water sources. Monitoring and controlling the pH of wastewater is important to ensure its suitability for various uses, including irrigation and treatment for reuse (Benaafi *et al.*, 2024).

Regular testing and monitoring can help to identify any fluctuations in the pH and take appropriate measures to ensure the water is safe and suitable for its intended use.

2.1.6 Electrical Conductivity of wastewater

Electrical conductivity (EC) is a measure of the ability of wastewater to conduct electricity and can be used as an indicator of the concentration of dissolved salts in the water.

High levels of dissolved salts in wastewater can negatively affect plant growth and lead to soil salinization (Gao *et al.*, 2021). The recommended level of EC for irrigation water should not exceed 2.0 dS/m. Electrical conductivity (EC) is a measure of the ability of a solution to conduct an electrical current.

The EC of wastewater is an important parameter to consider when assessing its quality and suitability for various uses, including irrigation (Al Hadidi, 2021). The EC of wastewater can be influenced by a variety of factors, such as the presence of dissolved salts, organic matter, and other solutes in the water. Wastewater has a relatively low EC, typically ranging from 200 to 2000 $\mu\text{S}/\text{cm}$ (Hussaini *et al.*, 2023). However, the EC can vary depending on a number of factors, such as the source of the wastewater, the time of day, and the activities taking place in the household. High levels of EC in wastewater can indicate the presence of dissolved salts, such as sodium, chloride, and sulfate. These salts can be introduced into the wastewater from a variety of sources, such as cleaning products, food waste, and human and animal waste (Ruan *et al.*, 2024). The EC of wastewater is an important parameter to consider when using the water for irrigation, as high levels of dissolved salts can negatively impact plant growth and yield (Hashem 2021b).

High EC can lead to the buildup of salts in the soil, reducing its fertility and overall quality. To ensure that wastewater is suitable for use in irrigation, it is important to monitor and control the EC of the water. Treatment processes such as reverse osmosis or electro dialysis can be used to remove dissolved salts from the wastewater and reduce the EC to acceptable levels (Biesheuvel *et al.*, 2022). Regular testing and monitoring of the EC in both the wastewater and the irrigation water can help to ensure that the water is safe and suitable for its intended use (Pratap *et al.*, 2023a).

The EC of wastewater is an important parameter to consider when assessing its quality and suitability for various uses, including irrigation. High levels of EC can negatively impact plant growth and soil fertility, and regular testing and monitoring of the water is essential to ensure its safety and suitability for use (Pratap *et al.*, 2023a).

2.1.7 Sodium Adsorption Ratio

Sodium Adsorption Ratio (SAR) is a measure of the sodium concentration in relation to the calcium and magnesium concentrations in wastewater. High SAR values can lead to soil degradation and negatively affect plant growth (J. Wang *et al.*, 2023). The recommended level of SAR for irrigation water should not exceed 10. Sodium Adsorption Ratio (SAR) is a measure of the potential for sodium (Na) to displace other cations such as calcium (Ca) and magnesium (Mg) from soil particles, which can lead to the degradation of soil structure and fertility (Rai *et al.*, 2021). The SAR is an important parameter to consider when assessing the quality and suitability of wastewater for irrigation. In wastewater, the SAR can be influenced by a number of factors, such as the source of the water, the activities taking place in the household, and the time of day (Moussaoui *et al.*, 2023).

High levels of SAR in wastewater can indicate the presence of high levels of sodium and low levels of Ca and Mg, which can lead to soil degradation and reduced crop growth and yield.

The SAR of wastewater can be calculated using the following equation:

$$\text{SAR} = (\text{Na}^+ / (\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2})) \text{ (Amoah et al., 2022)}$$

Where Na^+ is the concentration of sodium in milliequivalents per liter (meq/L) and Ca^{2+} and Mg^{2+} are the concentrations of calcium and magnesium in milligrams per liter (mg/L), respectively. Wastewater has a low SAR, typically ranging from 0 to 5. However, the SAR can vary depending on a number of factors, such as the source of the wastewater and the activities taking (Verma *et al.*, 2024). To ensure that wastewater is suitable for use in irrigation, it is important to monitor and control the SAR of the water. Treatment processes such as reverse osmosis, electrodialysis, or ion exchange can be used to remove excess sodium and adjust the SAR to acceptable levels (Amoah *et al.*, 2022).

The use of blended water sources or crop selection can also be used to mitigate the negative effects of high SAR in irrigation water (Parsa, 2023). Regular testing and monitoring of the SAR in both the wastewater and the irrigation water can help to ensure that the water is safe and suitable for its intended use. The SAR of wastewater is an important parameter to consider when assessing its quality and suitability for irrigation, and regular testing and monitoring of the water is essential to ensure its safety and suitability for use (Badr *et al.*, 2023).

2.1.8 Odour of wastewater used for irrigation

Odour can be an indicator of the presence of organic matter and other contaminants in wastewater. While odour does not directly affect plant growth, it can be a concern for farmers and other individuals who come into contact with the water (Wang *et al.*, 2021).

It is necessary to monitor the odour of wastewater and treat it if necessary. Odour in wastewater is a common issue and can be caused by a variety of factors, including the presence of organic matter, bacteria, and other contaminants (Wysocka, 2023). Foul odours from wastewater can not only be unpleasant, but they can also indicate the presence of harmful pathogens and chemicals that can pose a health risk to humans and the environment (Dwumfour-Asare *et al.*, 2018).

One of the most common causes of odour in wastewater is the presence of organic matter, such as food waste, human and animal waste, and cleaning products (Czarnota *et al.*, 2023).

Organic matter can produce volatile organic compounds (VOCs), such as ammonia and sulfides, which can cause a foul odour. Bacterial growth in the wastewater can also produce odours, particularly in warm and humid environments (Zhu *et al.*, 2022). To reduce and eliminate odour in wastewater, various treatment methods can be used. The most effective treatment method will depend on the specific cause of the odour. For example, aeration and the addition of oxygen to the wastewater can help to reduce odour caused by organic matter (Amoah *et al.*, 2022).

Similarly, the use of ultraviolet light or chemical disinfectants can help to control bacterial growth and reduce odour caused by pathogens. It is also important to properly manage

wastewater to prevent odours (Fan *et al.*, 2020). This can include properly disposing of food waste and other organic matter, ensuring that drains are clear and not clogged, and regularly cleaning wastewater treatment systems to prevent bacterial growth and accumulation of organic matter. Regular monitoring and testing of the wastewater for odour and other contaminants can help to identify potential issues and allow for appropriate action to be taken to prevent and mitigate odour (Waqas *et al.*, 2023).

The presence of odour in wastewater can indicate the presence of harmful pathogens and chemicals, and proper management and treatment of the wastewater are necessary to prevent and eliminate odour and ensure the safety of the water for humans and the environment (Prasanthrajan *et al.*, 2020). wastewater. Regular testing and monitoring of the wastewater and crops can help to ensure that any potential health risks are identified and addressed in a timely manner (Dickin *et al.*, 2016).

2.1.9 Total dissolved solids

Total dissolved solids (TDS) are a measure of the total amount of dissolved ions and minerals in wastewater. When wastewater is used for irrigation, high levels of TDS can have both positive and negative impacts on crops, soil, and the environment (Singh, 2021a). On the positive side, TDS can contribute to the mineral and nutrient content of the soil, improving soil fertility and promoting plant growth. However, high levels of TDS can also lead to negative impacts on crop growth and the environment (Baloch *et al.*, 2023). When wastewater with high TDS levels is used for irrigation, the dissolved salts can accumulate in the soil over time, leading to increased soil salinity.

High soil salinity can reduce water availability for plants and inhibit root growth, leading to reduced crop yields. High levels of TDS can cause leaf burn and damage to crops, further reducing yields (Urooj *et al.*, 2022).

High levels of TDS in wastewater can also have negative impacts on the environment. When TDS is discharged into surface waters or groundwater, it can increase the salinity of the water, leading to negative impacts on aquatic organisms and reducing water quality for human use. Proper treatment and management of wastewater used for irrigation is essential to ensure that TDS levels are safe and suitable for crop production (Mishra, 2023b). Reverse osmosis, electrodialysis, and other physical and chemical treatment processes can be used to remove dissolved salts from wastewater. Management practices such as leaching and drainage can be used to reduce soil salinity and minimize the negative impacts of high TDS levels (Mohanavelu *et al.*, 2021).

2.2 Chemical parameters of wastewater

Organic matter: wastewater contains a variety of organic compounds, including fats, oils, and greases from cooking, food waste, human and animal waste, and cleaning products. These organic compounds can contribute to the formation of organic acids and other chemicals that can have negative effects on water quality and the environment (Peña, 2022). Organic matter is a key component of wastewater and can include a variety of substances, such as food waste, human and animal waste, and cleaning products. Organic matter can be both beneficial and harmful in wastewater depending on the amount and how it is managed (Coha *et al.*, 2021).

Organic matter in wastewater can be beneficial in that it can provide nutrients to plants and soil when used for irrigation or fertilization. This can help to reduce the use of synthetic

fertilizers, which can have negative effects on the environment (Tyagi *et al.*, 2022). However, organic matter can also contribute to the formation of organic acids, which can lower the pH of the water and have negative impacts on aquatic life. When organic matter decomposes, it can consume oxygen, which can lead to low dissolved oxygen levels in water bodies, particularly in warmer months (Chapra *et al.*, 2021).

This can have negative impacts on aquatic life, as fish and other organisms require oxygen to survive. The decomposition of organic matter can produce foul odours and attract insects, which can be a nuisance to humans. To manage organic matter in wastewater, various treatment methods can be used, such as sedimentation, filtration, and aeration (Amoah *et al.*, 2022).

These methods can help to remove or break down organic matter in the water and reduce its negative impacts on the environment (Saravanan *et al.*, 2021).

People can reduce the amount of organic matter in wastewater by properly disposing of food waste and using environmentally-friendly cleaning products. The management of organic matter in wastewater is essential for maintaining water quality and protecting the environment. Proper treatment and management can help to reduce the negative impacts of organic matter while still providing benefits for the environment and human use (Silva, 2023).

Nutrients: wastewater is a significant source of nutrients, such as nitrogen and phosphorus, which can contribute to the eutrophication of water bodies (Amoah *et al.*, 2022). Eutrophication can result in algal blooms, which can deplete oxygen levels in the water and harm aquatic life.

Wastewater can contain a range of nutrients, including nitrogen, phosphorus, and potassium, which can have both positive and negative impacts on the environment (Saravanan *et al.*, 2021). Nitrogen is a key nutrient in wastewater and is essential for plant growth. However, when nitrogen is present in high concentrations in water bodies, it can cause eutrophication, a process in which algae growth is stimulated (Mishra, 2023c). This can lead to oxygen depletion in the water and harm aquatic life. Nitrogen in wastewater can also contribute to the formation of nitrous oxide, a greenhouse gas that is a potent contributor to climate change (Aryal *et al.*, 2022). Phosphorus is another important nutrient in wastewater and is also essential for plant growth. However, when phosphorus is present in high concentrations in water bodies, it can also cause eutrophication (Amoah *et al.*, 2022).

This can lead to algal blooms and reduced water clarity, which can have negative impacts on aquatic life and human recreational activities (Brooks *et al.*, 2016). Potassium is also present in wastewater, but in much lower concentrations than nitrogen and phosphorus. While it is less likely to cause environmental harm than nitrogen and phosphorus, excess potassium in soil can affect plant growth and health (Yahaya *et al.*, 2023).

To manage nutrients in wastewater, various treatment methods can be used, such as biological treatment, chemical precipitation, and filtration (Samer, 2015). These methods can help to remove or reduce nutrients in the water and ensure its safety for human and environmental use. There are a number of best practices that householders can follow to reduce the amount of nutrients in their wastewater (Qadir *et al.*, 2010).

The less water used in the home; the less nutrients are discharged to the wastewater system. Properly dispose of hazardous waste: hazardous waste, such as cleaning products and pharmaceuticals, can contain nutrients that can contribute to eutrophication if not disposed of properly (Amoah *et al.*, 2022). Proper disposal can help prevent these nutrients from entering the wastewater and causing harm (Amoah *et al.*, 2022). Use environmentally-friendly cleaning products: Many cleaning products contain nutrients that can contribute to eutrophication. Using environmentally-friendly cleaning products can help to reduce the amount of nutrients in wastewater (Jena *et al.*, 2023). Compost food waste: Composting food waste can help to reduce the amount of nutrients in wastewater and provide a valuable source of organic matter for use in gardening and landscaping. Avoid over-fertilizing lawns and gardens Over-fertilization can contribute to excess nutrients in wastewater (Wielemaker, 2019). The management of nutrients in wastewater is essential for maintaining water quality and protecting the environment. wastewater can also contain heavy metals, such as lead, mercury, and cadmium, which can be toxic to humans and the environment (Saravanan *et al.*, 2021).

These metals can come from a variety of sources, including cleaning products, plumbing materials, and industrial processes (Sharma *et al.*, 2023).

Wastewater can contain a variety of heavy metals, including lead, cadmium, chromium, mercury, and copper. These heavy metals can originate from a variety of sources, such as cleaning products, paints, and plumbing materials, and can have negative impacts on human health and the environment (Sharma *et al.*, 2023).

Exposure to heavy metals in wastewater can lead to a range of health problems, including neurological damage, developmental delays, and cancer. Heavy metals can persist in the environment for long periods of time, potentially causing long-term harm to wildlife and ecosystems (Ali *et al.*, 2019). To manage heavy metals in wastewater, various treatment methods can be used, such as sedimentation, filtration, and chemical precipitation. These methods can help to remove or reduce heavy metals in the water and ensure its safety for human and environmental use (Wang *et al.*, 2022). There are several best practices that householders can follow to reduce the number of heavy metals in their wastewater, such as:

Properly dispose of hazardous waste: Hazardous waste, such as batteries, fluorescent light bulbs, and electronics, can contain heavy metals (Wang & Wang, 2025). Proper disposal can help prevent these heavy metals from entering the wastewater and causing harm. Use environmentally-friendly cleaning products. Many cleaning products contain heavy metals that can be harmful to the environment. Using environmentally-friendly cleaning products can help to reduce the number of heavy metals in wastewater (Qasem *et al.*, 2021).

Using lead-free plumbing Use lead-free plumbing materials. Lead is a common heavy metal in plumbing materials, and can contaminate wastewater if not properly managed. materials can help to reduce the amount of lead in wastewater (Lei *et al.*, 2018).

If a household relies on well water, it is important to regularly test the water for heavy metals to ensure its safety for human use. The management of heavy metals in wastewater is essential for maintaining human health and protecting the environment (Mitra *et al.*, 2022).

Using best practices and utilizing effective treatment methods, householders can help to reduce the negative impacts of heavy metals while still providing benefits for the environment and human use. Pharmaceuticals and personal care products: wastewater can also contain trace amounts of pharmaceuticals and personal care products, such as antibiotics, hormones, and fragrances (Amoah *et al.*, 2022). These compounds can enter the environment and have negative effects on aquatic life and human health. Pharmaceuticals and personal care products (PPCPs) are a class of emerging contaminants that have become a growing concern in wastewater (Kumar *et al.*, 2023). These chemicals are widely used in daily life and can enter the wastewater stream through excretion, bathing, and washing. PPCPs can have a range of negative impacts on the environment and human health. They can cause hormonal changes, reproductive problems, and can negatively affect aquatic life (Rahman *et al.*, 2009). Moreover, PPCPs are not effectively removed in traditional wastewater treatment plants, which means that they can end up in the waterways and affect the environment. To address this issue, various treatment technologies are being developed and implemented to remove PPCPs from wastewater (Kumar *et al.*, 2023).

Activated carbon is an effective adsorbent for removing PPCPs from wastewater. Activated carbon has a large surface area that attracts and traps PPCPs in the wastewater (Mitra *et al.*, 2022). Ozone treatment is a process that uses ozone to oxidize and destroy PPCPs in wastewater. Ozone is a powerful oxidizing agent that can break down a variety of organic chemicals (Jamali *et al.*, 2024).

Biological treatment uses microorganisms to break down PPCPs in wastewater. These microorganisms can metabolize PPCPs, transforming them into harmless compounds.

Membrane Filtration: Membrane filtration is a process that uses a semipermeable membrane to remove PPCPs from wastewater. The membrane acts as a physical barrier that allows only water and small molecules to pass through (Ansar *et al.*, 2023).

This helps to prevent medications from being flushed down the toilet and entering the wastewater stream. Limiting the use of personal care products and selecting products with fewer chemicals can help to reduce the amount of PPCPs in wastewater (Mitra *et al.*, 2022).

Hazardous waste such as cleaning products and pesticides should be disposed of properly to avoid contamination of the wastewater stream. PPCPs in wastewater pose a significant risk to human health and the environment. Effective treatment methods and management practices can help to reduce the negative impacts of these chemicals and ensure the safety of the water supply for all (Kumar *et al.*, 2023). Chlorine and chloramine are commonly used in water treatment systems to disinfect the water. However, these chemicals can react with organic matter in the wastewater to form disinfection byproducts, which can have negative health effects if ingested (Mitra *et al.*, 2022).

Chlorine and chloramine are commonly used disinfectants in municipal water treatment plants to kill harmful pathogens in the water supply. As a result, chlorine and chloramine can also be present in wastewater (Hossain *et al.*, 2022). Chlorine and chloramine can be corrosive to plumbing systems, which can lead to leaks and other damage over time (Kumar *et al.*, 2023).

Environmental impacts: Chlorine and chloramine can be toxic to aquatic life if they are discharged into waterways without proper treatment.

Exposure to chlorine and chloramine can cause skin and eye irritation, respiratory issues, and other health problems (Hossain *et al.*, 2022).

To mitigate the impacts of chlorine and chloramine in wastewater, several treatment options are available. Chlorine and chloramine can be removed from wastewater using activated carbon, which absorbs the chemicals and removes them from the water (Hossain *et al.*, 2022).

Alternatively, chlorine and chloramine can be neutralized using dichlorination agents, which convert the chemicals into harmless compounds. Householders can take steps to reduce their exposure to chlorine and chloramine in their daily lives. These include: Filtering drinking water: Drinking water filters can remove chlorine and chloramine from the water supply, providing safer and better-tasting water (Kumar *et al.*, 2023). Using natural cleaning products: Many cleaning products contain chlorine or other harsh chemicals that can contribute to the presence of chlorine and chloramine in wastewater. Using natural cleaning products can help to reduce the amount of chlorine and chloramine in the wastewater. The more water that is used in a place, the more chlorine and chloramine will be present in the wastewater (Hossain *et al.*, 2022).

Being mindful of water use and reducing water consumption can help to reduce the amount of chlorine and chloramine in the wastewater. Managing the presence of chlorine and chloramine in wastewater is important for protecting human health and the environment (Hossain *et al.*, 2022). By utilizing effective treatment methods and being mindful of water use, householders can help to reduce the potential negative impacts of these chemicals to manage the chemical characteristics of wastewater, various treatment methods can be used, such as sedimentation, filtration, and disinfection (Ahmed *et al.*, 2021a).

These methods can help to remove or reduce contaminants in the water and ensure its safety for human and environmental use. It is also important to properly dispose of hazardous waste, such as cleaning products, batteries, and pharmaceuticals, to prevent these chemicals from entering the wastewater and causing harm (Elbeshbishy & Okoye, 2019).

2.2.1 Mercury in wastewater

Mercury is a toxic heavy metal that can cause serious harm to human health and the environment. When mercury enters wastewater, it can be transported to rivers, lakes, and other bodies of water, where it can contaminate aquatic life and affect ecosystems (Sharma *et al.*, 2023). If wastewater containing mercury is used for irrigation, the mercury can also accumulate in soil and crops, potentially leading to harmful effects on human health if consumed (Khalid *et al.*, 2018). Wastewater is water that has been used for various purposes, such as domestic, industrial, or agricultural activities, and contains contaminants that need to be treated before being discharged into the environment. Wastewater treatment involves various processes that aim to remove contaminants and make the water safe for reuse or discharge (Saravanan *et al.*, 2021).

However, the effectiveness of wastewater treatment processes in removing contaminants such as mercury depends on various factors, such as the concentration of mercury in the wastewater, the type of treatment process used, and the quality of the wastewater treatment plant (Hargreaves *et al.*, 2016). In some cases, even after treatment, some contaminants such as mercury may still remain in the treated wastewater, which can pose a risk to human health and the environment if the water is used for irrigation (Antwi-Agyei *et al.*, 2016).

The use of wastewater for irrigation is becoming increasingly common in many parts of the world, particularly in areas where water resources are scarce (Ungureanu *et al.*, 2020). However, the use of wastewater for irrigation raises concerns about the potential health and environmental risks associated with the presence of contaminants such as mercury. In general, it is not recommended to use wastewater for irrigation unless it has been properly treated to remove harmful contaminants such as mercury (Hashem 2021c).

Depending on the source and quality of the wastewater, treatment may involve physical, chemical, and biological processes to remove pollutants before the water is deemed safe for agricultural use (Saravanan *et al.*, 2021). If wastewater containing mercury is used for irrigation, the mercury can accumulate in soil and crops, potentially leading to harmful effects on human health if consumed (Gashaye, 2020).

Mercury exposure can cause a range of health problems, including damage to the nervous system, kidneys, and lungs (Amoah *et al.*, 2022). Children and pregnant women are particularly vulnerable to the harmful effects of mercury. Therefore, it is important to ensure that proper measures are in place to ensure the safety of agricultural products grown with treated wastewater (Amoah *et al.*, 2022).

This may involve monitoring the quality of the treated wastewater, establishing appropriate standards for the concentration of mercury in the water, and testing crops grown with the water to ensure that they are safe for consumption (Pratap *et al.*, 2023b). It is important to take appropriate measures to protect human health and the environment from the potential risks associated with the use of wastewater for irrigation (Mishra *et al.*, 2023b).

2.2.2 Lead in wastewater used for irrigation

Lead is a toxic heavy metal that can cause serious harm to human health and the environment. When lead enters wastewater, it can be transported to rivers, lakes, and other bodies of water, where it can contaminate aquatic life and affect ecosystems (Pandey & Kumari, 2023). If wastewater containing lead is used for irrigation, the lead can also accumulate in soil and crops, potentially leading to harmful effects on human health if consumed.

Wastewater is water that has been used for various purposes, such as domestic, industrial, or agricultural activities, and contains contaminants that need to be treated before being discharged into the environment (Crini, 2018). Wastewater treatment involves various processes that aim to remove contaminants and make the water safe for reuse or discharge. However, the effectiveness of wastewater treatment processes in removing contaminants such as lead depends on various factors, such as the concentration of lead in the wastewater, the type of treatment process used, and the quality of the wastewater treatment plant (Arbabi *et al.*, 2019).

Depending on the source and quality of the wastewater, treatment may involve physical, chemical, and biological processes to remove pollutants before the water is deemed safe for agricultural use (Amoah *et al.*, 2022). If wastewater containing lead is used for irrigation, the lead can accumulate in soil and crops, potentially leading to harmful effects on human health if consumed (Akhtar *et al.*, 2022).

Lead exposure can cause a range of health problems, including damage to the nervous system, kidneys, and reproductive system. Children and pregnant women are particularly vulnerable to the harmful effects of lead.

Therefore, it is important to ensure that proper measures are in place to ensure the safety of agricultural products grown with treated wastewater (Amoah *et al.*, 2022). This may involve monitoring the quality of the treated wastewater, establishing appropriate standards for the concentration of lead in the water, and testing crops grown with the water to ensure that they are safe for consumption (Hashem 2021b).

2.2.3 Arsenic in wastewater

Arsenic is a toxic metalloid that can be found naturally in the environment, as well as in industrial processes such as mining and smelting (Amoah *et al.*, 2022). When arsenic enters wastewater, it can be transported to rivers, lakes, and other bodies of water, where it can contaminate aquatic life and affect ecosystems. If wastewater containing arsenic is used for irrigation, the arsenic can also accumulate in soil and crops, potentially leading to harmful effects on human health if consumed (Saravanan *et al.*, 2021).

The presence of arsenic in wastewater used for irrigation of crops is a significant concern in many regions around the world (Shahid *et al.*, 2021). A study revealed that the concentration of arsenic in wastewater used for irrigation was significantly higher than the World Health Organization's safe limit for drinking water, indicating a potential risk to human health if crops grown with the water are consumed. Another research revealed that rice crops grown with wastewater irrigation had higher levels of arsenic compared to rice crops grown with fresh water, highlighting the potential risks of using wastewater for irrigation (Amoah *et al.*, 2022). The effectiveness of wastewater treatment processes in removing arsenic depends on various factors, such as the concentration of arsenic in the wastewater, the type of treatment process used, and the quality of the wastewater treatment plant (Shahid *et al.*, 2021).

In some cases, even after treatment, some contaminants such as arsenic may still remain in the treated wastewater, which can pose a risk to human health and the environment if the water is used for irrigation (Pesewu *et al.*, 2017b). In general, it is not recommended to use wastewater for irrigation unless it has been properly treated to remove harmful contaminants such as arsenic (Amoah *et al.*, 2022).

Depending on the source and quality of the wastewater, treatment may involve physical, chemical, and biological processes to remove pollutants before the water is deemed safe for agricultural use (Shahid *et al.*, 2021).

If wastewater containing arsenic is used for irrigation, the arsenic can accumulate in soil and crops, potentially leading to harmful effects on human health if consumed. Arsenic exposure can cause a range of health problems, including skin lesions, cancer, and cardiovascular disease (Amoah *et al.*, 2022). Therefore, it is important to ensure that proper measures are in place to ensure the safety of agricultural products grown with treated wastewater. This may involve monitoring the quality of the treated wastewater, establishing appropriate standards for the concentration of arsenic in the water, and testing crops grown with the water to ensure that they are safe for consumption (Antwi-Agyei *et al.*, 2016).

The presence of arsenic in wastewater used for irrigation of crops is a significant concern, and appropriate measures should be taken to ensure the safety of agricultural products grown with treated wastewater (Antwi-Agyei *et al.*, 2016). It is important for wastewater treatment plants and environmental agencies to monitor the quality of treated wastewater and establish appropriate standards to prevent the accumulation of harmful contaminants such as arsenic in soil and crops (Gbedemah *et al.*, 2024a).

2.2.4 Chemical oxygen demand in wastewater

Chemical oxygen demand (COD) is a measure of the amount of organic matter present in wastewater. It is often used as an indicator of the level of pollution in wastewater and can provide insight into the suitability of the water for irrigation purposes (Matheri *et al.*, 2021). High levels of COD in wastewater used for irrigation can have negative impacts on crops and the environment. The presence of organic matter can reduce soil permeability, limiting the movement of water and nutrients to plant roots. This can result in reduced crop yields and poor plant growth. High levels of organic matter can attract pests and insects, leading to increased crop damage (Gbedemah *et al.*, 2024b).

Furthermore, the decomposition of organic matter in wastewater can result in the depletion of dissolved oxygen in surface waters. This can lead to the death of aquatic organisms, causing further environmental problems (Amoah *et al.*, 2022). Proper treatment and monitoring of wastewater used for irrigation is essential to reduce the levels of COD and ensure that the water is safe for crop production (Matheri *et al.*, 2021). Biological treatment processes, such as activated sludge and trickling filters, can be effective in reducing COD levels. Physical and chemical treatment processes, such as coagulation and flocculation, can also be used to remove organic matter from wastewater (Dwumfour-Asare *et al.*, 2020a).

2.2.5 Total organic carbon in wastewater used for irrigation

Total organic carbon (TOC) is another measure of the amount of organic matter present in wastewater. Unlike COD, TOC measures the total amount of carbon present in the organic matter, including both biodegradable and non-biodegradable carbon compounds.

TOC in wastewater used for irrigation can have both positive and negative impacts on crop growth and soil quality (Kanwar *et al.*, 2019). On the positive side, organic matter can improve soil fertility, water-holding capacity, and nutrient availability, leading to improved crop yields (Bashir *et al.*, 2021).

Organic matter can provide a food source for soil microorganisms, which can improve soil structure and reduce soil erosion. However, high levels of TOC can also have negative impacts on crop growth and soil quality (Aulakh *et al.*, 2022).

The presence of high levels of organic matter can result in reduced soil permeability and soil compaction, making it difficult for roots to grow and access water and nutrients. High levels of organic matter can lead to the production of phytotoxic compounds, which can be harmful to plant growth (Bashir *et al.*, 2021). Furthermore, organic matter can act as a source of nutrients for algae and other aquatic plants in surface waters, leading to eutrophication and other environmental problems (Tiwari & Pal, 2022). The decomposition of organic matter in surface waters can also lead to the depletion of dissolved oxygen, which can result in the death of aquatic organisms (Tiwari & Pal, 2022).

Proper treatment and management of wastewater used for irrigation is essential to ensure that TOC levels are safe and suitable for crop production (Kanwar *et al.*, 2019). Biological treatment processes, such as activated sludge and trickling filters, can be effective in reducing TOC levels. Physical and chemical treatment processes, such as coagulation and flocculation, can also be used to remove organic matter from wastewater (Sukmana *et al.*, 2021).

2.2.6 Total nitrogen in wastewater

Total nitrogen (TN) is a measure of the total amount of nitrogen present in wastewater. Nitrogen is an essential nutrient for plant growth, but high levels of TN in wastewater used for irrigation can have both positive and negative impacts on crops and the environment. On the positive side, nitrogen can improve soil fertility and promote plant growth (Bering *et al.*, 2018). However, excess nitrogen can lead to environmental problems such as eutrophication and contamination of groundwater. When wastewater with high TN levels is used for irrigation, the nitrogen can be taken up by crops, leading to improved yields (Craswell, 2021).

However, if the nitrogen is not fully taken up by the plants, it can accumulate in the soil and groundwater, resulting in contamination. Nitrogen can be converted into nitrate, which can leach into groundwater and surface waters, leading to eutrophication and other environmental problems (Craswell, 2021). the impacts on the environment, excess nitrogen can also have negative impacts on crop growth. High levels of nitrogen can lead to the production of vegetative growth at the expense of fruit or seed production. High levels of nitrogen can make crops more susceptible to diseases and pests (Craswell, 2021). Proper treatment and management of wastewater used for irrigation is essential to ensure that TN levels are safe and suitable for crop production (Bering *et al.*, 2018).

Biological treatment processes, such as activated sludge and trickling filters, can be effective in reducing TN levels. Physical and chemical treatment processes, such as coagulation and flocculation, can also be used to remove nitrogen from wastewater (Sukmana *et al.*, 2021).

2.2.7 Total phosphate

Total phosphate (TP) is a measure of the total amount of phosphorus present in wastewater. Phosphorus is an essential nutrient for plant growth, but high levels of TP in wastewater used for irrigation can have both positive and negative impacts on crops and the environment (Gupta *et al.*, 2017). On the positive side, phosphorus can improve soil fertility and promote plant growth. However, excess phosphorus can lead to environmental problems such as eutrophication and contamination of groundwater (Liu *et al.*, 2021). When wastewater with high TP levels is used for irrigation, the phosphorus can be taken up by crops, leading to improved yields. However, if the phosphorus is not fully taken up by the plants, it can accumulate in the soil and groundwater, resulting in contamination (Abdallah & Mourad, 2021).

Phosphorus can be converted into orthophosphate, which can leach into groundwater and surface waters, leading to eutrophication and other environmental problems. excess phosphorus can also have negative impacts on crop growth (Craswell, 2021). High levels of phosphorus can lead to reduced availability of other nutrients, such as zinc and iron, which can result in reduced crop yields. Excess phosphorus can make crops more susceptible to diseases and pests (Amoah *et al.*, 2022).

Proper treatment and management of wastewater used for irrigation is essential to ensure that TP levels are safe and suitable for crop production (Šostar-Turk *et al.*, 2005). Biological treatment processes, such as activated sludge and trickling filters, can be effective in reducing TP levels. Physical and chemical treatment processes, such as coagulation and flocculation, can also be used to remove phosphorus from wastewater (Musa & Idrus, 2021).

2.3 Biological characteristics of wastewater

Biological parameters are important indicators of the quality of wastewater used for irrigation. These parameters include the presence of pathogenic microorganisms, as well as other indicators of the health and viability of the microbial community in the wastewater (Chowdhari *et al.*, 2022). Here are some of the key biological parameters of wastewater used for irrigation.

2.3.1 Pathogens

Wastewater can contain a variety of pathogens, including bacteria, viruses, and parasites, that can pose a risk to human health if the water is not properly treated before use (Amoah *et al.*, 2016). These pathogens can be introduced into wastewater from a variety of sources, including human and animal feces, food waste, and other organic matter (Yang *et al.*, 2022). The presence of pathogens in wastewater is a major concern for the use of this water source in irrigation, as they can be transmitted to crops and potentially cause foodborne illness in humans (Sampson *et al.*, 2017).

Escherichia coli (E. coli): E. coli is a type of bacteria that is commonly found in the intestines of humans and animals. While most strains of E. coli are harmless, some can cause illness if ingested. E. coli can be an indicator of fecal contamination in wastewater (Puvača *et al.*, 2021).

Salmonella: Salmonella is a type of bacteria that can cause food poisoning if ingested. It is commonly found in the intestines of animals, and can be transmitted to humans through contaminated food and water (Ehuwa *et al.*, 2021).

Campylobacter: Campylobacter is a type of bacteria that is commonly found in the intestines of poultry, cattle, and other animals. It can cause diarrhea and other gastrointestinal symptoms in humans if ingested (Wu *et al.*, 2022).

Giardia: Giardia is a parasite that can be found in human and animal feces. It can cause diarrhea and other gastrointestinal symptoms in humans if ingested (Dixon, 2021).

Norovirus: Norovirus is a highly contagious virus that can cause stomach and intestinal inflammation. It is commonly spread through contaminated food and water (Varshini *et al.*, 2023). In order to reduce the risk of pathogen transmission, wastewater must be properly treated before use in irrigation. This typically involves a combination of physical, chemical, and biological treatments that can remove or inactivate pathogens (Ahmed *et al.*, 2021b).

2.3.2 Total coliform in wastewater

Total coliform is a group of bacteria that are commonly used as an indicator of the microbial quality of water, including wastewater used for irrigation. The presence of total coliform bacteria in irrigation water may indicate the presence of fecal contamination or other potential pathogens (Yang *et al.*, 2024). Total coliform bacteria are not necessarily harmful to human health, but their presence in high concentrations can indicate a potential risk. Total coliform bacteria are found in the intestines of humans and animals and are excreted in feces (Kudirkiene *et al.*, 2025). They can enter the environment through wastewater and other sources of contamination such as animal waste, septic systems, and stormwater runoff. Total coliform bacteria are often used as an indicator of water quality because they are relatively easy to detect and are present in high numbers in feces (Tambi *et al.*, 2023).

Testing for total coliform bacteria is an important part of monitoring the safety of wastewater used for irrigation. The United States Environmental Protection Agency (EPA) has set standards for the maximum concentration of total coliform bacteria in wastewater used for irrigation. The EPA requires that the geometric mean of the total coliform concentration in samples taken over a 30-day period should not exceed 23 MPN/100 mL (most probable number per 100 milliliters) and that no single sample should exceed 58 MPN/100ml (Chen *et al.*, 2023).

If total coliform bacteria are found in concentrations that exceed the EPA standards, it may indicate that the wastewater is contaminated with fecal matter or other potential pathogens. In this case, further testing is necessary to determine the source of the contamination and to ensure that the wastewater is properly treated before it is used for irrigation. Fecal coliform bacteria are also commonly used as an indicator of water quality (Monney *et al.*, 2019).

Fecal coliform bacteria are a subset of total coliform bacteria and are specifically associated with the feces of warm-blooded animals (Chen *et al.*, 2023). Fecal coliform bacteria are considered to be a better indicator of fecal contamination than total coliform bacteria and are often used to assess the safety of water for recreational activities such as swimming (Ferreira *et al.*, 2022).

2.3.3 Fecal coliform in wastewater

Fecal coliform is a subgroup of total coliform bacteria that is commonly used as an indicator of fecal contamination in wastewater used for irrigation. These bacteria are commonly found in the intestines of warm-blooded animals, including humans, and are excreted in feces (Khan *et al.*, 2023). They are often used as an indicator of water quality because they are relatively

easy to detect and are present in high numbers in feces. The presence of fecal coliform bacteria in irrigation water may indicate the presence of fecal contamination or other potential pathogens (Gurtler & Gibson, 2022).

Fecal coliform bacteria are not necessarily harmful to human health, but their presence in high concentrations can indicate a potential risk. Other bacterial indicators of fecal contamination that are commonly used in water quality monitoring include *Escherichia coli* (E. coli) and enterococci. Testing for fecal coliform bacteria is an important part of monitoring the safety of wastewater used for irrigation (Partyka & Bond, 2022).

The United States Environmental Protection Agency (EPA) has set standards for the maximum concentration of fecal coliform bacteria in wastewater used for irrigation. The EPA requires that the geometric mean of the fecal coliform concentration in samples taken over a 30-day period should not exceed 200 MPN/100 mL (most probable number per 100 milliliters) and that no single sample should exceed 400 MPN/100ml (Partyka & Bond, 2022).

If fecal coliform bacteria are found in concentrations that exceed the EPA standards, it may indicate that the wastewater is contaminated with fecal matter or other potential pathogens. In this case, further testing is necessary to determine the source of the contamination and to ensure that the wastewater is properly treated before it is used for irrigation (Samayamanthula *et al.*, 2019). It is also important to consider the source of the wastewater. Wastewater from different sources can have different concentrations of fecal coliform bacteria and other potential contaminants. For example, wastewater from domestic sources may contain higher concentrations of fecal coliform bacteria than wastewater from industrial sources (Bonetta *et al.*, 2022).

The treatment of wastewater is an important factor in reducing the concentration of fecal coliform bacteria and other potential contaminants. Treatment processes such as sedimentation, filtration, and disinfection can help to reduce the concentration of fecal coliform bacteria in wastewater. The use of wastewater for irrigation should be carefully managed to ensure that it is properly treated and that the risk of fecal contamination is minimized (Singh, 2021b).

2.3.5 *Escherichia coli* (*E. coli*)

Escherichia coli (*E. coli*) is a bacterium commonly found in the intestinal tract of humans and animals. Its presence in wastewater used for irrigation can indicate fecal contamination and a potential risk of waterborne illness (Ali *et al.*, 2023).

In Ghana, the use of wastewater for irrigation is common, particularly in urban areas where access to freshwater is limited. This practice is not without its risks, and the presence of *E. coli* in wastewater used for irrigation is a concern for public health. The majority of wastewater used for irrigation comes from domestic sources, including households, schools, and hospitals (Yuan & Pian, 2023).

The wastewater is often untreated or inadequately treated, and may contain high levels of pathogens, including *E. coli* (Ali *et al.*, 2023). The use of this wastewater for irrigation can lead to contamination of crops, soil, and water sources, which can in turn pose a risk to human health (Singh, 2021b).

Several studies have been conducted to assess the prevalence of *E. coli* in wastewater used for irrigation in Ghana. these researches examined the microbial quality of wastewater used for

irrigation in the Accra Metropolitan Area of Ghana (Deh-Haghi *et al.*, 2020). The study revealed that *E. coli* was present in all of the wastewater samples collected, with concentrations ranging from 2.8×10^3 to 1.5×10^7 CFU/mL (Alshammari, 2025).

Another research examined the prevalence of *E. coli* in wastewater used for irrigation in the Kumasi Metropolitan Area of Ghana. The study revealed that *E. coli* was present in all of the wastewater samples collected, with concentrations ranging from 2.7×10^3 to 1.3×10^6 CFU/ml (Tabesh, 2025). The research found that *E. coli* concentrations were higher in the dry season than in the wet season, likely due to reduced dilution of the wastewater during the dry season (Kist *et al.*, 2008). The presence of *E. coli* in wastewater used for irrigation in Ghana poses a significant risk to public health. Consuming crops that have been irrigated with contaminated water can lead to the ingestion of pathogens, which can cause a range of illnesses, including diarrhea, vomiting, and fever (Ali *et al.*, 2023).

Exposure to contaminated soil and water sources can lead to the transmission of waterborne diseases, including cholera and typhoid fever (Manetu & Karanja, 2021).

To mitigate the risks associated with the use of wastewater for irrigation in Ghana, there is a need for improved wastewater treatment and management practices (Silva, 2023). This includes the implementation of appropriate treatment technologies, such as wastewater stabilization ponds and constructed wetlands, to reduce the concentration of pathogens in wastewater. The use of appropriate irrigation practices, such as drip irrigation, can help to minimize contact between crops and contaminated water sources (Karanja, 2021).

2.3.6 *Salmonella* spp in wastewater

Salmonella is a bacterium that is commonly associated with foodborne illness. Its presence in wastewater used for irrigation can pose a significant risk to public health, particularly in countries like Ghana where the use of untreated or inadequately treated wastewater for irrigation is common (Oteng-Peprah *et al.*, 2018). It is important to understand the prevalence of *Salmonella* in wastewater used for irrigation in Ghana and the potential risks associated with its presence. Several studies have been conducted to assess the prevalence of *Salmonella* in wastewater used for irrigation in Ghana (Asirifi *et al.*, 2021).

A study that *Salmonella* was present in 55% of the wastewater samples collected, with concentrations ranging from 2.3×10^2 to 3.5×10^4 CFU/mL. Another study, published in the *Journal of Water and Health* in 2019, examined the prevalence of *Salmonella* in wastewater used for irrigation in the Accra Metropolitan Area (Hossain *et al.*, 2022).

The study found that *Salmonella* was present in all of the wastewater samples collected, with concentrations ranging from 6.8×10^2 to 7.5×10^3 CFU/ml. The study also found that *Salmonella* concentrations were higher in the dry season than in the wet season, likely due to reduced dilution of the wastewater during the dry season (Makuwa *et al.*, 2022a).

The presence of *Salmonella* in wastewater used for irrigation in Ghana poses a significant risk to public health. Consuming crops that have been irrigated with contaminated water can lead to the ingestion of pathogens, which can cause a range of illnesses, including diarrhea, vomiting, and fever (Gupta *et al.*, 2017).

Exposure to contaminated soil and water sources can lead to the transmission of waterborne diseases, including cholera and typhoid fever. To mitigate the risks associated with the use of wastewater for irrigation in Ghana, there is a need for improved wastewater treatment and management practices (Makuwa *et al.*, 2022b).

2.3.7 Enterococci in wastewater

Enterococci are a group of bacteria that are commonly found in the intestinal tracts of humans and animals. Their presence in wastewater used for irrigation can indicate fecal contamination and pose a risk to public health (Dickin *et al.*, 2016). In Ghana, the use of untreated or inadequately treated wastewater for irrigation is common, which increases the potential for the transmission of enterococci and other pathogens through contaminated crops, soil, and water sources. In this context, it is important to understand the prevalence of enterococci in wastewater used for irrigation in Ghana and the potential risks associated with its presence (Amoah *et al.*, 2022). Several studies have been conducted to assess the prevalence of enterococci in wastewater used for irrigation in Ghana (Manetu & Karanja, 2021). A study revealed that enterococci were present in all of the wastewater samples collected, with concentrations ranging from 2.2×10^3 to 2.5×10^6 CFU/ml (Gotkowska-Płachta, 2021).

Another study, revealed that enterococci were present in all of the wastewater samples collected, with concentrations ranging from 1.2×10^3 to 1.7×10^5 CFU/ml. The study also found that enterococci concentrations were higher in the dry season than in the wet season, likely due to reduced dilution of the wastewater during the dry season (Makuwa *et al.*, 2022a).

The presence of enterococci in wastewater used for irrigation in Ghana poses a significant risk to public health. Consumption of crops that have been irrigated with contaminated water can lead to the ingestion of pathogens, which can cause a range of illnesses, including diarrhea, vomiting, and fever. Exposure to contaminated soil and water sources can also lead to the transmission of waterborne diseases, including cholera and typhoid fever (Amoah *et al.*, 2022). To mitigate the risks associated with the use of wastewater for irrigation in Ghana, there is a need for improved wastewater treatment and management practices. This includes the implementation of appropriate treatment technologies, such as wastewater stabilization ponds and constructed wetlands, to reduce the concentration of pathogens in wastewater (Shayannejad, 2021).

2.4 Technologies used to treat wastewater

2.4.1 Wastewater stabilization ponds

Wastewater stabilization ponds are widely used in Ghana for treating wastewater for irrigation purposes. WSPs are designed to mimic the natural process of purification that occurs in lakes and other bodies of water (Abagale, 2021a). The ponds are typically shallow and can be either aerobic or anaerobic. The use of WSPs for wastewater treatment is advantageous due to its low cost, simplicity, and effectiveness. In Ghana, WSPs are commonly used in small towns and rural areas where there is no access to conventional wastewater treatment facilities (Duku *et al.*, 2024).

The ponds are typically designed in a series of three to four ponds, each with a different treatment stage (Abagale, 2021b).

The first pond is a primary pond where solids settle out and organic matter is decomposed. The second pond is a facultative pond where both aerobic and anaerobic processes occur (Ghangrekar, 2022). The third pond is a maturation pond where sunlight and algae are used to further treat the wastewater. The final pond, if present, is a polishing pond where further treatment occurs before the effluent is discharged for irrigation (Abagale, 2021b).

WSPs are effective at removing organic matter, nutrients, and pathogens from wastewater (Mahapatra *et al.*, 2022). The anaerobic process in the first pond removes a significant amount of organic matter from the wastewater. In the facultative pond, oxygen is supplied through diffusion and photosynthesis from algae, which helps to further break down organic matter and remove nutrients. The maturation pond is designed to promote the growth of algae, which can remove pathogens and nutrients from the wastewater (Amoah *et al.*, 2022). Although WSPs are effective at removing contaminants from wastewater, they are not designed to remove all pollutants. In some cases, the effluent from WSPs may still contain high levels of nutrients, suspended solids, and pathogens. Therefore, the effluent must be further treated before it can be used for irrigation (Mahapatra *et al.*, 2022). The use of WSPs for treating wastewater for irrigation in Ghana has been successful in providing an affordable and sustainable solution for small communities and rural areas. However, for larger communities and urban areas, more advanced wastewater treatment technologies may be required (Mahapatra *et al.*, 2022).

2.4.2 The use of constructed wetlands

Constructed wetlands are an innovative and sustainable approach to wastewater treatment that can be used for irrigation purposes in Ghana (Adu-Boakye, 2022).

Constructed wetlands are essentially engineered systems designed to mimic natural wetland ecosystems, which use plants, bacteria, and other microorganisms to remove contaminants from wastewater (Adu-Boakye, 2022). In Ghana, constructed wetlands have been successfully used to treat wastewater from small communities and households for irrigation. These systems are typically constructed with a lined basin or pond that is filled with a bed of gravel or sand. Wetland plants are then planted in the bed, which provide the necessary oxygen and nutrients for the microorganisms to break down the organic matter in the wastewater (Rosendo *et al.*, 2022).

As the wastewater flows through the bed, it is naturally filtered and treated by the plants and microorganisms, which remove nutrients, organic matter, and pathogens. The treated wastewater can then be used for irrigation, which can provide a reliable source of water for agriculture, especially during dry seasons (Hossain *et al.*, 2022).

Constructed wetlands have several advantages over other wastewater treatment systems. They are relatively low-cost and require minimal energy and maintenance, making them a good option for small communities and rural areas. They are also effective at removing a wide range of contaminants, including nutrients, organic matter, and pathogens. Also, they provide additional benefits, such as creating wildlife habitats and improving water quality in downstream water bodies. However, there are some challenges associated with the use of constructed wetlands for wastewater treatment in Ghana (Adu-Boakye, 2022). The systems may require regular monitoring and maintenance to ensure that they are functioning properly, and there may be concerns about the potential for flooding or contamination of nearby water bodies if the system fails (Adu-Boakye, 2022).

Nonetheless, constructed wetlands can be a sustainable and effective option for treating wastewater for irrigation in Ghana, especially in areas where other wastewater treatment options may be limited (Amankwah-Yeboah *et al.*, 2023).

2.4.3 The use of rapid sand filtration for wastewater treatment

Sand and other granular materials are used in a bed to physically remove suspended solids from water in a process known as rapid sand filtration (Adu-Boakye, 2022).

High filtration rates and sporadic backwashing to clean the filter media are its defining features. The components of rapid sand filter include Filter Media; The primary filtering medium is typically sand, but anthracite or other granular materials can also be used (Thomas & Kani, 2016). Underdrain System; A system at the bottom of the filter that collects the filtered water and distributes the backwash water (Turan, 2023). Backwash System; This system reverses the flow of water to clean the filter media, typically involving water and air scour. Rapid sand filters can be used to polish secondary effluents from biological treatment processes (Adu-Boakye, 2022).

This step is essential for removing residual suspended solids and reducing turbidity. In tertiary treatment, rapid sand filters can be employed to achieve higher quality effluent, often necessary for water reuse applications or discharge into sensitive environments (Yaseen *et al.*, 2019). This process helps in the further reduction of biochemical oxygen demand (BOD), suspended solids, and sometimes phosphorus. Rapid sand filters operate at a higher rate than slow sand filters, typically processing 5-15 gallons per minute per square foot of filter bed area. They efficiently remove particles that can affect downstream processes and the final quality of treated water (Liang *et al.*, 2021).

2.4.4 The use of slow sand filters for wastewater treatment

Filter Bed: Composed of sand with an effective grain size of 0.15-0.35 mm and a depth of 0.5-1.5 meters (Cairncross *et al.*, 2018). **Biological Layer (Schmutzdecke):** A layer of microorganisms that forms on the surface of the sand bed and plays a crucial role in breaking down organic matter and capturing pathogens. **Underdrain System:** Collects filtered water and supports the sand bed. **Supernatant Water:** The layer of water above the sand bed that provides a constant head for filtration. Slow sand filters are often used after primary treatment processes like sedimentation or primary clarifiers (Cairncross *et al.*, 2018). This ensures that large particles and most of the suspended solids are removed before the water enters the sand filter. They are also used in tertiary treatment to further polish the effluent from secondary treatment processes, improving the quality of water to meet discharge standards or for reuse purposes (Czuba *et al.*, 2021).

2.5 Regulatory requirements for water used for irrigation

Regulatory requirements for wastewater used for irrigation vary depending on the country, region, and specific local regulations. However, several common principles and guidelines are typically applied to ensure the safe and sustainable use of wastewater in agriculture (Bering *et al.*, 2018). Here are some key regulatory aspects often addressed: International organizations like the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations provide guidelines and recommendations for the safe use of wastewater in agriculture (Amoah *et al.*, 2022). These guidelines often serve as reference points for the development of national regulations and standards (Hashem, 2021a).

It's essential for stakeholders, including wastewater treatment facilities, farmers, regulatory agencies, and the public, to collaborate and adhere to these regulatory requirements to ensure the safe and sustainable use of wastewater in agriculture while protecting human health and the environment (Bering *et al.*, 2018).

2.6 Conceptual Framework

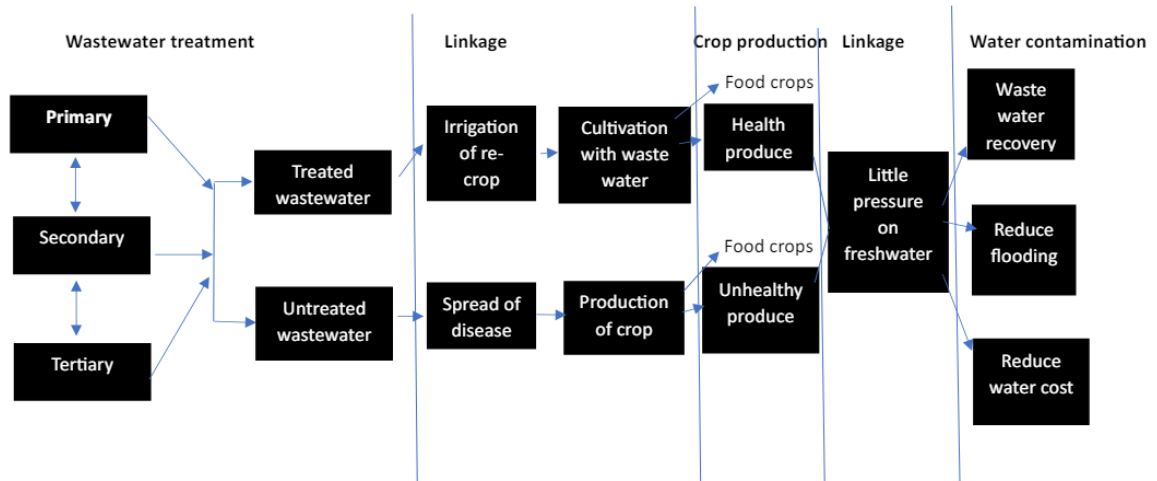


Figure 2.1: Conceptual framework of wastewater treatment

Figure 2.1 shows a conceptual framework of the link between wastewater treatment, quality of vegetables irrigated with wastewater vis a vis the importance of wastewater usage for irrigation.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

In this chapter, the study explores methodologies of the research employed to achieve each objective of the study. It also demonstrates the computation and extrapolations made to design and experimental scale system as well as the data collection, laboratory and data analysis technique making it possible for the study to be duplicated in other researches.

3.1 Study site

Korle-Bu vegetable farm is located east of the Korle-Bu teaching hospital (Marnah & Manortey, 2022). It shares the same catchment with similar land use activities. the hospital is located in Ablekuma south district in Accra metropolis. It is the main referral center and the apex of all in the country. Diverse wastewater of a wide range of characteristics is generated from the hospital due to the wide range of services rendered. The entire catchment of the hospital and vegetable farm is a single compound established on 9th October 1923 under Sir Gordon Guggisberg, the then governor of the Gold Coast now referred to as Ghana (Asante *et al.*, 2022). the Korle-Bu vegetable farm serves as an outfall where runoff and other forms of wastewater from Laterbiokorshie, some parts of Mamprobi, Mataheko, some parts of Kaneshie, and portions of Abossey Okai feeds into (Asante *et al.*, 2022). Wastewater from apartments and school around the vegetable farms also feeds into the drains of the vegetable farm which is the impounded by farmers and used for irrigation of crops (Pesewu *et al.*, 2017b).

3.2 Sampling technique

3.2.1 Research Design

The study employed an experimental study design to ascertain some physical wastewater characteristics such as colour and odour as well as the number and types of impoundments created by farmers to store wastewater for irrigation. An observational method was also used to conduct a feasibility study on the type of treatment facility that can be adopted to treat wastewater for irrigation given the available materials and land space required to treat wastewater. A laboratory experiment was also conducted to compare the characteristics of raw and treated wastewater against the World Health Organisation standards.

3.2.2 Sample size determination of raw wastewater

Given the number of impounded sites of 3 obtained by observation, a census was used where all the impoundments were included in the study.

3.3 Sample collection of raw wastewater

3.3.1 Raw wastewater samples

One liter each of Three (3) locations of wastewater was sampled between the hours of 05:00gmt to 6:00gmt as prescribed by the American public health association 1998 23rd edition updated in 2017. The samples were then transported to the Ghana atomic energy commission for laboratory analysis.



Figure 3.1 sampling and laboratory analysis of wastewater

3.3.2 Treated Wastewater Samples

One liter of treated wastewater samples was taken every 24hours as well as its corresponding raw wastewater and transported to the atomic energy commission of Ghana. The process was repeated for eight days to compare the quality of treated and untreated wastewater for each. The process was adapted from the guidelines provided by the American public health association (Arismendy *et al.*, 2021).

3.4. Design of experimental scale system

3.4.1 Preparation of sand

Sand was collected from Korle-Gonno beach and transported to the Civil Engineering Laboratory of Accra Institute of Technology, for sieve analysis. Samples were dried to remove moisture. The recommended particle size for developing a slow sand filter according to engineering standards

0.15 μm , 0.36 μm , 0.6 μm , 1.18 μ and 2.26 were obtained by putting dry samples of sand in the sieve and sorting them with the use of a mechanical vibrator (Verma *et al.*, 2017).

3.4.2 Preparation of sawdust activated carbon

Raw materials were collected from the sawmill and other wood processing companies in Accra. The sawdust was washed with tap water and then dried under the sunlight for 24 hours. The sawdust was compacted into pallets and burnt at a temperature of 800°C to 1100°C for 1 to 3 hours under a controlled condition by putting the sawdust pallets in a metal container (Sichone, 2013). The container was placed into a muffle furnace, containing material separately at the redecided temperature and time. The lower temperature in the carbonization process gives a better result than high temperature (Ashtaputrey , 2016). After taking out the samples from the furnace, the samples were cooled for 30 min at room temperature, washed with distilled water; to remove dust and impurities, and dried in the oven at 105°C for 1 hour (Senga *et al.*, 2024).

The charred was mixed with zinc chloride in A ratio of 1:1 by weight. Mixture was allowed to sit for 24 hours to ensure thorough impregnation. A mortar and pestle were used to grind charcoal for smaller particle with sieve and mechanical vibrator (Acheampong *et al.*, 2013a).

3.4.3 Experimental setup

Pump: wastewater was raised to a storage tank with at a height of 10m. The wastewater was then allowed to flow gently under the influence of gravity through the sedimentation tank and filtration system. A sieve was filtered into the first storage tank to remove course materials.

Sedimentation tank: a sedimentation tank of volume 0.8m³ was connected at a height of 6m with a 2mm pipe network. Entry and exit of sedimentation tank were rubber mesh fitter to

remove fine and floating materials from wastewater while settleable solids are made to settle gradually under the influence of gravity.

Filtration system: a filtration system is connected at a height of 2m to the sedimentation tank with a 2mm pipe network. the bottom layer is made of coarse gravel of 2.26 μ m in diameter and occupies 15cm of the filter, the activated carbon layer made of charcoal of particle size of 2.26 μ m in diameter and a depth of 15cm in the filtration system, the transition layer made of intermediate-sized gravels of 1.18 μ m in diameter and occupies 10cm of the filter depth and the main sand layer made of fine sand of 0.15 μ m to 0.36 μ m and covers 60cm of the filter depth. Schmutzdecke was allowed to form naturally and treatment proceeds.

3.4.4 Model of wastewater treatment system

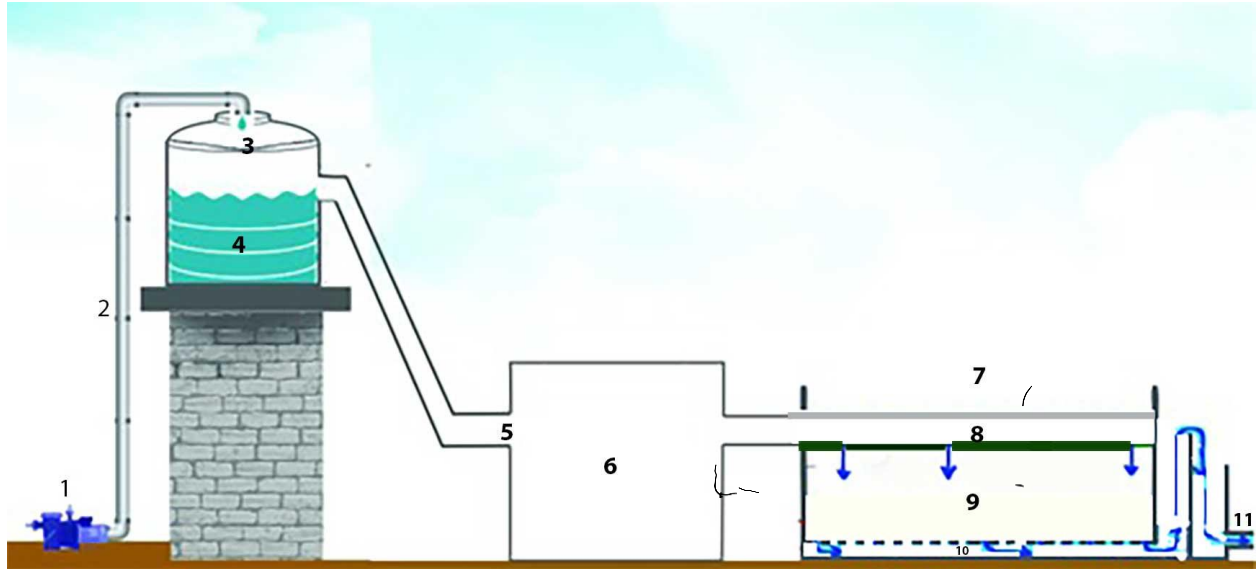


Figure 3.2: schematic of the laboratory scale treatment system

Adapted from (Abdiyev *et al.*, 2023)

Key to model of treatment system

| | | |
|----------------|----------------------|-----------------|
| 1 Pump | 5 Rubber mesh | 9 Filter medium |
| 2 Pipe | 6 Sedimentation tank | 10 Under drain |
| 3 Grit chamber | 7 Schmutzdecke | 11 Outlet |
| 4 Storage tank | 8 Supernatant water | |

3.4.5 Size of Sedimentation Tank

Wastewater to be treated per day = 2400 liters = 2.4m³

Q = wastewater to be produced X detention period (T)/time of treatment.

$$Q = 2.4 \times 2/6$$

$$Q = 0.8\text{m}^3 = 800\text{L}$$

Dimension of sedimentation tank

$$L \times B \times D = 0.8\text{m}^3$$

Given the height (H) as 0.4 meters and the length-to-breadth ratio of 4:1, the dimension of sedimentation tank was calculated with a capacity of 0.8 cubic meters.

Let B be the breadth. Then, the length (L) is 4 times the breadth:

$$L=4B \quad L=4B$$

The volume (V) of the tank is given by the formula:

$$V=L \times B \times H \quad V=L \times B \times H$$

Substitute the given values:

$$0.8=(4B) \times B \times 0.4 \quad 0.8=(4B) \times B \times 0.4$$

Simplify and solve for B:

$$0.8=1.6B^2 \quad 0.8=1.6B^2$$

$$B^2=0.5 \quad 1.6B^2=1.6 \times 0.5$$

$$B^2=0.5 \quad B^2=0.5$$

$$B=0.5 \quad B=0.5$$

$$B \approx 0.71 \text{ meters} \quad B \approx 0.71 \text{ meters}$$

Now that we have the breadth (B), we can find the length (L):

$$L=4 \times B \quad L=4 \times B$$

$$L=4 \times 0.71 \quad L=4 \times 0.71$$

$$L \approx 2.84 \text{ meters} \quad L \approx 2.84 \text{ meters}$$

So, the dimensions of the sedimentation tank with a capacity of 0.8 cubic meters, a height of 0.4 meters, and a length-to-breadth ratio of 4:1 are approximately:

Length (LL): 2.84 meters Breadth (BB): 0.71 meters Height (HH): 0.4 meters

Dimension of tank = L X B X D

$$2.84\text{m} \times 0.71\text{m} \times 0.4\text{m} = 0.8\text{m}^3.$$

we add 10% for inlet and outlet and 10% for free board.

$$3.1\text{m} \times 0.71\text{m} \times 0.44\text{m}$$

3.4.6 Overflow Velocity (Surface Loading Rate)

$V_0 = Q/\text{surface area}$, but surface area = B X L

$$V_0 = 2.4/0.71 \times 2.84$$

$$= 1.19\text{m}^3/\text{day}$$

3.4.7 Flow Through Velocity

$V_s = \text{discharge}/\text{area}$, where area = B X H

$$2.4/0.71 \times 0.4$$

$$8.45 \text{ m}^3/\text{day}$$

3.4.8 Inflow Rate

Inflow rate $Q = \text{volume to be treated}/6\text{hr}/60/60$

1 hour = 3600 seconds So, to convert 400 liters per hour to liters per second:

$$400 \text{ liters}/\text{hour} \times \frac{1 \text{ hour}}{3600 \text{ seconds}} = 400 \text{ liters}/\text{hour} \times \frac{1}{3600} \text{ seconds}/1 \text{ hour}$$

$$\approx 0.111 \text{ liters}/\text{second} \approx 0.111 \text{ liters}/\text{second}.$$

$$0.111\text{L}/\text{sec}$$

$$6.67 \text{ L}/\text{min}$$

3.4.9 Designing an experimental scale system

1: 100 of the treatment system was designed at an experimental scale.

QUANTITY OF WATER TO BE TREATED = 24 LITERS OR 0.024

$$Q = 0.024 \times 2/6 = 0.008\text{m}^3$$

3.4.10 Dimensions of Sedimentation Tank

$$L \times B \times H = 0.008$$

$$L = 0.028$$

$$B = 0.0071$$

$$H = 0.004$$

$$0.028\text{m} \times 0.007\text{m} \times 0.004\text{m} = 0.008\text{m}^3$$

3.4.11 Filter Bed Depth

The recommended depth for a slow sand filter bed is typically between 60 to 90cm.

(Abdiyev *et al.*, 2023). 24 inches was chosen (60 cm) for this design.

3.4.12 Surface Area

Surface area (A) = Flow rate / Filtration rate

Filtration rate is typically 0.1 to 0.4 meters per hour. 0.2 meters per hour was chosen for this design.

$$A = (0.4 \text{ m}^3/\text{hr.}) / (0.2 \text{ m/hr.}) = 2 \text{ square meters}$$

3.4.13 Determining the depth of filter bed

For a rectangular filter bed

$$\text{Width (W)} = \text{Length (L)} = \sqrt{A}$$

The ratio of length to breath is 1:2, therefore for a filter of 2m^2

$$L = 2B$$

$$2B \times L = A$$

$$2B^2 = A$$

$$\text{BUT } A = 2\text{m}^2 \text{ OR } 200\text{cm}^2$$

$$2B^2 = 200\text{cm}^2$$

$$B = 10\text{cm}$$

$$L = 2 \times 10 = 20.$$

Therefore, the dimensions of the filter are given as;

$$10\text{cm} \times 20\text{cm} = 200\text{cm}^2$$

3.4.14 Filter Medium

The filter medium typically consists of a combination of sand and gravel. The particle size of the sand is 0.35 to 0.6 micrometers in diameter. Particle size of activated carbon is 0.36 to 1.18 micrometers in diameter (Verma *et al.*, 2017).

3.4.15 Trial Studies

In order to understand the adsorption behavior a number of batch studies was conducted to investigate the effect of adsorbent dose and contact time, pH, temperature, turbidity, concentration of metal, and particle sizes.

Wastewater of various concentrations of similar contaminants was prepared from the stock solution and kept separately in glass stoppered conical flasks. The wastewater prepared from the laboratory was then be treated with the wastewater treatment system designed to treat municipal wastewater. This helped to correct and adjust the system to treat the wastewater more efficiently.

3.5 Laboratory analysis

3.5.1 Parameters to be determined

Wastewater samples were collected from the secondary drains at Korle-Bu vegetable farms, at places where water is drawn for irrigation of vegetables. This wastewater was collected, stored, transported and analyzed in the laboratory in accordance with the recommendations given by The American public health association (Arismendy *et al.*, 2021). Parameters that were determined include pH, Temperature, Turbidity, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total suspended solids (TSS), Total Dissolved Solids (TDS), Electrical conductivity (E.C), Salinity, Total Hardness, Alkalinity, Chlorine, Sodium, Calcium, Magnesium, Total phosphate, Total nitrogen, Mercury, Lead, Arsenic, Total coliform, Faecal coliform, *Escherichia coli*, and Salmonella species.

3.5.2 pH

pH probe was calibrated with a buffer solution of known Ph (7.01). 500ml of wastewater sample was measured into a clean flask. PH probe was dipped into wastewater sample and reading was allowed to stabilize. It was then recorded (Arismendy *et al.*, 2021).

3.5.3 Dissolved oxygen

Dissolved oxygen concentration was determined by electrochemical method with a DO meter. The dissolved oxygen probe was calibrated with a solution of known dissolved oxygen level. The probe was inserted into the wastewater sample and reading was recorded when stabilized from the figures displayed on the meter (Maddah, 2023).

3.5.4 Biochemical oxygen demand

Wastewater was filled into two of 250ml black bottles to the brim. One was labelled as day one and the other as day-5. Care was taken to prevent samples from reach of light rays. sample labelled day-5 was kept in a dark cupboard for 5 days from the day of sampling. Sample labelled day 1 was fixed by adding 1ml of wrinkler 1, 1ml of wrinkler 2 and 5ml of concentrated sulfuric acid. The bottle was covered and mixed gently. The titrant ($\text{Na}_2\text{S}_2\text{O}_7$) was filled into the burette to the zero mark. 50ml of the fixed sample (day 1) was taken into a clean conical flask. 2 to 3 drops of starch indicator were added to it. The mixture content was titrated against sodium thiosulphate solution to the end point. Titre value was recorded when colour change from blue-black to colourless (Abdullahi *et al.*, 2021).

3.5.5 Chemical oxygen demand

The burette was filled with FAS (ferrous ammonium sulphate) to the zero-meniscus level. 10ml portion of the sample was taken into a clean conical flask. 3ml of potassium dichromate and 3ml of concentrated Sulfuric acid added to it. A petri dish was placed on the conical flask containing the mixture content and reflux for 5 minutes. after refluxing, 20ml of distilled water was taken to wash back any trapped sample into the conical flask. The mixture content was allowed to cool at room temperature. 2 to 3 drops of ferroin indicator were added to the mixture content and titrated against the FAS to the end point. The titre value was recorded when colour changed from green to brick-red precipitate (Tebeje *et al.*, 2021).

3.5.6 Total suspended solids

A clean and dry glass fiber filter was pre-weighed using an analytical balance and recorded to the nearest 0.1mg. vacuum filtration apparatus was assembled. The pre-weighed filter was placed in the filtration apparatus.

The wastewater sample was thoroughly Shaked to ensure it is homogeneous. A specific volume of the water sample(500ml) was measured and poured into the filtration apparatus. The vacuum was applied to filter the sample through the glass fiber making sure all the sample passes through the filter. Forceps was used to carefully remove the filter and transferred to a drying oven at a temperature of 103°C to 105°C. filter and residue were dried for 1 hour. With the aid of a forceps, the filter was removed from the oven and placed in a desiccator to cool for 20 minutes. the filter was weighed again with the residue to the nearest 0.1mg (Meneceur *et al.*, 2023).

The total suspended solids are the given mathematically as $TSS (mg/l) = \frac{W_2 - W_1}{V} \times 1000$ /Volume of sample.

W_1 = initial weight of filter

W_2 = final weight of filter

Volume of sample = volume of wastewater sample filtered

3.5.7 Total dissolved solids

The evaporating dish was cleaned and dried in an oven at temperature of 103°C to 105°C for 1 hour. The dish was cooled in a desiccator to room temperature and weighed to the nearest 0.1mg and recorded as W_1 , the wastewater sample was filtered to remove suspended solids. 500ml of wastewater sample was measure into an evaporating dish. The evaporating dish was placed on an oven between the temperature of 103°C to 105°C. the water sample was evaporated to dryness (Adjovu *et al.*, 2023).

The dried evaporating dish was removed and placed in a desiccator to cool for 20 minutes and weighed as W_2 the total dissolved solid is then computed as $TDS \text{ (mg/l)} = (W_2 - W_1) \times 1000 / \text{volume of sample (ml)}$

3.5.8 Electrical conductivity

Probe was calibrated with a solution of known electrical conductivity. 500ml of wastewater was measured into a clean beaker. Probe was dipped into wastewater sample and readings were allowed to stabilize. It was then recorded and repeated for all other samples (H. Wang *et al.*, 2021).

3.5.9 Salinity

Refractometer was cleaned using distilled water. 3 drops were placed on the prism, closed and adjusted until it reads zero salinity. The prism was cleaned with distilled water and allowed to dry. 3 drops of wastewater samples were placed on the prism. It was covered and through the eyepiece, reading was taken directly and recorded (Indrasari *et al.*, 2021).

3.6.10 Total hardness

Ethylenediaminetetraacetic acid (EDTA) solution and pH 10 buffer solution were prepared. 50ml wastewater was pipetted into a conical flask. 1-2ml of pH 10 buffer solution was added to the wastewater sample. This ensures pH is maintained around 10, which is optimal for the reaction. 3 drops of Eriochrome black T indicator were added to the sample. The burette was filled with EDTA solution to the zero meniscus. The EDTA was slowly titrated into the sample while continuously swirling the flask (Guardiano *et al.*, 2025).

The titration was continued until the colour changes from wine-red to pure blue indicating that the calcium and magnesium ions have reacted with the EDTA.

The total hardness is computed as;

Hardness (mg/l as CaCO₃) = volume of EDTA (ml) x molarity of EDTA/volume of sample
(Guardiano *et al.*, 2025).

3.5.11 Alkalinity

pH meter was calibrated with a buffer solution. 100ml of wastewater sample was measured into a conical flask. The initial pH was taken by measuring the sample PH of wastewater. The conical flask was placed on a magnetic stirrer. Standard acid solution was slowly added to the sample while stirring. The pH was monitored closely and titration was terminated with pH reached 8.3 (Dhoke, 2023). the alkalinity is the computed mathematically as alkalinity (as CaCO₃) = V₁ X N X 50000/Volume of sample(ml)

V₂= volume of acid used to reach Ph 8.3 (mL)

N = normality of acid (eq/l)

3.5.12 Chlorine

The calorimeter was calibrated according to manufacturer's instruction. Wastewater sample was collected into a container cover to prevent chlorine lost by sunlight and air. Diethyl-p-phenylenediamine (DPD) reagent was added to wastewater sample. The sample turns brick-red. The sample is placed in the calorimeter (A. Jain & Verma, 2025).

3.5.13 Sodium

The filtered wastewater sample was aspirated into the flame photometer and readings were recorded. Dilution is done when reading is outside range of calibration curve.

The sodium is calculated by using the calibration curve from reading on the instrument (Bhupathyraaj *et al.*, 2024).

3.5.14 Calcium

All glassware were cleaned with distilled water to avoid contamination. 50ml wastewater sample was pipetted into a conical flask. 2ml of pH 10 buffer solution was added to wastewater sample. This ensure the pH was maintained at 10. 2 drops of ammonium purpurate indicator was added to the wastewater sample. The solution turned pink if calcium is present. The EDTA was filled into a burette to the zero meniscus. EDTA was slowly titrated into the wastewater sample while swirling continuously in the flask. The colour changes from pink to purple (Babilas *et al.*, 2021).

The calcium level is computed mathematically as; $\text{calcium (mg/l)} = \text{volume of EDTA} \times \text{molarity of EDTA} \times 40.08 / \text{volume of wastewater sample}$.

3.5.15 Magnesium

50ml of wastewater was pipetted into a conical flask. 2ml of pH 10 buffer solution was added to wastewater sample. 2 drops of Eriochrome black T indicator were added to wastewater sample. The solution turns wine-red to indicate the presence of magnesium. The burette was filled with EDTA to the zero meniscus. Titrate EDTA against wastewater sample to the end point (M. Verma *et al.*, 2022).

3.5.16 Total phosphate

50ml of sulfuric acid solution was mixed with 5ml of ammonium molybdate reagent, 5ml of ascorbic acid reagent and 2ml of antimony potassium tartrate solution to prepare the combined reagent. Wastewater sample was filtered to remove particles.

50ml of wastewater was pipetted into a clean conical flask. 8ml of the combined reagent was added to the wastewater sample and mixed thoroughly for 10 minutes. calorimeter was set to a wavelength of 880nm. The absorbance of the wastewater sample was measured against the blank. Phosphate concentration was determined using the calibration curve (Sun *et al.*, 2024).

3.5.17 Total nitrogen

Pipette 5ml of wastewater into a test tube and prepare a nitrite standard solution. The absorbance of the wastewater sample was measured at 220nm to detect nitrate and at 275nm to correct for interference from organic matter. The calibration curve of absorbance was plotted at 220nm against nitrate concentration using the standards. the wastewater sample absorbance was corrected by subtracting twice the absorbance at 275nm to account for organic matter interference (Hicks *et al.*, 2022).

3.5.18 Mercury

Wastewater sample was filtered to remove particulates. Wastewater samples were acidified to a pH of less than 2 by adding concentrated. Hydrochloric acid. 5ml of concentrated sulfuric acid and 5ml concentrated nitric acid was added to 100 ml wastewater sample in the digestion flask. 5ml of potassium permanganate solution was added to the wastewater sample in the flask (Kassim *et al.*, 2022).

The sampled was cooled and 3 drops of hydroxylamine solution added to reduce any excess potassium permanganate. The spectrometer was set to the appropriate wavelength (253.7nm) for mercury detection. The calibration curve was used to determine mercury concentration in the wastewater samples from the absorbance reading (Kassim *et al.*, 2022).

3.5.19 Lead

Wastewater sample was filtered to remove particulates. It was then acidified by adding nitric acid to achieve a pH less than 2. 100ml of the wastewater sample was transferred into a digestion flask. The sample was heated gently to 95°C for 2 hours until sample was clear. Sample was to cooled and diluted with distilled water. The absorbance of each standard solution was measured using atomic absorption spectrometer set to a wavelength of 217nm. The calibrated curve was used to determine the lead concentration in the wastewater sample from the reading (Kassim *et al.*, 2022).

3.5.20 Arsenic

Wastewater sample was were collected in a clean acid-washed polyethylene bottle. Nitric acid was added to preserve the sample and prevent metal precipitation. The sample was digested using a sulfuric acid to break down organic matter and release arsenic into the solution. The digested sample was analyzed using AAS and concentration recorded (Kassim *et al.*, 2022).

3.5.21 Total coliform

1000ml wastewater sample was collected into a clean container. Filter 100ml of sample through membrane filter of pore size 0.45µm. the filter was then placed on a petri dish containing m-endo agar. The petri dish was then incubated at a temperature of 35°C to 37°C for 24 hours. The number of colonies were counted with a metallic sheen (Olalemi *et al.*, 2021).

3.5.22 Fecal coliform

1000ml wastewater sample was collected into a clean container. Filter 100ml of sample through membrane filter of pore size 0.45µm.

The filter was then placed on a petri dish containing m-FC agar. The petri dish was then incubated at a temperature of 44.5°C for 24 hours. The number of colonies were counted with a metallic sheen (Olalemi *et al.*, 2021).

3.5.23 *Escherichia coli*

1000ml wastewater sample was collected into a clean container. Filter 100ml of sample through membrane filter of pore size 0.45µm. the filter was then placed on a petri dish containing m-colibblue24 agar. The petri dish was then incubated at a temperature of 35°C to 37°C for 24 hours. The number of blue colonies were counted with a metallic sheen (Olalemi *et al.*, 2021).

3.5.24 *Salmonella spp*

1000ml wastewater sample was collected into a clean container. Filter 100ml of sample through membrane filter of pore size 0.45µm. the filter was then placed on a petri dish containing salmonella shigella agar. The petri dish was then incubated at a temperature of 35°C to 37°C for 24 to 48 hours. The number of black colonies were counted (Olalemi *et al.*, 2021).

3.5.25 Turbidity

The turbidimeter was calibrated with a blank solution of 0.02 turbidity. The probe was then dipped into the wastewater sample and reading was allowed to stabilize before recording (Azil *et al.*, 2021).

3.5.25 Computation of Sodium Adsorption Ratio

$SAR = (Na^+ / (\sqrt{(Ca^{2+} + Mg^{2+})/2}))$. Where: Na^+ is the concentration of sodium in milliequivalent per liter, Ca^+ is the concentration of calcium in milliequivalent per liter and Mg^+ is the concentration of magnesium in milliequivalent per liter.

3.6 Statistical Analysis

Statistical analyses such as T-test, standard deviations of means, averages and percentages were computed using R software (R version 3.4.3) to test statistically significant differences for the untreated and treated wastewater characteristics.

Line graphs and tables were used to represent the difference in wastewater characteristics over the period by which the system was used without cleaning or backwashing. The mean, standard deviation, standard deviation of means, maximum, minimum and the p-values of all raw and treated wastewater parameters namely; dissolved oxygen, biochemical oxygen demand, total nitrogen, total phosphate, turbidity, PH, temperature, arsenic, mercury, lead, chemical oxygen demand, dissolved oxygen, total suspended solids, salinity and *Escherichia coli* was computed and represented on tables.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Introduction

This chapter provides the results of findings on the physicochemical and microbiological characteristics of wastewater used for irrigation at the Korle-Bu vegetable farm, pictures of the baseline study, graphical representation of results on the removal efficiency of a designed treatment system as well as a comparative study on the quality of treated and untreated wastewater over an eight-day period. The chapter also presents the statistical analysis of the physicochemical parameters of untreated and treated wastewater use for irrigation.

4.1 Results

4.1.1 Physical Observation and Description of Wastewater

A survey on the physical characteristics of wastewater used for irrigation at the vegetable farm basically centered on observation. The source of wastewater and the land use activities around the catchment where the wastewater was used in the vegetable farm was studied. Plate C shows the flow channel of wastewater that serves the vegetable farm. Wastewater from Laterbiokorshie, Kaneshie, Sempe, some parts of Abossey Okai and some parts of Dansoman serves as the remotest areas of water during runoff and other activities that produces wastewater. Due to the population density as well as major institution located in the catchment, there was a regular flow of wastewater through the drains in both wet and dry seasons of the year. Plate D shows impoundment created by farmers to serve as a source of water for irrigation. The impounded water serves a maximum of four farmers in the vegetable farm.

A physical observation of the wastewater shows suspected high levels of turbidity made up of different forms of solids such as suspended solids, settleable solids and colloidal solids.

Wastewater is suspected to contain high levels of organic matters from plants and animals due to the colour and odour. Wastewater from upstream to the outfall is exposed directly to sunlight and also in a concrete drain which has the ability to absorb some form of heat when exposed to heat. This makes wastewater relatedly warmer and can foster the growth of certain microorganisms such as mesophilic bacteria and fungi. Solid waste materials in the catchment area are dumped in the open drain which also serve as a source of pollution into wastewater in the vegetable farm.



Figure 4.1: Picture of flow channel impoundment of wastewater

4.1.2 Physical characteristics of wastewater

Table 4.1 shows the physical characteristics of wastewater used for irrigation of vegetable crops at Korle-Bu vegetable farms. Wastewater generally flows from households, schools and other premises upstream of the vegetable farm and are impounded by famers for a constant water supply. Parameters such as temperature measured in degrees Celsius, electrical conductivity in microsiemens per centimeter, total dissolved solids in milligrams per liter, total suspended solids in milligrams per liter, turbidity in nephelometric turbidity unit and salinity in practical salinity unit.

Table 4.1: Physical characteristics of wastewater

| PARAMETER | SITE A | SITE B | SITE C | MIN | MAX | MEAN | S. S.DEV | EPA GH LIMIT |
|------------------|--------|--------|--------|--------|--------|---------|----------|---|
| Temperature (°C) | 33.50 | 32.35 | 33.20 | 32.35 | 33.50 | 33.02 | 0.60 | |
| E.C (µS/cm) | 1790 | 1785 | 1795 | 1785 | 1790 | 1790 | 5.00 | 1500 |
| TDS (mg/L) | 1128 | 1125 | 1130 | 1125 | 1130 | 1127.67 | 2.52 | 1000 for most crops 500 for leafy vegetables |
| TSS (mg/L) | 1256 | 1250 | 1266 | 1250 | 1266 | 1257.33 | 8.08 | 50 for most crops 10 for vegetable crops |
| Turbidity (mg/L) | 400 | 398 | 405 | 398 | 405 | 401 | 3.61 | General crops = 10 Leafy vegetables=5 |
| Salinity (mg/l) | 228.71 | 228.52 | 229.51 | 228.52 | 228.71 | 228.91 | 0.52 | 700 |

Source: Field Data 2024

A laboratory assessment of the physical parameters revealed that the temperature of wastewater used for irrigation at the Korle Bu vegetable farms was 33.50°C, 32.35°C and 33.20°C for site A, B and C and a mean and standard deviation of 33.02 and 0.60 respectively. The less standard deviation is accounted as a result of similarity in the temperatures as a result single sourced wastewater for different impoundment.

Electrical conductivity of wastewater used for irrigation at the time of the research was 1790 µS/cm, 1785 µS/cm and 1785 respectively for site A, B and C with a mean and standard deviation of 1790 µS/cm and 5. The variability in electrical conductivity of wastewater is less due to similarity in source of water and type of pollutant resulting in the increase in solids present that contribute to high conductivity.

Total dissolved solids (TDS) of wastewater used for irrigation at the vegetable farm in Korle-bu was 1128mg/L, 1125mg/l and 1130mg/L for site A, site B and site C respectively with a mean and standard deviation of 1127.67 and 2.52. The little variation in TDS levels is due to similar levels of solids due to single source of wastewater. In similar study conducted by Anim et al 2014 where total dissolved solids for some parts of the eastern region of Ghana recorded 488mg/L ± 23mg/L. The Ghana environmental protection agency recommends that, the level of total dissolved solids for wastewater used for irrigation should not exceed 1000mg/L for most crops especially non-leafy vegetables and 500mg/L or less for leafy vegetables. High levels of total dissolved solids mean a conducive environment for the growth of microorganism and other pathogen.

The laboratory experiment revealed that, the level of total suspended solids in wastewater used for irrigation was 1256mg/L, 1250mg/L, and 1266mg/L for site A, site B and site C respectively. The mean total dissolved solids computed was 1257.38mg/L and a standard deviation of 8.08.

Variation in total suspended solids is accounted for by the differences in flow velocities for different impoundments. The higher the flow velocity into the impoundment, the high the total suspended solids in the wastewater. The difference in total suspended solids levels stem from difference in wastewater type, source, rate of flow and the contaminants that makes up wastewater. The environmental protection agency of Ghana recommended a total suspended solid level of 50mg/L for reuse and disposal. The world health organisation recommends a total suspended solids levels of less than 50mg/L for irrigating leafy vegetables.

Turbidity level of wastewater is 400mg/L, 398mg/L, and 405mg/L for site A, site B and site C respectively and a mean of 401mg/L and 3.61 standard deviation. The consistency in test results for turbidity levels is due to point source of pollution for wastewater on the fields.

In others earlier researches, turbidity levels of wastewater according to Abdallah et al 2021 suggest a turbidity level of wastewater to be 118 NTU, 120 NTU and 19NTU for three different study sites. The difference is accoutered for by different wastewater sources and types of pollution points. The commended level of turbidity of water used for irrigation is 10 NTU and 5NTU for general and leafy vegetable crops respectively. High turbidity in wastewater is a function of the presence of solids which create a conducive environment for growth of microorganisms due to increased surface area for adsorption of microbes.

Salinity in wastewater is a function of the presence of salt what also accounts for electrical conductivity in water. High salinity reflects in a correspondent high electrical conductivity. Electrical conductivity in wastewater also arises due to the presence of suspended and dissolved solids. The salinity levels of wastewater in the study area were 228.71mg/l, 228.52mg/l and 229.51 respectively for site A, site B and site C respectively with a mean and standard deviation of 228.91 and 0.52. the standard deviation of the results implies that there is little variation in salinity amongst the three different impoundments where water is drawn by farmers for irrigation. the similarity arises from the similarity in suspended and dissolved oxygen levels. In other studies, salinity is shown to interfere with the growth, development and production of plants by reducing the nitrogen uptake potential of plant. The salinity of wastewater exceeds the recommended limits prescribed by the world health organisation and the Ghana environmental protection agency of less than or equal to 0.7PSU or 700mg/l. prior treatment is therefore necessary for wastewater before usage for leafy vegetable irrigation.

Water used for irrigation at the vegetable farm was recorded at 890, 895 and 888 for site A, site B and site C respectively with a mean and standard deviation of 891 and 3.61. Since wastewater emanate from same source to feed into the impoundment created by farmers, it is scientifically logical to record similar levels of physical parameters such as colour.

4.1.3 Chemical characteristics of wastewater

Table 4.2 shows a table of the chemical parameters of wastewater used for irrigation at Korle-bu vegetable farm. The following parameters were measured. Sodium ion concentration, dissolved oxygen(DO) measured in milligrams per liter, biochemical oxygen demand(BOD) measured in milligrams per liter, chemical oxygen demand(COD) measured in milligrams per liter, calcium (Ca) measured in milligrams per liter, magnesium(Mg) measured in milligrams

per liter, total phosphate(TP) measured in milligrams per liter, sodium measured in milligrams per liter, total nitrogen measured in milligrams per liter, mercury(Hg) levels measured in milligrams per liter, lead(Pb) levels measure in milligrams per liter, arsenic(As) levels measured in milligrams per liter and sodium absorption ratio(SAR) calculated as a function of the amount of sodium relative to calcium and magnesium. The wastewater taken from impoundments where wastewater flows from other parts of the catchment to feed the vegetable farm and used by farmers for irrigation purposes. The parameter that records the highest value is denoted as maximum (Max), lowest denoted as minimum (Min), the average of that specific parameters denoted as mean and the sample standard deviation denoted as S.S.DEV.

The results are therefore compared with standards prescribed by the food and agricultural organisation (FAO), the Ghana environmental protection agency (Gh-EPA) and the world health organisation (WHO). Specific emphasis was given to guidelines of water parameters required for the irrigation of vegetable crops since parameters might differ at certain instances from general crops.

Table 4.2 Chemical Parameters of Wastewater

| Parameters | Site A | Site B | Site C | MIN | MAX | MEAN | S.DEV | GH-EPA LIMITS |
|-------------|--------|--------|--------|-------|-------|----------|----------|---------------|
| pH | 5.9 | 6.52 | 6.35 | 5.9 | 6.52 | 6.256667 | 0.320364 | 6 to 9 |
| DO (mg/L) | 1.63 | 1.61 | 1.59 | 1.59 | 1.63 | 1.61 | 0.02 | ≥5.0 |
| BOD (mg/L) | 325 | 315 | 335 | 315 | 335 | 325 | 10 | ≤50 |
| COD (mg/L) | 1073 | 1060 | 1083 | 1060 | 1083 | 1072 | 11.53256 | ≤200 |
| Ca(mg/L) | 54.51 | 54.3 | 53.01 | 53.01 | 54.51 | 53.94 | 0.812219 | 40 to 100 |
| Mg(mg/L) | 20.46 | 21.36 | 20.55 | 20.46 | 21.36 | 20.79 | 0.49 | 10 to 50 |
| TP (mg/L) | 26.00 | 25.55 | 26.55 | 25.55 | 26.55 | 26.01 | 0.50 | 0.1 to 1.0 |
| Na (mg/L) | 80.76 | 81.00 | 81.50 | 80.76 | 81.50 | 81.08 | 0.38 | 20 to 50 |
| TN (mg/L) | 28.2 | 27.21 | 29.25 | 27.21 | 29.25 | 28.22 | 1.020147 | < 5 |
| Hg(mg/L) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ≤0.0005 |
| Pb(mg/L) | 0.37 | 0.36 | 0.34 | 0.34 | 0.37 | 0.356667 | 0.015275 | ≤0.1 |
| As(mg/L) | 1.6 | 1.8 | 1.4 | 1.4 | 1.8 | 1.6 | 0.2 | 0.05 |
| SAR (meq/L) | 2.35 | 2.35 | 3.39 | 2.35 | 2.39 | 2.36 | 0.02 | 0 to 3 |

Source: field data 2024

Laboratory analysis of the chemical parameters of wastewater used for irrigation in the vegetable farm was examined. Even though not all the chemical parameters are necessary caused of water quality parameter and does not automatically disqualify water from being used for irrigation purposes, they are evidence of pollution. The hydrogen ion concentration of wastewater for site A, B and C were 5.9, 6.52 and 6.35 respectively. The mean and standard deviation were 6.26 and 0.32 respectively. This suggest that wastewater is slightly acidic and might enhance the growth of acidophilic microorganisms. This occurrence of a slight acidic condition in the water can be accounted for by the land use activities and the characteristics of the catchment. Runoff water flow from mostly residential places which normally generate slightly acidic water due to cooking activities.

Dissolved oxygen in irrigation water is a determinant of the organic pollution level of water. The reported dissolved oxygen for wastewater used for irrigation at the vegetable farm was 1.63, 1.61 and 1.59 for site A, B and C respectively. The mean dissolved oxygen was 1.61 with a standard deviation of 0.02. the difference in dissolved oxygen levels is little and is accounted for in the standard deviation. Wastewater has approximately the same dissolved oxygen levels due to single source of wastewater and similarity in the nature of catchment that serves as water shed for the wastewater.

The difference is however as a result of differences in activities the produced wastewater. The Ghana environmental protection agency, the world health organisation and food and agriculture organisation prescribed the dissolved oxygen level for the irrigation of vegetable crops to be less than or equal to 5mg/L. this therefore implies that the use this wastewater without prior treatment is harmful to human and public health.

The biochemical oxygen demand of wastewater used for irrigation was reported at 325mg/L, 315mg/L, and 335mg/L for site A, site B and site C respectively with a mean and standard deviation of 325mg/L and 10. In other previous studies, urban blackwater has a biochemical oxygen demand level between 290mg/L to 3480mg/l while industrial blackwater falls within a biochemical oxygen demand level of 420mg/L. The wastewater used for irrigation however is similar to the BOD₅ of industrial blackwater which suggests extreme organic pollution of irrigation water. Seasonal variations also have an impact on wastewater quality.

Comparatively, it is easier to treat such wastewater for irrigation with simple technologies to wastewater used for irrigation at Korle Bu vegetable farms. The World Health Organisation, the Food and Agriculture Organisation and the Ghana Environmental Protection Agency prescribed a mean biochemical oxygen demand level for wastewater used for irrigation at less than or equal to 50mg/L. The implication of this wastewater for irrigation is that it contains excessive levels of organics which is detrimental to public health especially when it is used to irrigate vegetable crops which can be eaten raw without prior processing.

Chemical oxygen demand in the wastewater under study was found to be 1073mg/L, 1060mg/L, and 1083mg/L in site A, site B and site C respectively. The mean and standard deviation of chemical oxygen demand was 1072mg/L and 11.53. The result on chemical oxygen demand is relatively higher than most recent similar findings. The Food and Agricultural Organisation, the World Health Organisation and the Ghana Environmental Protection Agency prescribed a chemical oxygen demand level of less than or equal to 200mg/L for vegetable crops and less than or equal to 500mg/L for irrigation of other general crops which goes through some form of processing before use.

Calcium levels in wastewater used for irrigation was 54.51mg/L, 53.30mg/L and 53.01mg/L respectively. The mean and standard deviation of the results were 53.94 mg/L and 0.81 respectively. the results of wastewater levels at the three different sampling points are consistent due to the similarity in source of wastewater and the land use activities around the catchment. The world health organisation, food and agricultural organisation and the environmental protection agency of Ghana prescribed a calcium level for wastewater and other water sources used for irrigation between 40mg/L and 100mg/L. therefore, the nutrient level in wastewater used for irrigation is within the limits prescribed by the WHO, FAO and Gh-EPA. The use of this water is therefore considered safe for use in irrigation and does not pose any public health threats in terms of the level of calcium.

Magnesium levels for site A, site B and site C were 20.46mg/L, 21.36mg/L and 20.55mg/L respectively. the mean and standard deviation of the results were 20.79 mg/L and 0.49 respectively. the consistency of magnesium levels in the three-sampling site is as a result of similarity in catchment characteristic and the type of land use activity in the area. The water used for irrigation also emanate from a similar source which is likely to contain similar levels of contaminants. The mean calcium level of wastewater located in drains of Kumasi; a subregion of Ghana had a mean of 3.75 different from this finding. the difference can be attributed to differences in catchment characteristics and the source of wastewater. The acceptable level of magnesium allowed by the food and agricultural organisation and the environmental protection agency of Ghana is 10mg/L to 50mg/L. this implies that in terms of magnesium levels, wastewater used for irrigation is fit for purpose and not likely to pose any public health risk.

Total phosphate levels for sampling site A, site b and site C were 26.00mg/L, 25.55mg/L and 26.55mg/L respectively. the mean and standard deviation were 26.03mg/L and 0.50 respectively. similarity in the phosphate levels of wastewater for the different sampling sites can be attributed to the similarity in land use activity along the catchment as well as the point source of wastewater the feeds the vegetable farm.

Sodium levels of wastewater used for irrigation from the three sampling points were 80.78mg/L, 81.00mg/l and 81.50 mg/L for sampling site A, site B and site C respectively. the mean and standard deviation are 81.08mg/L and 0.38. the results for three sampling sites are similar due to similarity in the characteristics of the catchment and the nature of land use activities. The source of wastewater that feeds into the vegetable farm is also from a single source which is likely to have similar levels of a particular contaminant. The sodium levels of irrigation water are essential in computing the sodium absorption ration which is a function of the amount of sodium, magnesium and calcium. The food and agricultural organisation and the environmental protection agency of Ghana prescribed a sodium level of 20mg/L to 50mg/L. it therefore implies that wastewater used for irrigation exceeds the levels allowed for irrigation. the use of this water without prior treatment is therefore detrimental to public health.

Total nitrogen levels for site A, site B and site C were 28.2mg/L, 27.21mg/L and 29.25mg/L respectively. the mean and sample standard deviation were 28.22mg/L and 1.02. the nitrogen levels for the three sampling sites are similar to each other due to the similarity in the land use around the catchment. The source of water into the vegetable farm is generated from similar sources which is likely to contain similar levels of the same contaminant. In other similar research, the mean level of sodium in wastewater is 11.72mg/L.

The levels exceed the guideline limits provided by the world health organisation, food and agricultural organisation and the environmental protection agency of Ghana.

This implies that continual usage of this wastewater for irrigation of vegetable crops can pose serious public health implications.

Mercury levels for irrigation water is an essential parameter in safeguarding public health. The levels of mercury for all the sampling points were below detectable limits. In other the average mercury level for wastewater is 0.2mg/L. parameters of mercury in wastewater used for irrigation at the vegetable farm is below the limits set by FAO, WHO and Gh-EPA of ≤ 0.0005 . the use of water for irrigation will therefore not pose health risk to farmers and consumers in terms of the levels of mercury exclusively.

Lead levels for sampling site A, site B and site C were 0.37mg/L, 0.36mg/L and 0.34mg/L respectively. The mean lead level was 0.35mg/L and sample standard deviation of 0.01. in other similar studies lead levels were reported to be between 0.12mg/L and 0.4mg/L. This level exceeds the limits allowed by the WHO, FAO and Gh-EPA of ≤ 0.1 mg/L. the use of this wastewater for irrigation without prior treatment can therefore pose health risk to consumers and farmers.

Arsenic levels for wastewater used for irrigation were 1.6mg/L, 1.8mg/L and 1.4mg/L for site A, site B and site C respectively. the mean level was 1.6mg/L and a sample standard deviation of 0.2. the arsenic level exceeds the limits prescribed by the world health organisation and the Ghana environmental protection agency on irrigation water. The continuous use of this wastewater can cause risk to farmers and consumers of this produce especially in the case of vegetables where prior processing is not necessarily done before consumption.

4.1.4 Microbial characteristics of wastewater

Table 4.3 presents the microbial parameters of wastewater used for irrigation at Korle-bu vegetable farm. The following parameters were measured. Salmonella count of CFU/100ml, *Escherichia coli* in CFU/100ml, fecal coliform in CFU/100ml and total coliform in CFU/100 ml. The wastewater taken from impoundments where wastewater flows from other parts of the catchment to feed the vegetable farm and used by farmers for irrigation purposes. The parameter that records the highest value is denoted as maximum (Max), lowest denoted as minimum (Min), the average of that specific parameters denoted as mean and the sample standard deviation denoted as S.S.DEV.

The results are therefore compared with standards prescribed by the food and agricultural organisation (FAO), the Ghana environmental protection agency (Gh-EPA) and the world health organisation (WHO). Specific emphasis was given to guidelines of water parameters required for the irrigation of vegetable crops since parameters might differ at certain instances from general crops.

Table 4.3 Microbial Analysis of Wastewater

| PARAMETER | SITE A | SITE B | SITE C | MIN | MAX | MEAN | S. DEV | GH-EPA/FAO LIMITS |
|-------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|----------------------|
| Salmonella (CFU/100ml) | 1.1×10^3 | 1.6×10^3 | 1.2×10^3 | 1.1×10^3 | 1.6×10^3 | 1.3×10^3 | 2.6×10^2 | 0 |
| E-Coli (CFU/100ml) | 2.1×10^4 | 2.1×10^4 | 2.0×10^4 | 2.0×10^4 | 2.1×10^4 | 2.1×10^4 | 5.8×10^2 | 0 |
| F. Coliform (CFU/100ml) | 2.4×10^4 | 2.3×10^4 | 2.4×10^4 | 2.3×10^4 | 2.4×10^4 | 2.4×10^4 | 5.8×10^2 | 0 |
| T. Coliform (CFU/100ml) | 4.3×10^6 | 4.1×10^6 | 4.2×10^6 | 4.1×10^6 | 4.3×10^6 | 4.2×10^6 | 1.0×10^5 | 1×10^3 |

Source: field data 2024

A laboratory count of salmonella present in the wastewater used for irrigation at the vegetable farm revealed 1.1×10^3 , 1.6×10^3 , and 1.2×10^3 for site A, site B and site C respectively with a mean and sample standard deviation of 1.3×10^3 and 2.6×10^2 . the existence of higher variability in the colony count of salmonella can be attributed to difference in clusters and locations of impoundments which are exposed differently to sunlight and other environmental condition which may or may not favor the survival of salmonella. The result is in contrast with the results of s study conducted on the same site by Pesewu *et al.* (2017) which also revealed a salmonella count of 21% of 17.52×10^5 , this exceeds the recommended standards given by the food and agricultural organisation, that world health organisation and the Ghana environmental protection agency of 100 colonies per 100ml of wastewater.

Colonies of *Escherichia coli* was 2.1×10^4 , 2.1×10^4 , 2.0×10^4 for site A, site B and site C respectively. the mean and sample standard deviation of 2.1×10^4 and 5.8×10^2 . the variability in colony counts of *Escherichia coli* for different impoundment can be as a result of differences in environmental condition such as exposure to sunlight which will favor the growth of *Escherichia coli* in some clusters more than others. The food and agricultural organisation and the world health organisation recommends that, no colony of *Escherichia coli* is present in water used for irrigating vegetable especially when they do not require prior cooking before consumption. In terms of *Escherichia coli* levels, wastewater used for irrigation does not meet regulatory standards and can therefore pose risk to public health.

Colonies of faecal coliform count were 2.4×10^4 , 2.3×10^4 , and 2.4×10^4 for site A, site B and site C with a mean and sample standard deviations of 2.4×10^4 and 5.8×10^2 respectively. Number of faecal coliform count of different clusters vary significantly due to difference in prevailing environmental conditions for different sites.

Difference in conditions such as flow rate, exposure of sunlight and depth of impoundment can cause different condition for growth of fecal coliform. The acceptable level of fecal coliform in water used for irrigation according to the food and agricultural organisation, world health organisation and the Ghana environmental protection agency is 0CFU/100ml. This implies that wastewater used for irrigation does not conform to acceptable limits and can therefore pose serious public health risk especially when it is used to irrigate vegetable crops.

The total coliform levels in wastewater used for irrigation were 4.3×10^6 , 4.1×10^6 and 4.2×10^6 for site A, site B and site C respectively. The mean coliform count was 4.2×10^6 with a sample standard deviation of 1×10^5 . The difference in total coliform count can be attributed to different conditions prevailing at different sampling sites. The world health organisation, food and agricultural organisation and the Ghana environmental protection agency prescribed a recommended limit of total coliform in water used for irrigation at 1×10^3 . The mean value of total coliform exceeds the recommended limits and can therefore pose public health risk.

4.1.5 Characteristics of raw and treated wastewater

Table 4.4 presents parameters of raw (RWW) and treated (TWW) wastewater sampled from Korle-Bu vegetable farm and taken through some form of treatment regime designed with sand and activated carbon prepared from coconut shell over an eight-day period. The table contains a before and after study of physical parameters such as temperature ($^{\circ}\text{C}$), sodium ion concentration, Total dissolved solids (TDS) measured in mg/L, electrical conductivity (EC) measured in $\mu\text{S}/\text{cm}$, salinity(mg/l), total suspended solids(TSS) in mg/L, turbidity in NTU, dissolved oxygen (DO) in mg/L, biochemical oxygen demand (BOD) in mg/L, chemical oxygen demand (COD) in mg/L, total hardness (TH) in mg/L, alkalinity in mg/L, chlorine level(Cl) in mg/L, sodium content (Na) in mg/L, calcium (Ca) in mg/L, magnesium(Mg) in

mg/L, total phosphate (TP) in mg/L, total nitrogen which comprises of nitrate and nitrite (TN) in mg/L, mercury levels (Hg) in mg/L, lead (Pb) in mg/L, arsenic (As) in mg/L, *Escherichia coli* count in CFU/100ml and sodium absorption ratio which is a function of the amount of sodium relative to magnesium and calcium in wastewater. In every column, a daily parameter of both raw and treated wastewater is represented.

Table 4.4: Parameters of raw and treated wastewater (Day one to day four)

| Parameters | Day 1 | | Day 2 | | Day 3 | | Day 4 | |
|--------------------|---------------------|-------|---------------------|-------|---------------------|-------|---------------------|-------|
| | RWW | TWW | RWW | TWW | RWW | TWW | RWW | TWW |
| T (°C) | 33.5 | 27.20 | 32.35 | 27.3 | 32.35 | 27.31 | 32.36 | 27.34 |
| pH | 5.9 | 7.62 | 6.1 | 7.42 | 6.03 | 7.44 | 6.1 | 7.45 |
| E.C(µS/cm) | 1790 | 355 | 1791 | 358 | 1790 | 361 | 1792 | 363 |
| TDS (mg/l) | 1128 | 668 | 1129 | 671 | 1128 | 671 | 1130 | 681 |
| TSS (mg/l) | 1256 | 1 | 1258 | 1 | 1258 | 2 | 1260 | 2 |
| Salinity(mg/l) | 228.71 | 0.67 | 228.51 | 0.67 | 228.00 | 0.68 | 228.8 | 0.69 |
| Turbidity. (NTU) | 400 | 4 | 398 | 4 | 399 | 4 | 396 | 5 |
| DO (mg/l) | 1.63 | 3.4 | 1.62 | 3.5 | 1.61 | 3.60 | 1.60 | 3.4 |
| BOD (mg/l) | 325 | 1.11 | 324 | 1.11 | 327 | 1.11 | 326 | 1.11 |
| COD (mg/l) | 1073 | 114 | 1072 | 112 | 1075 | 115 | 1080 | 117 |
| TH(mg/l) | 620 | 520 | 610 | 521 | 621 | 520 | 623 | 530 |
| Alkalinity (mg/l). | 1400 | 740 | 1410 | 745 | 1407 | 746 | 1415 | 750 |
| Cl(mg/l) | 118.11 | 23.33 | 120.22 | 24.22 | 134.32 | 32.12 | 135.88 | 39.98 |
| Na(mg/l) | 80.50 | 43.00 | 81.88 | 44.23 | 79.80 | 42.34 | 82.00 | 44.55 |
| Ca (mg/l) | 54.51 | 60 | 54.31 | 61 | 54.3 | 61 | 54.73 | 60 |
| Mg(mg/l) | 20.46 | 18.05 | 20.40 | 18.08 | 20.45 | 18.12 | 20.00 | 19.02 |
| TP(mg/l) | 26.00 | 0.30 | 26.00 | 0.31 | 20.01 | 0.32 | 26.03 | 0.32 |
| TN(mg/l) | 28.20 | 4 | 28.10 | 5 | 28.20 | 4 | 28.30 | 4 |
| Ag(mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pb(mg/l) | 0.37 | 0.06 | 0.37 | 0.06 | 0.37 | 0.06 | 0.39 | 0.07 |
| As(mg/l) | 1.6 | 0.01 | 1.6 | 0.01 | 1.6 | 0.01 | 1.7 | 0.02 |
| E-coli (100CFU) | 2.1x10 ⁴ | 0 | 2.1x10 ⁴ | 0 | 2.1x10 ⁴ | 0 | 2.2x10 ⁴ | 0 |
| SAR (meq/l) | 2.36 | 1.25 | 2.41 | 1.28 | 2.34 | 1.22 | 2.41 | 1.28 |

Source: field data 2024

Table 4.5: Parameters of raw and treated wastewater (Day-5 to Day-8)

| Parameters | Day 5 | | Day 6 | | Day 7 | | Day 8 | |
|-------------------|---------------------|-------|---------------------|-------|---------------------|-------|---------------------|-------|
| | RWW | TWW | RWW | TWW | RWW | TWW | RWW | TWW |
| T (°C) | 32.47 | 27.32 | 32.5 | 27.51 | 32.9 | 27.66 | 33 | 27.69 |
| Ph | 6.2 | 7.62 | 6.2 | 7.68 | 6.2 | 7.82 | 6.4 | 7.79 |
| E.C(μS/cm) | 1793 | 388 | 1780 | 360 | 1790 | 368 | 1790 | 367 |
| TDS(mg/l) | 1129 | 681 | 1150 | 719 | 1021 | 547 | 1140 | 669 |
| TSS(mg/l) | 1259 | 1 | 1260 | 1 | 1296 | 4 | 1270 | 3 |
| Salinity (mg/l) | 228.4 | 0.72 | 229.01 | 0.54 | 229.02 | 0.66 | 229.8 | 0.7 |
| Turbidity(mg/l) | 401 | 5 | 405 | 6 | 402 | 5 | 420 | 9 |
| DO(mg/l) | 1.62 | 3.4 | 1.61 | 3.29 | 1.6 | 3.4 | 1.57 | 3.11 |
| BOD(mg/l) | 329 | 1.5 | 329 | 0.5 | 335 | 1.93 | 323 | 0.6 |
| COD(mg/l) | 1120 | 141 | 998 | 93 | 1130 | 153 | 1004 | 98 |
| TH(mg/l) | 310 | 280 | 642 | 550 | 810 | 690 | 301 | 256 |
| Alkalinity(mg/l) | 1020 | 590 | 1300 | 705 | 1440 | 770 | 1420 | 755 |
| Cl(mg/l) | 135.21 | 32.98 | 114.4 | 22.99 | 135.98 | 33.98 | 121.55 | 27.99 |
| Na(mg/l) | 80.46 | 43 | 80.48 | 43 | 80.22 | 42.88 | 80.4 | 43 |
| Ca(mg/l) | 53.3 | 59 | 54.43 | 61 | 54.4 | 61 | 53.4 | 60 |
| Mg(mg/l) | 20.04 | 18.11 | 20.65 | 19.13 | 21.55 | 19.01 | 21.62 | 19.11 |
| TP(mg/l) | 26.05 | 0.32 | 26.04 | 0.32 | 26.14 | 0.34 | 26.05 | 0.31 |
| TN(mg/l) | 28.3 | 4 | 27.8 | 3 | 28.2 | 4 | 28.5 | 5 |
| Ag(mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pb(mg/l) | 0.39 | 0.07 | 0.37 | 0.06 | 0.37 | 0.05 | 0.38 | 0.06 |
| As(mg/l) | 1.7 | 0.02 | 1.6 | 0.01 | 1.6 | 0.01 | 1.7 | 0.02 |
| E.coli(100CFU/ml) | 2.1x10 ⁴ | 0 | 2.3x10 ⁴ | 0 | 2.3x10 ⁴ | 0 | 2.4x10 ⁴ | 0 |
| SAR(mg/l) | 2.38 | 1.26 | 2.35 | 1.23 | 2.33 | 1.23 | 2.35 | 1.24 |

Source: field data 2024

Table 4.6: Percentage Difference in Treated and Raw Wastewater

| Parameters | Day 1 (% diff) | Day 2 (% diff) | Day 3 (% diff) | Day 4 (% diff) | Day 5 (% diff) | Day 6 (% diff) | Day 7 (% diff) | Day 8 (% diff) | Min | Max | Mean | S. SD |
|----------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|--------|--------|----------|----------|
| T (°C) | -18.8 | -15.61 | -15.58 | -15.52 | -15.86 | -15.35 | -15.92 | -16.09 | -15.35 | -18.8 | -16.0913 | 1.120516 |
| P ^H | 29.15 | 21.63 | 23.38 | 22.13 | 22.9 | 23.87 | 26.13 | 21.71 | 21.63 | 29.15 | 23.8625 | 2.587811 |
| E.C | -80.17 | -80.01 | -79.83 | -79.74 | -78.36 | -79.77 | -79.44 | -79.49 | 78.36 | 80.17 | -79.6013 | 0.556736 |
| TDS | -40.78 | -40.57 | -40.51 | -39.73 | -39.68 | -37.48 | -46.43 | -41.31 | -37.48 | -46.31 | -40.8113 | 2.549932 |
| TSS | -99.92 | -99.92 | -99.84 | -99.84 | -99.92 | -99.92 | -99.7 | -99.77 | 99.7 | -99.92 | -99.8538 | 0.083313 |
| Salinity | -99.7 | -99.71 | -99.7 | -99.7 | -99.68 | -99.76 | -99.71 | -99.69 | -99.68 | -99.76 | -99.7063 | 0.023867 |
| Turbidity | -99 | -98.99 | -98.99 | -98.73 | -98.75 | -98.51 | -98.75 | -97.85 | -97.85 | -99 | -98.6963 | 0.382209 |
| DO | 108.59 | 116.05 | 123.6 | 112.5 | 109.87 | 104.35 | 112.5 | 98.08 | 98.08 | 123.6 | 110.6925 | 7.618023 |
| BOD | -99.66 | -99.66 | -99.66 | -99.66 | -99.54 | -99.84 | -99.42 | -99.81 | -99.42 | -99.84 | -99.6563 | 0.134583 |
| COD | -89.38 | -89.55 | -89.3 | -89.17 | -87.41 | -90.84 | -86.46 | -90.23 | 86.46 | -90.84 | -89.0425 | 1.435745 |
| TH | -16.13 | -14.59 | -16.26 | -14.73 | -14.37 | -14.33 | -14.81 | -14.95 | -14.33 | -16.26 | -15.0213 | 0.754632 |
| Alk | -47.14 | -47.16 | -46.97 | -46.99 | -42.16 | -45.76 | -46.53 | -46.83 | -42.16 | -47.16 | -46.1925 | 1.692114 |
| Cl | -80.25 | -79.85 | -76.08 | -70.58 | -75.6 | -79.9 | -75.01 | -76.97 | -70.58 | -80.25 | -76.78 | 3.266532 |
| Na | -46.58 | -45.98 | -46.94 | -45.67 | -46.55 | -46.57 | -46.55 | -46.51 | -45.67 | -46.94 | -46.4188 | 0.399372 |
| Ca | 10.07 | 12.32 | 12.34 | 9.63 | 10.69 | 12.07 | 12.13 | 12.35 | 9.63 | 12.35 | 11.45 | 1.13 |
| Mg | -11.77 | -11.37 | -11.39 | -11.53 | -12.34 | -12.39 | -11.78 | -11.61 | -11.37 | -12.39 | -11.773 | 0.3958 |
| TP | -98.85 | -98.8 | -98.4 | -98.77 | -98.77 | -98.77 | -98.67 | -98.81 | -98.4 | -98.85 | -98.73 | 0.142929 |
| TN | -85.82 | -82.21 | -85.81 | -85.86 | -85.86 | -89.2 | -85.81 | -82.45 | -82.21 | -89.2 | -85.3775 | 2.211992 |
| Ag | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pb | -83.78 | -83.78 | -83.78 | -82.05 | -82.05 | -83.78 | -86.49 | -84.21 | -82.05 | -86.49 | -83.74 | 1.388833 |
| As | -99.34 | -99.38 | -99.38 | -98.82 | -98.82 | -99.37 | -99.37 | -98.82 | -98.82 | -99.38 | -99.1625 | 0.283889 |
| E-coli | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 0 |
| SAR | -47.03 | -46.88 | -47.86 | -46.88 | -47.06 | -47.65 | -47.21 | -47.23 | -46.88 | -47.86 | -47.23 | 0.36 |

Source: Field Data 2024

An eight-day study on the physicochemical and microbiological wastewater parameters for raw and treated samples showed varying levels of contaminant removal efficiencies. Parameters of treated wastewater showed some extent of disparity with other previous studies but largely similar to studies that employed same or similar treatment technology.

On day one of the experiment, the temperature of wastewater reduced from 33.5⁰C to 27.20⁰C representing 18% reduction of temperature, 32.35⁰C to 27.3⁰C representing 15.61% reduction on day two, 32.35⁰C to 27.31⁰C which stands for 15.58% reduction efficiency on day three, 32.36⁰C to 27.37⁰C representing 15.52% reduction rate on day four of the experiment, 32.47⁰C to 27.32⁰C representing 15.58% reduction rate on day five, 32.50⁰C to 27.51⁰C representing 15.35% reduction on day six, 32.90⁰C to 27.66⁰C representing 15.92% reduction rate on day seven and 33.00⁰C to 27.69⁰C representing 16.09% reduction rate in day eight. The highest rate of reduction was recorded on day one while the lowest recorded on day six. The mean and sample standard deviation for the reduction rate were 16.09 and 1.12 respectively. Generally, the temperature is influenced by the ambient and room temperatures of the experimental environment as well as the sampling site. The environmental protection agency, world health organisation and the food and agricultural organisation does not specify the acceptable level of temperature for irrigation water, meanwhile, it must not influence the growth of other harmful contaminants.

The p^H increased from 5.9 to 7.62 (29.15%) in day one, 6.1 to 7.42 (21.63%) in day two, 6.03 to 7.44 (23.38%) in day three, 6.1 to 7.45 (24.13%) in day four, 6.2 to 7.62 (22.90%) in day five, 6.2 to 7.68 (23.87) on day six, 6.2 to 7.82 (26.13%) on day seven and 6.4 to 7.79(21.71%) on day eight of the experiment.

Day two recorded the lowest increase in p^H whereas day one recorded the highest rate of increase in hydrogen ion concentration of wastewater. The mean rate of increase was 23.86% with a sample standard deviation of 2.58.

Electrical conductivity reduced from 1790 $\mu\text{S}/\text{cm}$ to 355 $\mu\text{S}/\text{cm}$ representing 80.17% reduction rate on day one of the experiment, 1791 $\mu\text{S}/\text{cm}$ to 358 $\mu\text{S}/\text{cm}$ representing 80.01% reduction rate on day two of the experiment, 1790 $\mu\text{S}/\text{cm}$ to 351 $\mu\text{S}/\text{cm}$ which stands for 79.38% reduction rate on day three of the experiment, 1792 $\mu\text{S}/\text{cm}$ to 363 $\mu\text{S}/\text{cm}$ representing 79.74% reduction rate on day four of the experiment, 1793 $\mu\text{S}/\text{cm}$ to 388 $\mu\text{S}/\text{cm}$ representing 78.36% reduction rate on day five of the study, 1780 $\mu\text{S}/\text{cm}$ to 360 $\mu\text{S}/\text{cm}$ representing 79.77% reduction rate on day six of the study, 1790 $\mu\text{S}/\text{cm}$ to 368 $\mu\text{S}/\text{cm}$ representing 79.44% reduction efficiency on day seven and 1790 $\mu\text{S}/\text{cm}$ to 367 $\mu\text{S}/\text{cm}$ representing 80.17% on day eight. The maximum and minimum efficiency of reduction happened on day one and day five respectively with a mean reduction rate of 79.60%.

Total dissolved solids reduced from 1128mg/L to 668mg/L (40.78%) On day one of the study, 1129mg/L to 671mg/L (40.57%) on day two of the study, 1128mg/L to 671mg/L (40.51%) on day three, 1130mg/L to 681mg/L (39.78%) on day four of the study, 1129mg/L to 681mg/L (39.68%) on day five, 1150mg/L to 719mg/L (37.48) on day six of the study, 1021mg/L to 547 (46.43%) on day seven of the study and 1140mg/L to 669mg/L(41.31%) on day eight of the study. The highest reduction rate was achieved on day seven whereas the lowest was achieved on day six of the study. The sample mean and standard deviations of the reduction rate were 40.81% and 2.56% respectively.

Total suspended solids (TSS) reduced after treatment from 1256mg/L to 1mg/L representing 99.92% reduction efficiency on day one, 1258mg/L to 1mg/L representing 99.92% rate of reduction on day two, 1258mg/L to 2mg/L representing 99.84% reduction efficiency on day three, 2260mg/L to 2mg/L representing 99.84% reduction efficiency on day four, 1259mg/L to 1mg/L representing 99.92% reduction efficiency on day five, 1260mg/L to 1mg/L representing 99.92% reduction efficiency on day six, 1296mg/L to 4mg/L representing 99.70% reduction efficiency on day seven and 1270mg/L to 3mg/L representing 99.92% reduction rate on day eight.

Salinity of wastewater reduced from 228.71mg/L to 0.67mg/L representing 99.70% reduction rate on day one, 228.51mg/L to 0.67mg/L representing 99.71% reduction efficiency on day two of the study, 228.00mg/L to 0.68mg/L representing 99.70% reduction efficiency on day three, 228.80mg/L to 0.69mg/L representing 99.70% reduction efficiency on day four, 228.40mg/L to 0.72mg/L representing 99.68% reduction efficiency on day five of the experiment, 229.01mg/L to 0.54mg/L representing 99.76% reduction efficiency on day six, 229.02mg/L to 0.66mg/L representing 99.71% reduction rate on day seven and 229.80mg/L to 0.70mg/L representing 99.69% reduction efficiency on day eight. The maximum reduction rate was achieved on day six whereas the minimum rate was achieved on day five. The mean and standard deviation of reduction rates for salinity removal were 99.70% and 0.02% respectively.

Turbidity of wastewater reduced from 400NTU to 4NTU representing 99.00% reduction rate on day one, 398NTU to 4NTU representing 98.99% reduction efficiency on day two, 399NTU to 4NTU representing 98.99% reduction efficiency on day three, 396NTU to 5NTU representing 98.73% reduction efficiency on day four, 401NTU to 5NTU representing 98.75%

reduction rate on day five, 405NTU to 6NTU representing 98.51% reduction efficiency on day six, 402NTU to 5NTU representing 98.75% reduction rate on day seven and 420NTU to 9NTU representing 99.69% reduction rate in day eight. The highest reduction rate was recorded on day one whereas the lowest rate was recorded on day eight. The sample mean and standard deviation for turbidity removal were 98.69% and 0.38% respectively.

Dissolved oxygen (DO) of wastewater increased from 1.63mg/L to 3.4mg/L representing 108.59% rate of increase on day one of the experiment, 1.62mg/L to 3.5mg/L representing 116.05% increase on day two of the experiment, 1.61mg/L to 3.60mg/L representing 123.60% increase in dissolved oxygen level on day three, 1.60mg/L to 3.4mg/L which represents 112.50% increase in dissolved oxygen level on day four, 1.62mg/L to 3.4mg/L which represents 109.87% increase in dissolved oxygen level on day five, 1.61mg/L to 3.29mg/L representing 104.35% of dissolved oxygen level one day six, 1.60mg/L to 3.4mg/L representing 112.50% increase in dissolved oxygen level on day seven and 1.57mg/L to 3.11mg/L representing 98.08% increase in dissolved oxygen level of wastewater. The maximum increase in dissolved oxygen level was achieved on day three of the experiment whereas the lowest increase in dissolved oxygen concentration was achieved on day eight of the study. The sample mean and standard deviations of dissolved oxygen were 110.68% and 7.615 respectively.

Biochemical oxygen demand of wastewater reduced from 325mg/L to 1.11mg/L(99.66%) on day 1 of the experiment, 324 to 1.11mg/L (99.66%) on day 2 of the study, 327mg/L to 1.11mg/L(99.66%) on day 3 of the experiment, 326mg/L to 1.11mg/L(99.66%) on day 4 of the study, 329mg/L to 1.5mg/L(99.54%) on day 5, 329mg/L to 0.5mg/L (99.84%) on day 6

of the study, 335mg/L to 1.93mg/L (99.42%) on day 7 and 323mg/L to 0.60mg/L (99.81%) on day 7 of the study.

The highest (99.84%) reduction rate in biochemical oxygen demand of irrigation wastewater was achieved on day 6 of the experiment while the lowest (99.42%) was achieved on day 7 of the experiment. The sample mean and standard deviation for percentage reduction in biochemical oxygen demand over the eight-day period was 99.95% and 0.13% respectively.

Chemical oxygen demand of wastewater reduced from 1073mg/L to 114mg/L representing 89.38% reduction on day 1 of the study, 1072mg/L to 112mg/L representing 89.55% reduction of chemical oxygen demand on day 2 of the experiment, 1075mg/L to 115mg/L representing 89.30% reduction on day 3 of the study, 1080mg/L to 117mg/L representing 89.17% reduction in chemical oxygen demand on day 4 of the study, 1120mg/L to 141mg/L representing 87.41% reduction of chemical oxygen demand on day 5 of the study, 998mg/L to 93mg/L representing 90.84% reduction in the level of chemical oxygen demand on day 6, 1130mg/L to 153mg/L representing 86.46% reduction in the level of chemical oxygen demand on day 7 and 1004mg/L to 98mg/L which represents 90.23% reduction of chemical oxygen demand on day 8 of the experiment. The highest (90.84%) reduction rate occurred on day 6 of the study whereas the lowest (86.46%) reduction rate occurred on day 7 of the study. The sample mean and standard deviation of the percentage reduction in chemical oxygen demand were 89.04% and 1.44% respectively.

Total hardness of wastewater reduced from 620mg/L to 520mg/L representing 16.13% reduction on day 1 of the study, 610mg/L to 521mg/L representing 14.59% reduction rate on day 2, 621mg/L to 520mg/L representing 16.26% reduction rate on day 3, 623mg/L to 530mg/L representing 14.73% reduction rate on day 4, 310mg/L to 280mg/L representing

14.37% reduction in the total hardness on day 5, 642mg/L to 550mg/L representing 14.33% reduction rate on day 6, 810mg/L to 690mg/L representing 14.81% reduction rate on day 7 and 301mg/L to 256mg/L representing 14.95% reduction rate on day 8 of the study. The highest (16.26%) reduction occurred on day 3 of the experiment whereas the lowest (14.33%) reduction occurred on day 6 of the study. The sample mean and standard deviation of the reduction rates for total hardness were 15.02% and 0.74% respectively.

Alkalinity of wastewater reduced from 1400mg/L to 740 representing 47.14% reduction rate on day 1, 1410mg/L to 745mg/L which represents 47.16% reduction rate on day 2, 1407mg/L to 746mg/L representing 46.97% reduction rate on day 3, 1415mg/L to 750mg/L representing 46.99% reduction rate on day 4, 1020mg/L to 590mg/L representing 42.16% reduction rate on day 5, 1300mg/L to 705mg/L representing 45.76% reduction rate on day 6, 1440mg/L to 770mg/L representing 46.53% reduction efficiency on day 7 and 1420mg/L to 755mg/L representing 46.83% reduction rate on day 8 of the experiment on alkalinity of wastewater used for irrigation. the highest (47.16%) reduction rate in alkalinity of wastewater was achieved on day 2 whereas the lowest (42.16%) reduction achieved on day 5 of the study. The sample mean and standard deviation of the reduction rates of alkalinity in this study was 46.19% and 1.69% respectively.

Chlorine in wastewater used for irrigation reduced from 118.11mg/L to 23.33mg/L representing 80.25% reduction rate on day 1, 120.22mg/L to 24.22mg/L representing 79.85% reduction rate on day 2, 134.32mg/L to 32.12mg/L representing 76.08% reduction rate of chlorine on day 3, 135.88mg/L to 39.98mg/L representing 70.58%..reduction rate on day 4, 135.21mg/L to 32.98mg/L representing 75.60% reduction rate on day 5, 114.40mg/L to 22.99mg/L representing 79.90% reduction rate on day 6, 135.98mg/L to 33.98mg/L

representing 75.01% reduction rate on day 7 and 121.55mg/L to 27.99mg/L representing 76.97% reduction rate of chlorine on day 8 of the experiment. The highest (80.25%) rate of reduction of chlorine was achieved on day 1 while the lowest (70.58%) rate of reduction was achieved on day 4 of the experiment. The sample mean and standard deviation of chlorine reduction rate from wastewater was 76.78% and 3.27% respectively.

Sodium in wastewater reduced from 80.50mg/L to 43.00mg/L representing 46.58% reduction rate on day 1, 81.88mg/L to 44.23mg/L which represents 45.98% reduction on day 2, 79.80mg/L to 42.34mg/L representing 46.94% reduction rate on day 3, 82.00mg/L to 44.55mg/L representing 45.67% reduction rate on day 4, 80.46mg/L to 43.00mg/L representing 46.55% reduction rate on day 5, 80.48mg/L to 43.00mg/L representing 46.57% reduction rate on day 6, 80.22mg/L to 42.88mg/L representing 46.55% reduction rate on day 7 and 80.40mg/L to 43.00mg/L representing 46.51% reduction rate on day 8 of the experiment. The highest reduction rate of sodium was achieved on day 3 while the lowest reduction achieved on day 4 of the study. The sample mean and standard deviation of sodium reduction rate in wastewater for this study were 46.42% and 0.39% respectively.

Calcium increased from 54.51mg/L to 60mg/L (10.07%) on day 1, 54.31mg/L to 61mg/L (12.32%) on day 2, 54.30mg/L to 61mg/L(12.34%) on day 3, 54.73mg/L to 60mg/L (9.63%) on day 4, 53.30mg/L to 59mg/L (10.69%) on day 5, 54.43mg/L to 61mg/L (12.07%) on day 6, 54.40mg/L to 61mg/L (12.13%) on day 7 and 53.40mg/L to 60mg/L (12.35%) on day 8 of the experiment. The highest increase in the level of calcium was achieved on day 8 whereas the lowest achieved on day 4 of the study. The sample mean and standard deviation on the rate of increase in the level of calcium were 11.45% and 1.13 respectively.

Magnesium content reduced from 20.46mg/L to 18.05mg/L (11.77%) reduction rate on day 1, 20.40mg/L to 18.08mg/L (11.37) on day 2, 20.45mg/L to 18.12mg/L (11.39%) reduction rate on day 3, 20.00mg/L to 19.02mg/L (11.53%) on day 4, 20.04mg/L to 18.11mg/L (12.34%) on day 5, 20.65mg/L to 19.13mg/L (12.39%) on day 6, 21.55mg/L to 19.01mg/L (11.78%) on day 7 and 21.62mg/L to 19.11mg/L (11.61%) On day 8.

The highest (12.39%) reduction rate was achieved on day 3 while the lowest (11.37%) achieved on day 2. The sample mean and standard deviation of magnesium reduction rate were 11.77% and 0.39% respectively.

Total phosphate in wastewater reduced from 26.00mg/L to 0.30mg/L (98.85%) on day 1, 26.00mg/l to 0.31mg/L (98.80%)in day 2, 20.01mg/L to 0.32mg/L (98.40%) on day 3, 26.03mg/L to 0.32mg/L(98.77%) on day 4, 26.05mg/L to 0.32mg/L(98.77%) on day 5, 26.04mg/L to 0.32mg/L(98.775) on day 6, 26.14mg/L to 0.34mg/L (98.67%)on day 7 and 26.05mg/L to 0.31mg/L(98.81%) on day 8 of the study. The highest (98.85%) reduction rate was recorded on day 1 while the lowest (98.40%) reduction rate was recorded on day 3 of the study. The sample mean and standard deviation for the reduction rate of total phosphate were 98.73 and 0.14 respectively.

Total nitrogen content of wastewater reduced from 28.20mg/L to 4mg/L (85.82%) on day 1, 28.10mg/L to 5mg/L (82.21%) on day 2, 28.20mg/L to 4mg/L (85.81%) on day 3, 28.30mg/L to 4mg/L (85.86%) on day 4, 28.30mg/L to 4mg/L (89.20%) On day 5, 27.80mg/L to 3mg/L (85.81%) on day 6, 28.20mg/L to 4mg/L (82.45%) o day 7 and 28.50 to 5mg/L on day 8 of the study. The maximum (89.20%) reduction of nitrogen from wastewater in the study was recorded on day 6 while the minimum (82.21) reduction recorded on day 2 of the study.

The sample mean and standard deviation of total nitrogen reduction rate were 85.38% and 2.21% respectively. No recognizable level of mercury was detected in raw wastewater used for the laboratory analysis and treatment.

Lead levels reduced from 0.37mg/L to 0.06mg/L(83.78%) on day 1, 0.37mg/L to 0.06mg/L (83.78%) on day 2, 0.37mg/L to 0.06mg/L (83.78%) on day 3, 0.39mg/L to 0.07mg/L (82.05%) on day 4, 0.39mg/L to 0.07mg/L (82.05%) on day 5, 0.37mg/L to 0.06mg/L (83.78%) on day 6, 0.37mg/L to 0.06mg/L (86.49%) on day 7 and 0.38 to 0.06mg/L (84.21%) on day 8 of the study. The maximum (86.49%) was recorded on day 7 while the minimum (82.21%) recorded on day 2 of the experiment. The sample mean and standard deviation of lead reduction rate were 83.74% and 1.39% respectively.

Arsenic levels in wastewater reduced from 1.6mg/L to 0.01mg/L (99.34%) on day 1, 1.6mg/L to 0.01 mg/L (99.38%) on day 2, 1.6mg/L to 0.01mg/L (99.38%) on day 3, 1.7mg/L to 0.02mg/L (98.82%) on day 4, 1.7mg/L to 0.02mg/L (99.37%) on day 5, 1.6mg/L to 0.01mg/L (99.37%) on day 6, 1.6mg/L to 0.01mg/L (98.82%) on day 7 and 1.7mg/L to 0.02mg/L (98.82%) on day 8 of the experiment. The maximum (99.38%) was recorded on day 2 while the minimum (98.82%) recorded on day 5 and 6 of the experiment. The sample mean and standard deviation of arsenic reduction rates were 99.16% and 0.28% respectively.

Table 4.7: Statistical analysis of raw and treated wastewater characteristics

| Parameters | RAW WASTEWATER | | | | TREATED WASTEWATER | | | | T.TEST ($\alpha=0.05$) | EPA/FAO GUIDELINE |
|-----------------|--------------------|----------|--------|-------|--------------------|----------|-------|-------|-----------------------------|----------------------|
| | Mean (\bar{x}) | SDM | Max. | Min. | Mean(\bar{x}) | SDM | Max. | Min. | | |
| T(°C) | 32.67875 | 0.417456 | 33.5 | 32.35 | 27.41625 | 0.181182 | 27.69 | 27.2 | 0.0198 | |
| pH | 6.14125 | 0.147012 | 6.4 | 5.9 | 7.605 | 0.156753 | 7.82 | 7.42 | 0.019262 | 6-9 |
| E.C (µS/cm) | 1789.5 | 4 | 1793 | 1780 | 365 | 10.25392 | 388 | 355 | 0.018399 | 1500 |
| TDS (mg/l) | 1119.375 | 40.5108 | 1150 | 1021 | 663.375 | 49.89686 | 719 | 547 | 0.0301 | 500 |
| TSS (mg/l) | 1264.625 | 13.36239 | 1296 | 1256 | 1.875 | 1.125992 | 4 | 1 | 0.031136 | 50 |
| Salinity (mg/l) | 228.7813 | 0.532097 | 229.8 | 228 | 0.66625 | 0.054494 | 0.72 | 0.54 | 0.069985 | 700 |
| T(NTU) | 402.625 | 7.520211 | 420 | 396 | 5.25 | 1.669046 | 9 | 4 | 0.087518 | 10 |
| DO (mg/l) | 1.6075 | 0.018323 | 1.63 | 1.57 | 3.3875 | 0.1439 | 3.6 | 3.11 | 0.12451 | ≤5 |
| BOD (mg/l) | 327.25 | 3.807887 | 335 | 323 | 1.12125 | 0.456021 | 1.93 | 0.5 | 0.122613 | ≤50 |
| COD (mg/l) | 1069 | 47.46427 | 1130 | 998 | 117.875 | 20.14545 | 153 | 93 | 0.161299 | ≤200 |
| TH (mg/l) | 567.125 | 174.1054 | 810 | 301 | 483.375 | 144.6503 | 690 | 256 | 0.291807 | ≤300 |
| Alk (mg/l) | 1351.5 | 140.3852 | 1440 | 1020 | 725.125 | 57.62053 | 770 | 590 | 0.298236 | 1100 |
| Cl (mg/l) | 126.9588 | 9.211256 | 135.98 | 114.4 | 29.69875 | 6.084724 | 39.98 | 22.99 | 0.118802 | 10 |
| Na (mg/l) | 80.7175 | 0.788883 | 82 | 79.8 | 43.25 | 0.743102 | 44.55 | 42.34 | 0.219705 | 20-50 |
| Ca (mg/l) | 54.1725 | 0.525894 | 54.73 | 53.3 | 60.375 | 0.744024 | 61 | 59 | 0.281145 | 40-100 |
| Mg (mg/l) | 20.64625 | 0.619215 | 21.62 | 20 | 18.57875 | 0.524444 | 19.13 | 18.05 | 0.092192 | 10-50 |
| TP (mg/l) | 25.29 | 2.13389 | 26.14 | 20.01 | 0.3175 | 0.01165 | 0.34 | 0.3 | 0.071795 | 0.1-1.0 |
| TN (mg/l) | 28.2 | 0.2 | 28.5 | 27.8 | 4.125 | 0.64087 | 5 | 3 | 0.176183 | <5 |
| Ag (mg/l) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | NA | ≤0.0005 |
| Pb (mg/l) | 0.37625 | 0.009161 | 0.39 | 0.37 | 0.06125 | 0.006409 | 0.07 | 0.05 | 0.111754 | ≤0.1 |
| As (mg/l) | 1.6375 | 0.051755 | 1.7 | 1.6 | 0.01375 | 0.005175 | 0.02 | 0.01 | 0.098039 | 0.05 |
| SAR (meq/l) | 2.36625 | 0.030677 | 2.41 | 2.33 | 1.24875 | 0.022952 | 1.28 | 1.22 | | 0-3 |

Source: Field report 2024

4.2 Discussion of Findings

4.2.1 Physical characteristics of wastewater

The temperature range of 32.35 to 33.50 widely conforms to most wastewater located in open drains especially with wastewater found in locations with similar environmental conditions such as temperature, humidity and other characteristics such as flow rate of wastewater. (Eslami & Jalili, 2020). Temperature below 27°C is widely accepted for irrigation of vegetable crops. High temperatures encourage overgrowth of mesophilic microorganisms in wastewater (Gbedemah *et al.*, 2024b).

Electrical conductivity ranges from 1785 $\mu\text{S}/\text{cm}$ to 1790 $\mu\text{S}/\text{cm}$ conforms with existing study on physical properties of an anaerobic baffled reactor effluent system which also recorded electrical conductivity of 1500 $\mu\text{S}/\text{cm}$ (Kumatse *et al.*, 2020). The electrical conductivity of wastewater used for irrigation at the vegetable farms is relative to the properties of wastewater disposed into adjoining drainage systems that connects to the sampling site. Even though, different countries have acceptable limits for electrical conductivity in water used for irrigation, the food and agriculture organisation of Ghana accepts a limit no more than 1500 $\mu\text{S}/\text{cm}$ (Fianko & Korankye, 2020).

The range of electrical conductivity recorded in this research exceeds the guidelines given by the Environmental Protection Agency, the Food and Agricultural Organisation and the World Health Organisation making the treatment for reuse more imperative especially for irrigation of vegetables.

Total dissolved solids in wastewater used for irrigation at the Korle-Bu vegetable farm ranges from 1125mg/L to 1130mg/L which signifies very high pollution and a conducive environment for the growth of microorganism and other pathogen living creatures which tends to adsorb unto surfaces. The recorded parameters of total dissolved solids are similar to studies conducted by Kumatse *et al.* (2020) where the total dissolved solids of wastewater of similar characteristics recorded a mean of 1023 ± 65.27 mg/L. The amount of total dissolved solids are also in contrast with result on the physicochemical characteristics of greywater generated at the Kasena Nankana which reported 1541 ± 809 .mg/L (Kwabena Ntibrey *et al.*, 2020). These parameters exceed the limits prescribed by the World Health Organisation, the Food and Agricultural Organisation and the Environmental Protection Agency of Ghana.

Total suspended solids (TSS) in wastewater was within the range of 1250mg/L to 1266mg/L different from the level of total suspended solids revealed in a study conducted in Bolgatanga and Kasena Nankana district where wastewater recorded a total suspended solids levels of 159 ± 30.41 mg/L and 110.8 ± 42.40 mg/L respectively. (Kwabena Ntibrey *et al.*, 2020). The difference in total suspended solids can be attributed to difference in activities that leads to the production of wastewater, velocity of flow of wastewater along the drains and other climatic conditions. (He *et al.*, 2023).

Wastewater used for irrigation at the vegetable farm showed a turbidity range of 398 NTU to 405NTU. This signifies very high pollution in terms of the presence of solids in the wastewater.

This can be attributed to varying nature of source of wastewater that feeds into the impoundments of the farm. Similar studies on turbidity of wastewater was recorded by where the turbidity of wastewater was 279.89NTU (Kardeş *et al.*, 2024).

The high turbidity was likely to be as a result of high rate of flow of wastewater. The turbidity of wastewater exceeded the acceptable limits prescribed by the Food and Agricultural Organisation for the irrigation of vegetables. When the salinity of irrigation water is high, plants cannot easily absorb nutrient from the soil due to hindrance as a result of salinity (Zaman *et al.*, 2018). A mean salinity of 228.91mg/L can be attributed to the presence of excessive high levels of salt and other solids. The Food and Agricultural Organisation recommends a salinity level of 0.7mg/L which therefore suggest that wastewater used for irrigation needs some form of treatment before use (Zaman *et al.*, 2018).

4.2.2 Chemical characteristics of wastewater

A hydrogen ion concentration range of 5.9 to 6.2 signifies a slightly acidic nature of wastewater. This can be linked to the source of wastewater since portion of it is generated from households and contains kitchen waste such as fruits, vegetables, and other organics. Similar studies on wastewater characteristics in Accra revealed hydrogen ion concentration levels within the range of 7.02 and 7.77 which signifies a neutral to slightly basic wastewater which conforms to the guideline's limits prescribed by the Food and Agricultural Organisation for irrigation of vegetables (Fianko & Korankye, 2020). The difference in hydrogen ion concentration for the two study sites can be linked to difference in activities that result in the production of such wastewater and the catchment characteristics.

Dissolved oxygen ranged from 1.59mg/L to 1.63mg/L signifying a highly deficient oxygen amount. This will lead to the growth of anaerobic organisms and also increase the biochemical oxygen demand.

The results of this research on dissolved oxygen are similar to a study conducted by Anim *et al.* (2014) which also revealed that wastewater discharged in the Eastern Region of Ghana which can possibly be used by farmers for their activities recorded a dissolved oxygen level of 1.6 ± 0.30 mg/L. The use of water with low dissolved oxygen concentration might not necessarily result in health problem but will certainly lead to odour problem even though the issue of health problems cannot entirely be disregarded.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) ranged from 325mg/L to 335mg/L and 1060mg/L to 1083mg/L, respectively. This shows high anaerobic condition of water as well as the possible growth of other harmful microorganisms which can lead to health problems when used to irrigate crops especially for vegetables that do not require cooking and other processes. Similar studies on BOD and COD revealed 132.5mg/L to 269mg/L for BOD of greywater in three suburbs of Kumasi (Dwumfour-Asare *et al.*, 2020b), 309 ± 82 mg/L for greywater in Accra metropolis (Mohammed *et al.*, 2015) and 198.3 ± 33.3 mg/L for wastewater in KNUST, university campus Awuah *et al.*, (2014). Additionally, the COD from similar researches reveals 612.99 ± 66.35 mg/L for wastewater in Eastern Region of Ghana (Anim *et al.*, 2014). This parameter exceeds the recommended levels prescribed by the Food and Agricultural Organisation for irrigation of vegetables that will require prior treatment for safe reuse.

Calcium ranges from 53.01mg/L to 54.51mg/L which denote an optimum level of calcium according to the food and agricultural organisation for use in irrigation.

This is different from the calcium levels revealed in a study conducted by (Awuah *et al.*, 2014) on wastewater located at KNUST university campus which values were 2.81 ± 0.01 mg/L. the calcium level is important in determining the sodium absorption ratio of the wastewater.

Magnesium levels were within the recommended range provided for irrigation; meanwhile total phosphate recorded levels within the range of 26.01mg/L and 26.55mg/L. the existence of these element will result in eutrophication leading to the depletion of dissolved oxygen in water. Similar research on phosphate levels fell within the range of 26.01mg/l to 26.55mg/l by Oby *et al.*, (2019) and 26.18mg/L Niyonzima, (2007). Magnesium determines the sodium absorption ratio of water and needs to be kept within an optimum range. Magnesium level is within the acceptable level for irrigation and therefore does not need prior treatment before use.

Total phosphate ranged between 20.79mg/L to 21.36mg/L. this falls within the recommended range of 10mg/L to 50mg/L by the food and agricultural organisation for the irrigation of crops. Sodium level ranges from 80.76 to 81.50mg/L. these levels of sodium can be attributed to wastewater from households containing some levels of greywater due to its richness in sodium. High sodium level will result in an increase in the level of sodium absorption ratio. Similar studies revealed range of sodium at 3.73mg/L and 19.41mg/L (Dwumfour-Asare *et al.*, 2021). Prior treatment is therefore required to reduce sodium levels for safe usage in irrigation of vegetables crops.

Total nitrogen ranged from 27.21mg/L to 29.25mg/L. these levels of nitrogen above the acceptable limits is contained in organic materials which is a major component of kitchen waste. The levels can therefore be attributed to the component of wastewater emanating from home onto the vegetable farm. Similar studies on the physicochemical properties of wastewater revealed nitrate levels ranging from 0.5mg/L to 12.9mg/L. and nitrite levels ranging from 0.01mg/L to 0.05mg/L (Dwumfour-Asare *et al.*, 2021). Other studies conducted by Niyonzima, (2007) recorded nitrate levels within the range of 15.25mg/L.

The food and agricultural organisation suggest a total nitrogen level of less than 5mg/L for water used to irrigate vegetable crops. Its therefore necessary to employ some treatment regime be safe usage. No recognizable level of mercury was detected in wastewater used for irrigation at the vegetable farm similar to Khaliq *et al.*, (2022), Lead levels ranged from 0.34mg/L to 0.37mg/L. these levels exceed the recommended limits of lead proposed by the food and agricultural organisation for use in irrigation of vegetable crops. This is in conformity with Similar finding by Amjad *et al.*, (2024) which found lead levels in wastewater to be in a range of 0.34mg/L to 0.37mg/l. lead levels has also been found to fall within a range of 0.13mg/L and 0.47mg/L Dwumfour-Asare *et al.*, (2017). Recorded levels of arsenic was found to be withing 1.4mg/L and 1.8mg/L. high amounts of lead is carcinogenic and need to be treated to acceptable levels.

4.2.3 Removal efficiency of contaminants

Generally, the developed wastewater treatment system was very successful to a very large extent after testing considering the removal efficiencies of the system on various contaminants. Before wastewater enters the filtration system, the primary treatment system was able to improve certain condition such as odour, BOD₅, DO and COD. By introducing wastewater to some amount of atmospheric oxygen which increases the dissolved oxygen concentration which translate into a considerable reduction in the biochemical oxygen demand and the chemical oxygen demand.

Dissolved oxygen increased averagely by 110.69% which resulted in a corresponding reduction in biochemical oxygen demand and chemical oxygen demand by 99.65% and 89.04% respectively.

This is in agreement with Qin *et al.*, (2023). This reduction caused other volatile compounds present in the wastewater to be removed and also makes treatment of some other parameter possible.

The pre-treatment system also removes coarse particles such as gravels and other solids thereby resulting in a reduction of turbidity caused by settleable solids. Turbidity reduction at the pre-treatment was 98.69% similar to the turbidity reduction achieved by other studies in the removal of turbidity. The turbidity removal efficiency is therefore dependent on the nature of particles that causes turbidity as well as the treatment technology employed. Turbidity reduction of the treatment system is also similar to the efficiency of treatment in a study conducted by Salazar-Gómez *et al.*, (2024), where the rate of turbidity reduction was 94% to 99%.

Electrical conductivity which is also a function of the concentration of dissolved solids reduced by a consistent rate. Generally, the higher the amount of total dissolved solids, salinity and suspended solids, the higher the electrical conductivity. Electrical conductivity reduced by an average of 79.60%. the consistency of reduction is denoted by the standard deviation of the reduction rate of 0.56. the percentage reduction in electrical conductivity was similar to a study conducted by Thomas & Kani, (2016) on the efficiency of slow sand filter in wastewater treatment where electrical conductivity of wastewater reduced by 77%. This can be attributed to the reduction in dissolved solids which contains dissolved ions, dissolved salts and other solids.

A consistent reduction in the levels of salinity at an average of 99.71% was achieved. This can be explained as due to the reduction of total dissolved solids together with salts contents which increases the level of salinity.

Total hardness of wastewater after treatment reduced at a rate of 14.33% to 16.26%, alkalinity reduced at a rate ranging from 42.16% to 47.16%, chlorine reduced at a rate ranging from 70.58% to 80.25%.

Generally, increased chlorine results in an overall increase in alkalinity which also causes hardness in water. The reduction in hardness can therefore be attributed to the removal of alkalinity and chlorine.

Sodium levels in water are directly proportional to the sodium absorption ratio of water. The reduction of the amount of sodium results in a corresponding reduction in the level of sodium absorption ratio. After treatment, the level of sodium in wastewater reduced at a rate ranging from 45.67% to 46.94%. relative to calcium and magnesium which also reduced at a rate ranging from 9.63% to 12.35% and 11.37% to 12.39% respectively. this resulted in a significant decrease of sodium absorption ratio to an acceptable level prescribed by the food and agricultural organisation, the Ghana environmental protection agency and the world health organisation.

Total phosphate and total nitrogen reduced at a rate ranging from 98.4% to 98.85% and 82.21% to 89.20% respectively. the resultant concentration of nitrogen and phosphate meets the recommended levels of irrigation by the food and agricultural organisation and the Ghana environmental protection agency.

Lead and arsenic reduced at a rate ranging from 82.05% to 83.74%. arsenic reduced at a rate ranging from 98.82% to 99.38%.

This is in agreement with a study conducted by Acheampong *et al.*, (2013) on the treatment of gold mining effluent which achieved a 100% removal efficiency of lead and arsenic. Meanwhile, no recognizable level of mercury was detected in wastewater used for irrigation at the vegetable farm.

This can be attributed to the nature of activities around the catchment which predominantly are household which generally release greywater. Household generally do not produce wastewater that contains mercury

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter focuses on a brief summary of key findings and conclusion. It also suggests relevant and applicable recommendation for policy decisions, urban vegetable farmers and future researcher of the study area.

5.1 Conclusions

Generally, wastewater used for irrigation at the Korle-Bu vegetable farms can be classified as having high levels of total nitrogen(TN), total phosphate(TN), magnesium(Mg), calcium(Ca), chlorine(Cl), lead(Pb), arsenic(As), total dissolved solids(TDS), total suspended solids(TSS), total coliform(TC), feacal coliform(FC), *Escherichia coli*(E.coli), salmonella turbidity and other parameters that are indicative of pollution such as temperature, electrical conductivity(EC), salinity, biochemical oxygen demand(BOD), chemical oxygen demand(COD) and low dissolved (DO). These parameters were above the recommended limits prescribed by the Food and Agricultural Organisation (FAO), The world health organisation (WHO) and the Ghana Environmental Protection Agency (Gh-EPA).

This pollutants levels at their current state can potentially poses serious long and short term environmental and public health risk to farmer and consumers of farm products. Especially when used to irrigate vegetable crops which can be eaten raw without prior processing to reduce the level of contaminants. Contaminants such as lead and arsenic are known for their carcinogenic effects when found in higher quantities in food and water. Other microbial contamination can lead to disease outbreak and other infections.

High turbidity in water is also directly related to increase contamination of other harmful substances such as microbes since it allows for their exponential growth by creating adsorptive surfaces.

The volume of water required for irrigation at the vegetable farm is considerably low and can be treated with the aid of slow sand filtration. The adoption of slow sand filtration is seeming to be more feasible economically, financially, socially and ease of operation and maintenance.

Water is almost always impounded by farmers to ensure a sustainable provision of reserves for continual irrigation. Wastewater can therefore be treated at every point of impoundment for irrigation.

Treatment of wastewater used for irrigation at the vegetable farm with slow sand filter and activated carbon prepared from coconut shell produced good results on contaminants removal rates. Removal of electrical conductivity at an average rate of 79.6%, total dissolved solids at an average rate of 40.81%, total suspended solids at an average rate of 99.70%, turbidity at a rate of 98.69%, dissolved oxygen increased by 110.69%, biochemical oxygen demand increase at a rate of 99.65% relative to other research finding by previous researchers. Trace and heavy metal concentration in wastewater reduced significantly after treatment over a period of eight days which validates the treatment system as efficient. Removal of *Escherichia coli* was >99.9% while sodium absorption ratio was brought to normal.

The resultant wastewater met all the parameters required for use in irrigation of vegetable crops prescribed by the World Health Organisation, the Food and Agricultural Organisation and the Ghana Environmental Protection Agency.

5.2 Recommendations

5.2.1 Recommendation for policy decisions

The following recommendation are necessary to take advantage of this study for national development.

- Urban agricultural farmers especially those who rely on wastewater for irrigation should be trained on simple technologies such as the development of slow sand filters with activated carbon from waste materials to ensure safe food production.
- Sector ministries in-charge of sanitation, water resources and food production are encouraged to pilot the use of this system for farmers.
- The environmental protection agency is encouraged to conduct periodic assessment of water used for irrigation in urban centers to discourage the use of contaminated water.

5.2.2 Recommendation for further research

The following are recommended for future researcher to take up and study for further findings

- The pollution potential of the treatment system should be investigated to ascertain the safety of working with the treatment system if adopted.
- A general risk assessment of wastewater used for irrigation at the vegetable farm should be conducted.

5.2.3 Recommendation for Farmers

The following recommendations are made for farmers based on the findings of the study to promote the production of healthy crop yields

- Urban vegetable farmers should learn simple, scientific and cost-effective water quality testing mechanisms to ensure that irrigation water conforms to regulatory standards.
- Farmers should learn and adopt cost-effective and environmentally friendly wastewater treatment models to ensure quality farm produce.

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APPENDICES

Appendix I



PLATE 1
Plate 1: construction filter base



PLATE 3
Plate 2: construction of underdrain

Appendix II



PLATE 3
Plate 3: construction of filter outlet



PLATE 4
Plate 4: fitting of outlet and under drain

Appendix III



PLATE 5



PLATE 6

Plates 5 and 6: Preparation for sieve analysis of filter medium (charcoal and sand)

Appendix IV



PLATE 7

Plate 7: weighing of sand for sieve analysis

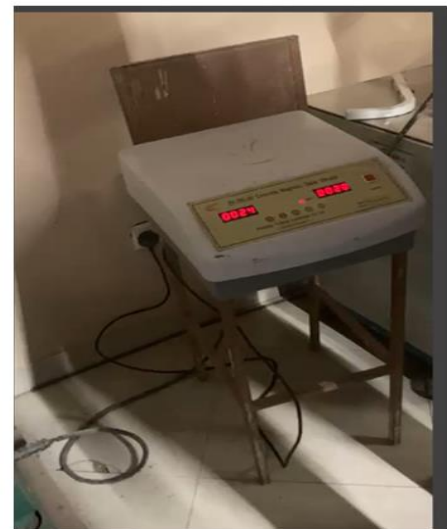


PLATE 8

Plate 8: sorting of sand into various sizes with a mechanical vibrator

Appendix V



PLATE 9



PLATE 10

Plates 9 and 10: experimental scale wastewater treatment system