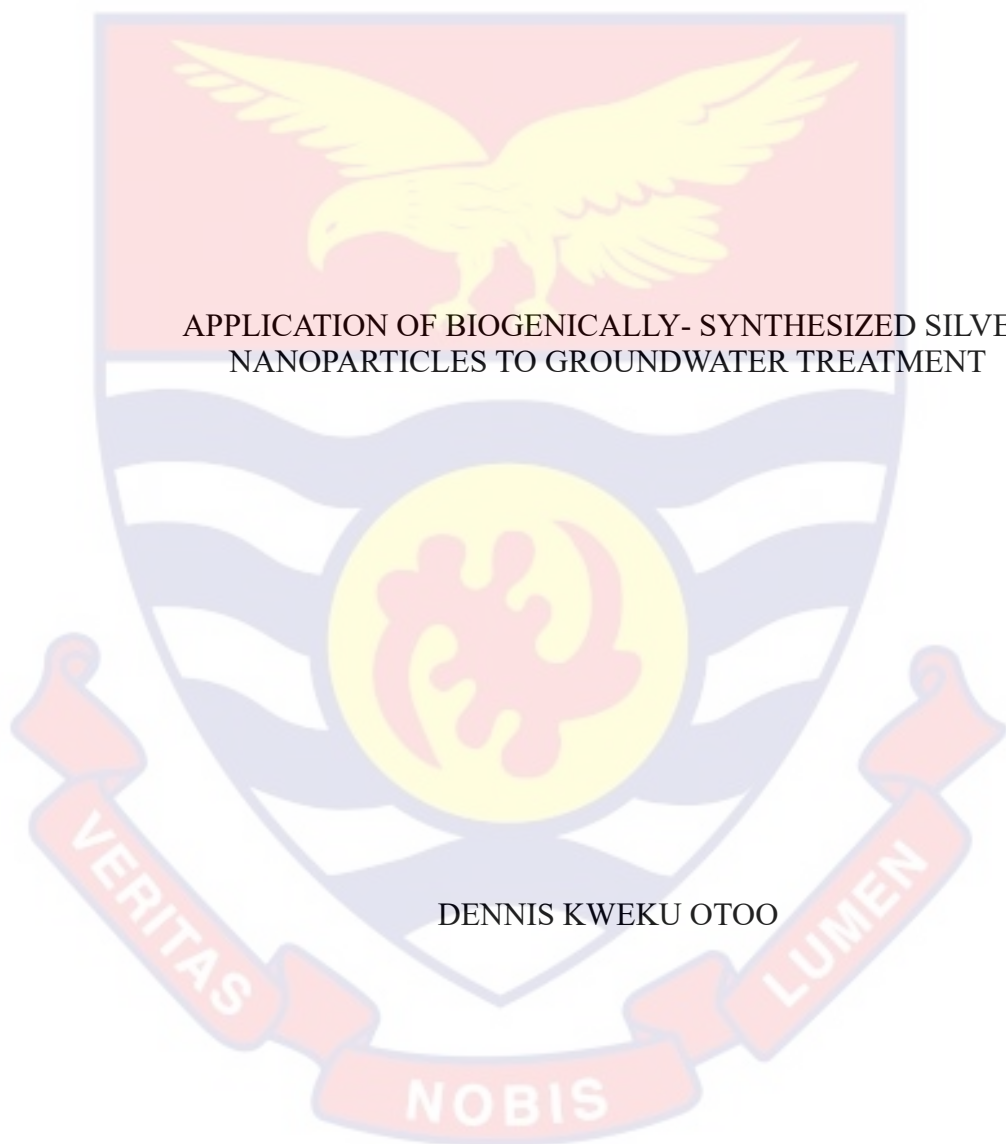


UNIVERSITY OF CAPE COAST



APPLICATION OF BIOGENICALLY- SYNTHESIZED SILVER  
NANOPARTICLES TO GROUNDWATER TREATMENT

DENNIS KWEKU OTOO

2024

UNIVERSITY OF CAPE COAST

APPLICATION OF BIOGENICALLY- SYNTHESIZED SILVER  
NANOPARTICLES TO GROUNDWATER TREATMENT

BY

DENNIS KWEKU OTOO

Thesis submitted to the Department of Chemistry of the School of Physical Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of Master of Philosophy degree in Chemistry

OCTOBER, 2024

## DECLARATION

### Candidate's Declaration

I hereby declare that this thesis is the result of my own original research, and no part of it has been presented for another degree in this University or elsewhere.

Candidate's signature ..... Date .....

Name: Dennis Kweku Otoo

### Supervisor's Declaration

I hereby declare that the preparations and presentation of the thesis were supervised in accordance with the guidelines on supervision of the thesis laid down by the University of Cape Coast.

Supervisor's signature ..... Date .....

Name: Dr. Francis Nsiah

## ABSTRACT

The proliferation of landfill sites has necessitated the need for effective remediation techniques to mitigate potential deterioration of groundwater quality. This study presents a novel approach to groundwater treatment near landfill sites through the synthesis of silver nanoparticles (AgNPs) using biogenic materials-specifically tiger nut, papaya peel, and noni leaves. These locally-sourced materials offer a cost-effective and sustainable means to catalyze the synthesis process, while also capitalizing on their essential properties that contribute to the reduction of silver ions. Characterization of the synthesized nanoparticles was performed using UV-visible spectroscopy, Fourier transform infrared spectroscopy and scanning electron microscopy (SEM), confirming the formation of spherical nanoparticles with an average size of 10-50 nm. AgNPs optimized for maximal adsorption and reactive capability, and the application was targeted to sites with significant heavy metal and microbial contamination as indicated by initial site surveys. The efficiency of the nanoparticles as contaminant removal media was tested *in situ* with water samples obtained from multiple points around the landfill sites. Parameters such as pH, heavy metal concentration, and microbial load were monitored before and after treatment. Results proved a significant reduction in heavy metals, with over 90% removal efficiency for Cr (IV), Co (II), Mn (II) and Fe (II). Moreover, bactericidal efficacy was confirmed with a differential reduction in total coliform counts. The use of these bio-sourced materials not only enhanced the synthesis process but also introduced additional phytochemicals that aided in the overall treatment efficacy.

## KEY WORDS

Biogenic Synthesis

Groundwater Pollution

Heavy Metal

Landfill Site

Microbial Contamination

Silver Nanoparticle



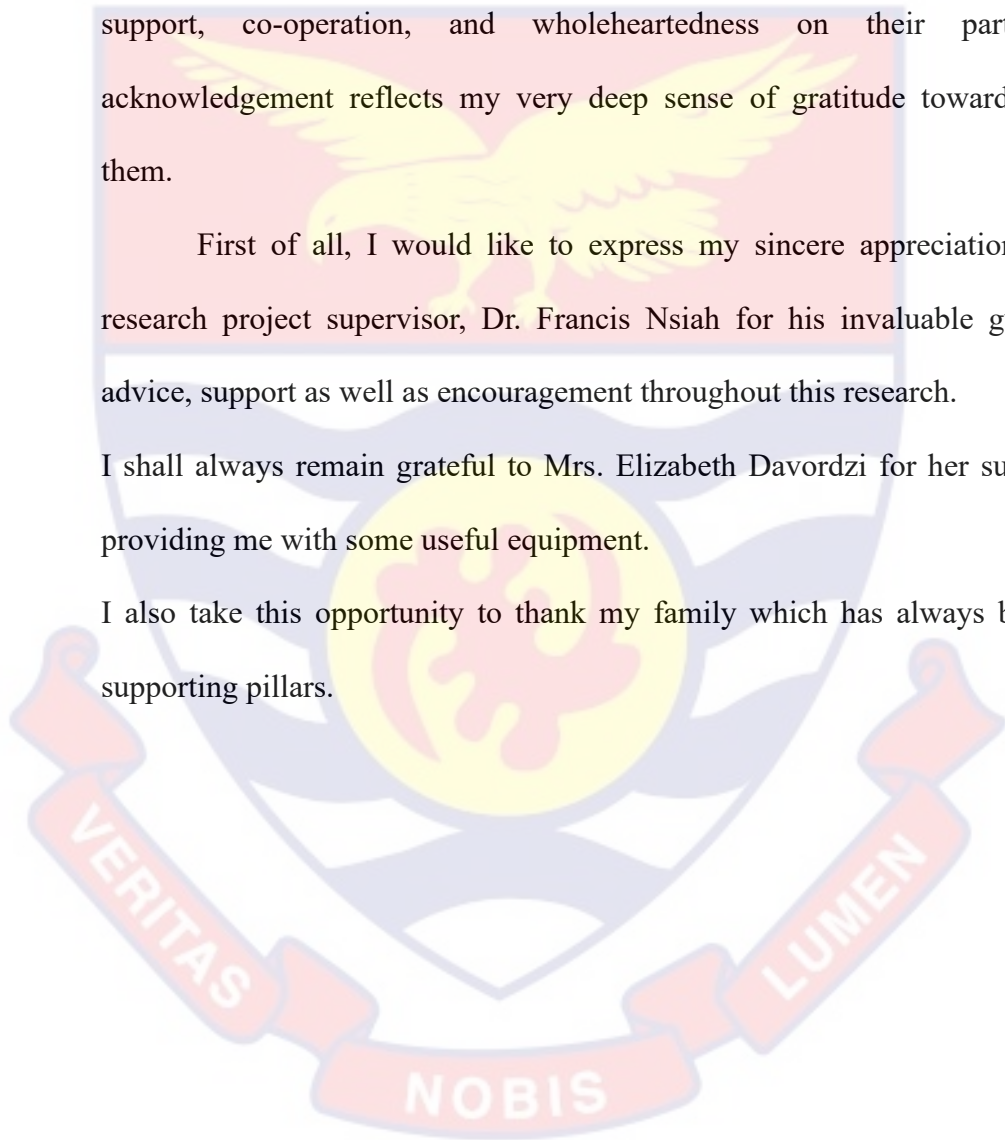
## ACKNOWLEDGEMENTS

It is a moment of immense pleasure for me as I reach this point in my journey of quest. And this is surely not an end, but a new beginning with a new vision. The tremendous amount of help and encouragement I received from several people made this work possible. I shall always cherish the support, co-operation, and wholeheartedness on their part. This acknowledgement reflects my very deep sense of gratitude towards all of them.

First of all, I would like to express my sincere appreciation to my research project supervisor, Dr. Francis Nsiah for his invaluable guidance, advice, support as well as encouragement throughout this research.

I shall always remain grateful to Mrs. Elizabeth Davordzi for her support in providing me with some useful equipment.

I also take this opportunity to thank my family which has always been my supporting pillars.



## DEDICATION

To my family and all my colleagues for their love and support.



## TABLE OF CONTENTS

|                                               | Page |
|-----------------------------------------------|------|
| DECLARATION                                   | ii   |
| ABSTRACT                                      | iii  |
| KEY WORDS                                     | iv   |
| ACKNOWLEDGEMENTS                              | v    |
| DEDICATION                                    | vi   |
| LIST OF TABLES                                | xi   |
| LIST OF FIGURES                               | xiv  |
| LIST OF ABBREVIATIONS                         | xvii |
| CHAPTER ONE: INTRODUCTION                     |      |
| Background to the Study                       | 1    |
| Statement of the Problem                      | 4    |
| Purpose of the Study                          | 5    |
| Specific Objectives of the Study              | 5    |
| Hypothesis                                    | 5    |
| Significance of the Study                     | 6    |
| Delimitation                                  | 7    |
| Limitation                                    | 7    |
| Organisation of the Study                     | 7    |
| CHAPTER TWO: LITERATURE REVIEW                |      |
| Introduction                                  | 9    |
| Silver Nanoparticles in Groundwater Treatment | 9    |
| Size, Shape, and Surface Characteristics      | 10   |
| Antibacterial and Antimicrobial Properties    | 10   |

|                                                             |    |
|-------------------------------------------------------------|----|
| Synthesis Methods of Silver Nanoparticles                   | 11 |
| Chemical Synthesis of Silver Nanoparticles                  | 11 |
| Green Synthesis of Silver Nanoparticles                     | 12 |
| Advantages and Limitations of Different Synthesis Methods   | 12 |
| Reduction of Microbial Load in Groundwater                  | 13 |
| Adsorption Properties of Silver Nanoparticles               | 14 |
| Mechanisms of Heavy Metal Removal                           | 14 |
| Case Studies on Silver Nanoparticles in Heavy Metal Removal | 15 |
| Catalytic Properties of Silver Nanoparticles                | 16 |
| Historical Background of Nanotechnology                     | 16 |
| Silver and its Medicinal History                            | 17 |
| Importance of Nanomaterial in Water Purification            | 18 |
| Application and use of Nanotechnology in Water Remediation  | 19 |
| Nanomaterials Demand for Water Purification                 | 19 |
| Drinking Water Purification with Nanoparticles Challenges   | 20 |
| Health Effect of Silver Nanoparticle                        | 21 |
| Characterization of Silver Nanoparticle Techniques          | 21 |
| Surface Plasmon Band (SPB)                                  | 22 |
| Heavy Metal                                                 | 22 |
| Landfill Site and its Effect on Groundwater                 | 26 |
| Chapter Summary                                             | 28 |
| <b>CHAPTER THREE: RESEARCH METHODS</b>                      |    |
| Introduction                                                | 30 |
| Study Area                                                  | 30 |
| Preparation of Glassware                                    | 31 |

|                                                                                    |    |
|------------------------------------------------------------------------------------|----|
| Chemicals and Reagents                                                             | 32 |
| Synthesis of Silver Nanoparticle using Carica Papaya (Pawpaw) Peels                | 32 |
| Synthesis of Silver Nanoparticle using Morinda Citrifolia (Noni) Leaves.           | 33 |
| Preparation of Cyperus Esculentus (Tiger nut) Tuber Extract                        | 34 |
| Green Synthesis of Cyperus Esculentus Tuber Stabilized Silver Nanoparticles        | 35 |
| Preparation of Chromium Complex Solution (Colorimetric Method)                     | 37 |
| Preparation of Ion Complex Solution (Phenanthroline method)                        | 37 |
| Preparation of Manganese Solution (Persulphate Method)                             | 38 |
| Microbial Analysis                                                                 | 40 |
| Physicochemical Analysis of Untreated Groundwater Samples                          | 42 |
| Nitric Acid Digestion of Groundwater Sample                                        | 44 |
| Groundwater Sample Treatment with AgNPs                                            | 45 |
| Chapter Summary                                                                    | 45 |
| <b>CHAPTER FOUR: RESULTS AND DISCUSSION</b>                                        |    |
| Introduction                                                                       | 46 |
| Characterization of Silver Nanoparticle                                            | 46 |
| UV-Vis characterization of AgNPs synthesized from tiger nut extract                | 50 |
| FTIR characterization of various extracts used in the synthesis of different AgNPs | 51 |
| Scanning Electron Images of the Various AgNPs from Different Extracts              | 53 |
| Efficiency of AgNPs Synthesized from Different Extract on Metal -Ion               |    |
| Contaminant Removal                                                                | 55 |
| Efficiency of AgNPs Synthesized from Different Extract as Chromium Ion             |    |
| Contaminant Removal Media.                                                         | 56 |

|                                                                                                    |     |
|----------------------------------------------------------------------------------------------------|-----|
| Efficiency of AgNPs Synthesized from Different Extract as Cobalt Ion Contaminant Removal Media.    | 69  |
| Efficiency of AgNPs Synthesized from Different Extract as Manganese Ion Contaminant Removal Media. | 82  |
| Efficiency of AgNPs Synthesized from Different Extract as Iron Ion Contaminant Removal Media.      | 94  |
| Incubation with AgNPs Synthesized using Extracts from Noni.                                        | 111 |
| Quantitative analysis of Cr, Co, Mn and Fe Ions in Groundwater Samples                             | 121 |
| Chapter Summary                                                                                    | 125 |
| <b>CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS</b>                                      |     |
| Overview                                                                                           | 126 |
| Summary                                                                                            | 126 |
| Conclusions                                                                                        | 127 |
| Recommendations                                                                                    | 128 |
| <b>REFERENCES</b>                                                                                  | 130 |
| <b>APPENDICES</b>                                                                                  | 157 |
| APPENDIX A: RATIOS OF NONI LEAVES EXTRACT TO THE PRECURSOR                                         | 157 |
| APPENDIX B: RATIOS OF PAWPAW PEEL EXTRACT TO THE PRECURSOR                                         | 159 |
| APPENDIX C: GRAPHS SHOWING BEFORE AND INCUBATED METAL IONS WITH AGNPS                              | 160 |

## LIST OF TABLES

|                                                                                                                                                        | Page |
|--------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1 Peak Maxima and their Respective Wavelengths for the Various Mix Ratios of the Noni Extract and the AgNO <sub>3</sub> Precursor Solution.            | 48   |
| 2 Peak Maxima and their Respective Wavelengths for the Various Mix Ratios of the Pawpaw Peel Extract and the AgNO <sub>3</sub> Precursor Solution      | 50   |
| 3 Percent of Cr (VI) Removed by AgNPs in Different Cr (VI) Complex Solution Incubated with AgNPs Synthesized with Noni Leaves for Five Different Days. | 58   |
| 4 Percent of Cr (VI) Removed by AgNPs in Different Cr (VI) Complex Solution Incubated with AgNPs Synthesized with Tiger Nut for Five Different Days.   | 62   |
| 5 Percent of Cr (VI) Removed by AgNPs in Different Cr (VI) Complex Solution Incubated with AgNPs Synthesized with Pawpaw Peel for Five Different Days. | 66   |
| 6 Percent of Co (II) Removed by AgNPs in Different Co (II) Complex Solution Incubated With AgNPs Synthesized with Noni Leaves for Five Different Days. | 71   |
| 7 Percent of Co(II) Removed by AgNPs in Different Co(II) Complex Solution Incubated with AgNPs Synthesized with Tiger Nut for Five Different Days.     | 75   |
| 8 Percent of Co (II) Removed by AgNPs in Different Co (II) Complex Solution Incubated with AgNPs Synthesized with Pawpaw Peel for Five Different Days. | 79   |

|    |                                                                                                                                                      |     |
|----|------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 9  | Percent of Mn (II) Removed by AgNPs in Different Mn (II) Complex Solution Incubated with AgNPs Synthesized with Noni Leaves for Five Different Days. | 84  |
| 10 | Percent of Mn (II) Removed by AgNPs in Different Mn (II) Complex Solution Incubated with AgNPs Synthesized with Tiger Nut for Five Different Days.   | 88  |
| 11 | Percent of Mn (II) Removed by AgNPs in Different Mn (II) Complex Solution Incubated with AgNPs Synthesized with Pawpaw Peel for Five Different Days. | 92  |
| 12 | Percent of Fe (II) Removed by AgNPs in Different Fe (II) Complex Solution Incubated with AgNPs Synthesized with Noni Leaves for Five Different Days. | 96  |
| 13 | Percent of Fe (II) Removed by AgNPs in Different Fe (II) Complex Solution Incubated with AgNPs Synthesized with Tiger Nut for Five Different Days.   | 100 |
| 14 | Percent of Fe (II) Removed by AgNPs in Different Fe (II) Complex Solution Incubated with AgNPs Synthesized with Pawpaw Peel for Five Different Days. | 104 |
| 15 | Total Coliform before Incubation AgNPs                                                                                                               | 107 |
| 16 | Faecal Coliform before Incubation AgNPs                                                                                                              | 108 |
| 17 | Total Coliform after Incubation with AgNPs                                                                                                           | 111 |
| 18 | Faecal Coliform after Incubation with AgNPs                                                                                                          | 113 |
| 19 | Physicochemical Analysis on the Selected Groundwater Samples before AgNPs Incubation                                                                 | 116 |

|    |                                                                                                                                    |     |
|----|------------------------------------------------------------------------------------------------------------------------------------|-----|
| 20 | Physicochemical Analysis on the Selected Groundwater<br>Samples after AgNPs Incubation                                             | 119 |
| 21 | ICP-OES Analysis of Cr, Co, Mn and Fe ions in Nitric Acid<br>Digested Groundwater Samples before and after Treatment with<br>AgNPs | 122 |

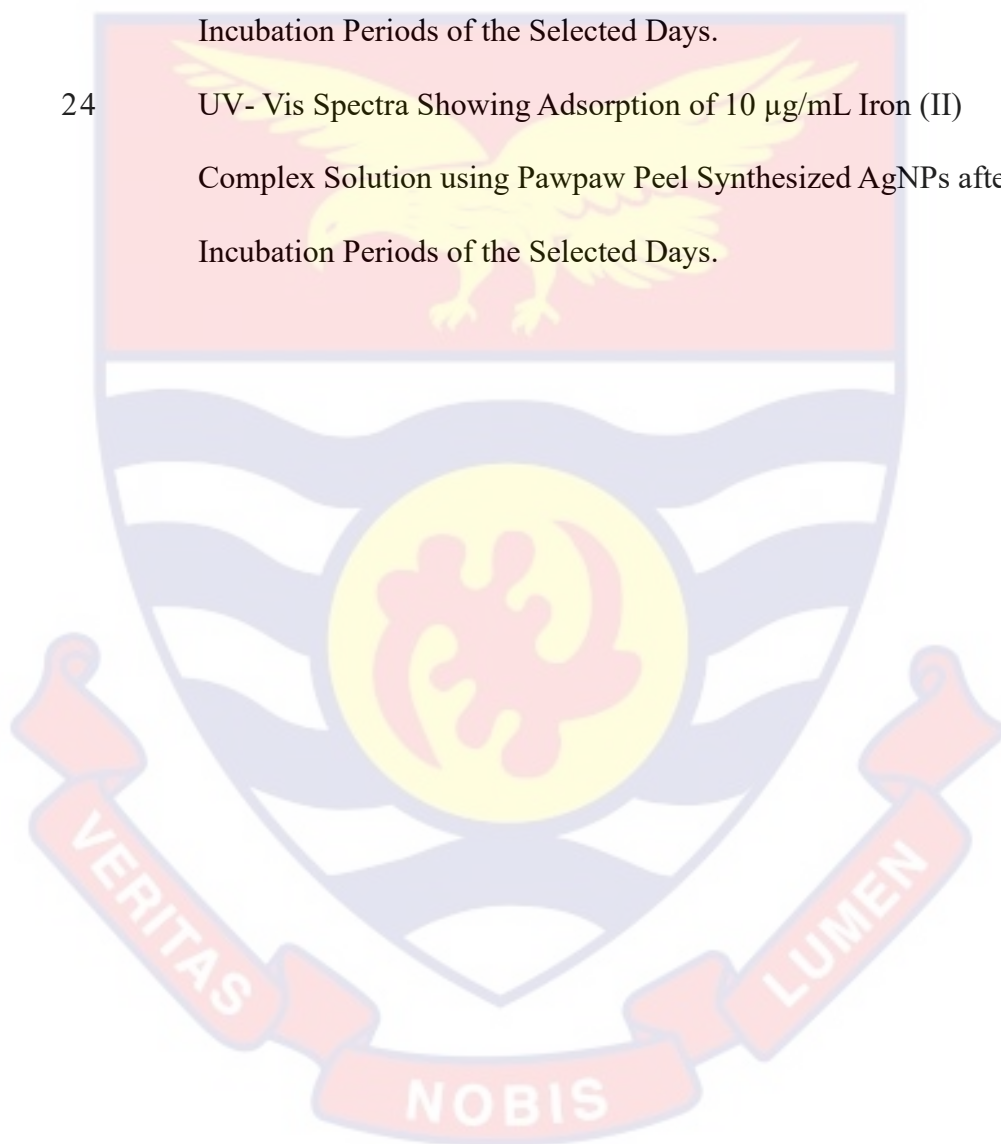


## LIST OF FIGURES

|    |                                                                                                                                                                    | Page |
|----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1  | A Map Showing Study Area                                                                                                                                           | 31   |
| 2  | Schematic Diagram Showing Synthesis of AgNPs from Pawpaw Peel Extract                                                                                              | 33   |
| 3  | A Schematic Diagram Showing Synthesis of AgNPs from Noni Leaves Extract                                                                                            | 34   |
| 4  | A Schematic Diagram Showing Synthesis of AgNPs from Tiger Nut Extract.                                                                                             | 35   |
| 5  | Pictures Showing Metal-Ion Solutions. A) Iron, B) Chromium, C) Cobalt, D) Manganese                                                                                | 39   |
| 6  | Macconkey Agar                                                                                                                                                     | 40   |
| 7  | Spectra Showing Plasmonic Absorption Spectra of the Ratios of Noni Leaf Extract                                                                                    | 47   |
| 8  | Graph Showing Plasmonic Absorption Spectra of the Ratios of Pawpaw Peel Extract                                                                                    | 48   |
| 9  | UV-Vis Absorption Spectrum for Silver Nanoparticle Showing Absorption at 458 nm using Tiger Nut.                                                                   | 50   |
| 10 | FTIR Spectrum of <i>Carica Papaya</i> Peel Extract.                                                                                                                | 52   |
| 11 | FTIR Spectrum of <i>Morinda Citrifolia</i> Leaves Extract.                                                                                                         | 53   |
| 12 | Scanning Electron Micrographs of AgNPs From (A) <i>Morinda Citrifolia</i> and (B) <i>Carica Papaya</i>                                                             | 54   |
| 13 | UV- Vis Spectra Showing Adsorption of 28.2 µg/mL Chromium (VI) Complex Solution using Noni Leaves Synthesized AgNPs after Incubation Periods of the Selected Days. | 57   |

|    |                                                                                                                                                                   |    |
|----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| 14 | UV- Vis Spectra Showing Adsorption of 28.2 µg/mL Chromium (VI) Complex Solution using Tiger Nut Synthesized AgNPs after Incubation Periods of the Selected Days.  | 61 |
| 15 | UV- Vis Spectra Showing Adsorption of 28.2 µg/mL Chromium (VI) Complex Solution using Pawpaw Synthesized Agnps after Incubation Periods of the Selected Days.     | 65 |
| 16 | UV- Vis Spectra Showing Adsorption of 25 µg/mL Cobalt (II) Complex Solution using Noni Leaves Synthesized AgNPs after Incubation Periods of the Selected Days.    | 70 |
| 17 | UV- Vis Spectra Showing Adsorption of 25 µg/mL Cobalt (II) Complex Solution using Tiger Nut Synthesized AgNPs after Incubation Periods of the Selected Days.      | 74 |
| 18 | UV- Vis Spectra Showing Adsorption of 25 µg/mL Cobalt (II) Complex Solution using Pawpaw Peel Synthesized Agnps after Incubation Periods of the Selected Days.    | 78 |
| 19 | UV- Vis Spectra Showing Adsorption of 10 µg/mL Manganese (II) Complex Solution using Noni Leaves Synthesised AgNPs after Incubation Periods of the Selected Days. | 83 |
| 20 | UV- Vis Spectra Showing Adsorption of 10 µg/mL Manganese (II) Complex Solution using Tiger Nut Synthesized AgNPs after Incubation Periods of the Selected Days.   | 87 |
| 21 | UV- Vis Spectra Showing Adsorption of 10 µg/mL Manganese (II) Complex Solution using Pawpaw Peel Synthesized AgNPs after Incubation Periods of the Selected Days. | 91 |

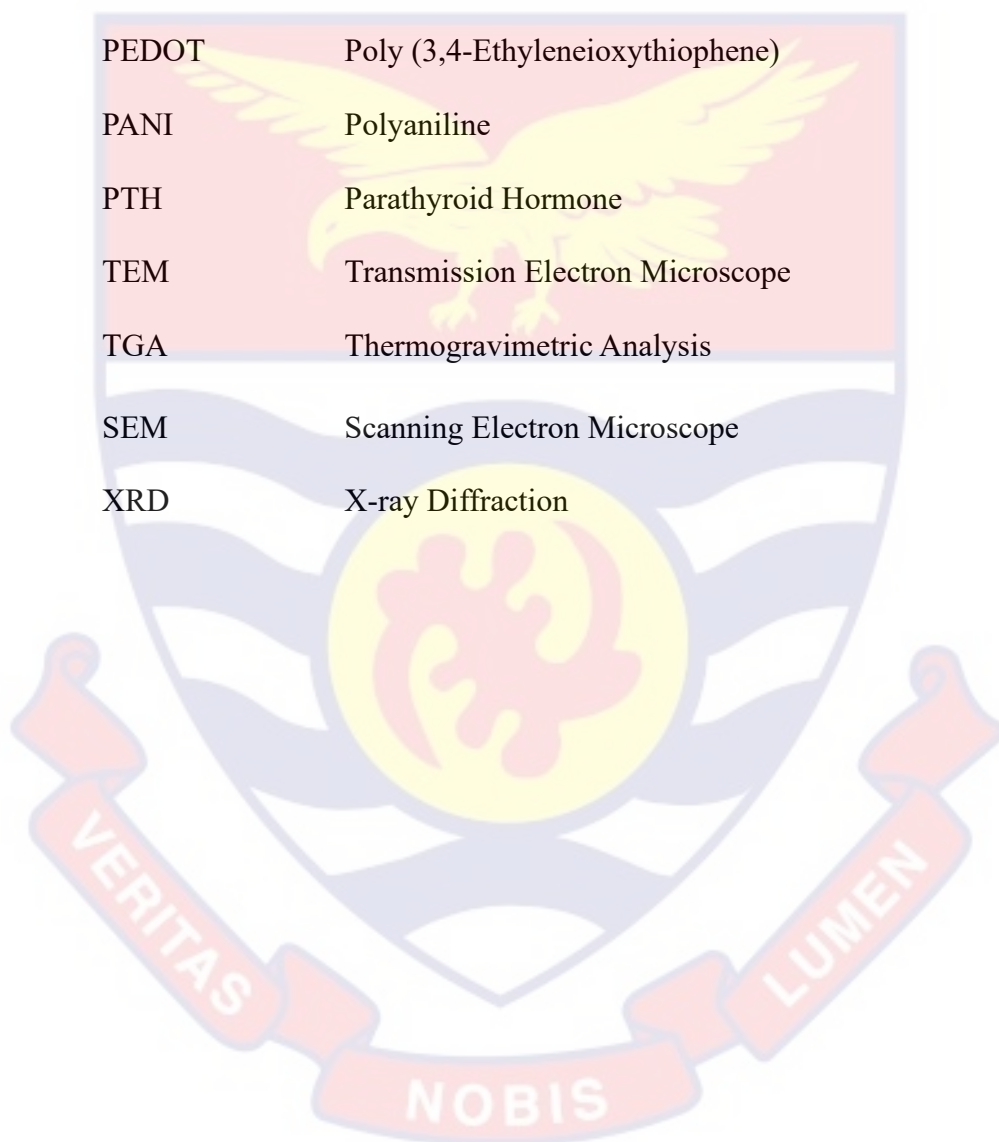
- 22 UV- Vis Spectra Showing Adsorption of 10  $\mu\text{g/mL}$  Iron (II)  
Complex Solution using Noni Leaves Synthesized AgNPs after  
Incubation Periods of the Selected Days. 95
- 23 UV- Vis Spectra Showing Adsorption of 10  $\mu\text{g/mL}$  Iron (II)  
Complex Solution using Tiger Nut Synthesized AgNPs After  
Incubation Periods of the Selected Days. 99
- 24 UV- Vis Spectra Showing Adsorption of 10  $\mu\text{g/mL}$  Iron (II)  
Complex Solution using Pawpaw Peel Synthesized AgNPs after  
Incubation Periods of the Selected Days. 103



## LIST OF ABBREVIATIONS

|         |                                                          |
|---------|----------------------------------------------------------|
| EDS     | Energy Dispersive X-ray Spectroscopy                     |
| FTIR    | Fourier Transform Infrared Spectroscopy                  |
| ICP-OES | Inductively Coupled Plasma Optical Emission Spectroscopy |

|       |                                  |
|-------|----------------------------------|
| PEDOT | Poly (3,4-Ethyleneioxythiophene) |
| PANI  | Polyaniline                      |
| PTH   | Parathyroid Hormone              |
| TEM   | Transmission Electron Microscope |
| TGA   | Thermogravimetric Analysis       |
| SEM   | Scanning Electron Microscope     |
| XRD   | X-ray Diffraction                |



## CHAPTER ONE

### INTRODUCTION

Chapter one provides background to the study under consideration. It also highlights the problem statement, research objectives, significance of the study, as well as hypothesis. In addition, the chapter presents the limitation and delimitation of the study, and overall organization of the work presented herein

#### **Background to the Study**

Since industry depends on water to function and life is unlikely to survive without it, water is one of the most significant natural resources in the planet. In several applications, water cannot be substituted, in contrast to numerous other raw materials (Nkansah *et al.*, 2010). Water of high quality is essential to human existence, good health, food production, and socioeconomic advancement and may be primarily sourced from two main natural sources. Unfortunately, population expansion and environmental changes cause daily fluctuations in water quality (Katata-seru *et al.*, 2017; Municipality, 2016). One of the most important natural resources and a fundamental need for human life is water. The hydrosphere covers more than 70% of the earth's surface. But only about 2.5% of it is available as freshwater in rivers, glaciers, groundwater, and atmospheric water vapor. (Agenda, 2023). Providing everyone with access to cheap and clean drinking water has emerged as one of the major issues of the twenty-first century, necessitating appropriate planning and management techniques for its effective use (Patanjali *et al.*, 2019).

Water is too often seen as an unlimited natural resource. However, pollution and growing demand for water are putting this resource, even in cases where they are plenty or adequate, at increasing danger. It is projected that two-thirds of the world's population would reside in nations experiencing moderate to severe water scarcity by 2025 (Agenda, 2023). However, achieving the worldwide objective of guaranteeing that every person has access to high-quality, drinkable water is not without its accompanying difficulties. Among these difficulties is the scarcity of groundwater supplies, which, when they exist, are often cyclical and vulnerable to pollution from human activity (Water & Management, 2022). Furthermore, it has been observed that solid human and animal waste, subsurface tanks, and septic tanks are among the causes of contamination found in many residential wells. Even in the absence of anthropogenic pollution sources, naturally occurring quantities of toxic metals and other compounds in groundwater have the potential to become harmful to human health (Akoto *et al.*, 2019).

Consumers of water are now concerned about metal toxicity-related pollution of water sources. The growing understanding of their toxicity to human health and biological systems has made this worry significant. One of the main issues endangering the living community is water contamination. Water supplies have been polluted with harmful substances as a result of industrialization. Furthermore, the issue is quite concerning because of the prolonged shortage of water (Ackah *et al.*, 2011; Marimuthu *et al.*, 2020).

Moreover, waste is produced by human activity in the manufacturing and processing of consumption. For large cities in developing nations, managing municipal solid waste (MSW) is a significant environmental and

public health issue (Cantarella *et al.*, 2017). Landfills are the most affordable, straightforward, and cost-effective method of handling solid waste among waste management techniques (Kwame *et al.*, 2019). In a middle-income nation like Ghana, the most common method of disposing of trash is to dump non-segregated solid waste in landfills. For the disposal of harmless solid waste, landfills are the preferred option because of their many benefits, including minimal technical obstacles and cost-effectiveness. Leachates and hazardous gasses are inadvertently discharged into the environment from a number of landfills in underdeveloped nations that are run below acceptable standards and do not sort their garbage (Kwame *et al.*, 2019; Parvin & Tareq, 2021).

Moisture permeates the debris in a landfill, bringing contaminants into the liquid phase and increasing the moisture content to a threshold where liquid flow is started. Leachate is produced by this method. Leachate occurs in a landfill when water and solid waste react. Leachate from a solid waste disposal site is known to contain important elements like calcium, magnesium, potassium, nitrogen, and calcium, as well as trace metals like iron, copper, manganese, chromium, nickel, and lead and organic compounds like phenols, polyaromatic hydrocarbons, acetone, benzene, toluene, and chloroform (Kanmani & Gandhimathi, 2013). The kind of garbage that is deposited, how the landfill is used, the oxygen content, the hydrogeological conditions, and the landfill's age are some of the many variables that affect the leachate composition. Because deposited garbage may cause leachate to infiltrate into the groundwater and endanger the local ecosystem, it is important to inspect municipal waste dump sites (Przydatek & Kanownik, 2019).

## Statement of the Problem

Disposing of solid waste in landfill sites is a prevalent waste management practice worldwide (Smith *et al.*, 2020), catering to the ever-increasing volume of municipal and industrial waste. However, the coexistence of these landfill sites and groundwater quality in their vicinity poses a significant environmental and public health concern. (Wdowczyk & Szymańska-Pulikowska, 2021, Hussein & Ibrahim, 2023). The groundwater contamination near landfill sites presents a pressing issue, necessitating the development of effective and environmentally sustainable remediation methods.

Though effective, traditional groundwater treatment methods, such as chemical precipitation and adsorption, often involve chemicals and materials that can introduce secondary pollutants and may not align with green and sustainable chemistry principles. Therefore, there is a need to explore alternative and eco-friendly approaches for groundwater remediation in proximity to landfill sites (Da'ana *et al.*, 2021)

The exceptional antibacterial and catalytic properties of silver nanoparticles (AgNPs) have led to a marked surge in interest in these particles in recent years. Furthermore, the ecologically friendly alternative to traditional chemical synthesis techniques is provided by the green synthesis of AgNPs, which uses biogenic sources such as plant extracts and microorganisms (Thakur *et al.*, 2023). These environmentally friendly AgNPs have shown promise in eliminating pollutants from water sources (Thakur *et al.*, 2023).

## Purpose of the Study

The purpose of this research is to synthesize AgNPs from three different local plant materials for groundwater treatment in Amamoma and Apewosika community in Cape Coast Metropolis.

## Specific Objectives of the Study

The objectives of this study are to:

Synthesize silver nanoparticles (AgNPs) from three different local plant materials (*Cyprus esculentus*, *Carica Papaya*, and *Morinda Citrofolia*).

Characterize the synthesized silver nanoparticles (AgNPs).

Conduct physiochemical and microbial analysis on the selected groundwater samples.

Use the AgNPs to remove heavy metals in selected groundwater samples.

## Hypothesis

Green synthesis of silver nanoparticles using plant extracts may be a feasible and ecologically responsible alternative for treating groundwater contaminated by organic pollutants and heavy metals near disposal sites. The discovery that plant extracts may be used to produce silver nanoparticles sustainably and successfully in the treatment of water contaminated with organic pollutants and heavy metals lends credence to this notion (Kirubaharan *et al.*, 2020; Shittu & Ihebunna, 2017). The synthesized nanoparticles have shown high antibacterial activity and catalytic efficiency for removing pollutants. Therefore, it is reasonable to hypothesize that this method can be applied to treat groundwater contaminated near landfill sites.

## Significance of the Study

The ecology and human health are seriously threatened by the toxic materials and contaminants that may seep into groundwater from landfills (Aleksandra Jakimiuk, 2022). One promising groundwater remediation technology is the use of ecologically friendly synthesized silver nanoparticles.

There are several benefits of synthesizing silver nanoparticles using eco-friendly and biocompatible substances such as lower environmental impact, cost-effectiveness, and scalability. This approach is consistent with green chemistry concepts, which place an emphasis on process design that reduces the usage of hazardous materials and waste production. Furthermore, silver nanoparticles' special qualities like their large surface area and antibacterial activity make them a great option for eliminating impurities from groundwater.

The successful development and application of silver nanoparticles synthesized through green methods for groundwater treatment near landfill sites could lead to a paradigm shift in environmental remediation practices. It can potentially provide an effective, sustainable, and less resource-intensive solution for mitigating the harmful effects of landfill leachate on local water resources. Moreover, the study may contribute to advancing our understanding of green nanotechnology and its role in addressing pressing environmental challenges.

Ultimately, the outcomes of this research will benefit local communities living near landfill sites and hold broader implications for the field of environmental science and engineering. By promoting the adoption of green synthesis techniques for nanoparticle production, the study underscores

the importance of responsible and forward-thinking approaches to groundwater treatment, setting a precedent for sustainable remediation practices in contaminated areas worldwide.

### **Delimitation**

The study focus itself to the synthesis of silver nanoparticles using biological methods, specifically from plant extracts or microorganisms, and their effectiveness in removing contaminants from groundwater. The study will exclude other synthesis methods, treatment of other water sources, and long-term environmental impacts of nanoparticle use.

### **Limitation**

Due to the potential environmental and health concerns related to nanoparticle release into the ecosystem. The scalability of biogenic nanoparticle synthesis for large-scale water treatment systems may also be challenging due to cost and efficiency constraints. Additionally, long-term effects on groundwater quality and the persistence of nanoparticles in the environment remain uncertain and require further investigation.

### **Organisation of the Study**

There are five chapters in this thesis. The study's background is covered in Chapter 1, along with an explanation on the issues of groundwater contamination near dumpsite and application of AgNPs for groundwater treatment. The real issue with this research is stated in the problem statement found in Chapter 1: Disposing of solid waste in landfill sites is a prevalent waste management practice worldwide, catering to the ever-increasing volume

of municipal and industrial waste. However, the coexistence of these landfill sites and groundwater quality in their vicinity poses a significant environmental and public health concern.

The literature review is covered in Chapter 2. In Chapter 2 several traditional of method of groundwater have been implemented and also different methods of nanoparticles have been used in the synthesis of the AgNPs.

This study's third chapter, looked at the research techniques used in this study such sampling of the groundwater samples. It also showcases the synthesis of the AgNPs from the three different local materials and preparation of standard solution of metals ions targeted. It also shows the scope of the study.

The study's fourth chapter summarizes the findings and discusses the efficiency of reduction in the standard solutions of the metal ions, quantitative reduction in concentration of the groundwater samples and reduction in microbial load.

Summaries, suggestions, and conclusions are included in Chapter 5. A broad conclusion based on the primary purpose of the research was reached after findings based on its goals were made. Finally, some more research and institutional initiatives were suggested.

## CHAPTER TWO

### LITERATURE REVIEW

#### Introduction

This chapter will review the available literature on the application of biogenically-synthesized silver nanoparticles to groundwater treatment. Besides, it will provide relevant information on the chemistry of nanotechnology. Moreover, the chapter will present the three general different methodologies employed in the synthesis of silver nanoparticles from different source materials. It also highlights the application of silver nanoparticles to the removal of microbial agents and heavy metals in the groundwater.

#### Silver Nanoparticles in Groundwater Treatment

Silver nanoparticles have shown promise in groundwater treatment (Berillo & Arysbeke, 2023; Giri *et al.*, 2023; Sharma & Sharma, 2023). They can effectively remove contaminants such as amoxicillin and residual antimicrobials in treated water (Fu & Wang, 2011). The use of silver nanoparticles in polyurethane membranes has demonstrated high amoxicillin degradation and antimutagenic potential (Ali & El-Shehawey, 2023). Additionally, nanomaterials, including silver nanoparticles, are effective in removing heavy metals, pesticides, and organic contaminants in groundwater. Nanotechnology offers advantages such as high reactivity, adsorption properties, and catalytic activities, making it a promising approach for wastewater treatment. Furthermore, the use of metallic nanoparticles, such as silver nanoparticles, has shown potential for water disinfection.

### Size, Shape, and Surface Characteristics

The behaviour and performance of nanoparticles in many applications are significantly influenced by their size, shape, and surface properties. The cellular internalization efficiencies of nanoparticles vary depending on their size, shape, and surface morphology (Rewatkar *et al.*, 2020). The biodistribution, cellular absorption, adhesion strength, half-life circulation, and drug release kinetics of nanoparticles are all impacted by their size (Liu *et al.*, 2022). It has been shown that spherical nanoparticles increase the bioavailability of oral drugs, but rod-shaped particles show better cellular absorption specificity (Xue *et al.*, 2018). Nanoparticles' interactions with the gastrointestinal system and their transport capacities are determined by their surface charge in addition to their size, shape, and chemical makeup (Sharma *et al.*, 2019). Additionally, the size and shape of nanoparticles impact their hydrodynamics, interfaces of vascular targeting, and controlled-release drug delivery systems (Calvo, 2023).

### Antibacterial and Antimicrobial Properties

Antibacterial and antimicrobial properties can be found in various materials and compounds. Conducting polymers such as PEDOT Poly (3,4-ethyleneioxythiophene), PANI (Polyaniline), and PTH (Parathyroid Hormone) have positive charges that can interact with bacterial membranes and induce cell death (Ahmadi & Rabiee, 2023). The antibacterial and antimicrobial qualities of medicinal herbs on fabrics, such as wormwood, wormwood, clove, marjoram, lavender, and expand, have been researched (Ahmadi *et al.*, 2022). Antimicrobial peptides, including GK-19 and HHC36, have shown the capacity to damage microbial cell membranes and impede bacterial

development without endangering mammalian cells (Gao *et al.*, 2023; Song *et al.*, 2022, Gao *et al.*, 2023; Song *et al.*, 2022). Furthermore, it has been shown that the peptide MOp3 from *Moringa oleifera* seeds damages membranes, triggers cell death, and prevents *Staphylococcus aureus* from growing. (Sun *et al.*, 2023).

### **Synthesis Methods of Silver Nanoparticles**

There are other ways of producing silver nanoparticles, such as green synthesis, which uses biomolecules from microbial and plant components (Devadharshini *et al.*, 2023). Another technique uses a standard kitchen microwave to reduce silver oxide by molecular hydrogen at high temperatures and pressures (Hanapin, 2023). Furthermore, plant extracts like sphagnum moss may be used to create silver nanoparticles, providing an easy, affordable, and sustainable substitute. (Akhatova *et al.*, 2023). Biological methods are considered the best method for synthesizing silver nanoparticles due to their safety, eco-friendliness, and availability (Ahmadi & Ramazani, 2023). These nanoparticles can have therapeutic activities and are particularly studied for their anticancer potential (Chaudhary *et al.*, 2023).

### **Chemical Synthesis of Silver Nanoparticles**

Several synthetic techniques are used in the chemical production of silver nanoparticles in order to accurately regulate the size and form of the particles (Aragaw *et al.*, 2022). During the synthesis process, several reducing agents and surfactants are used, including ascorbic acid and trisodium citrate (Santhi Yerragopu *et al.*, 2020). The size and morphology of the nanoparticles are influenced by the concentration of these agents; larger concentrations of

ascorbic acid cause the particles to alter form, while greater concentrations of trisodium citrate produce smaller particles (De Matteis *et al.*, 2018). The characteristics of the produced nanoparticles are also dependent on other factors, such stirring duration and silver nitrate concentration (Nogueira *et al.*, 2014).

### **Green Synthesis of Silver Nanoparticles**

One non-toxic, economical, and eco-friendly way to produce silver nanoparticles is using green synthesis. Silver nanoparticle synthesis has employed a range of plant extracts as stabilizing and reducing agents, including *Enteromorpha linza* (Devadharshini *et al.*, 2023), *Azadirachta indica* (Neem) leaves, *Morinda Citrifolia* (Noni) (Ahmed *et al.*, 2015), and *Gomphrena globosa* (Globe amaranth) leaves (Shankar *et al.*, 2004). Silver ions ( $\text{Ag}^+$ ) are reduced to metallic silver nanoparticles ( $\text{Ag}^0$ ) throughout the production process by use of phytochemicals found in plant extracts. The formation of silver nanoparticles is confirmed through colour change, UV-visible spectroscopy, and X-ray diffraction analysis (Nahar *et al.*, 2015; Tamilarasi & Meena, 2019). The synthesized silver nanoparticles exhibit excellent antibacterial activity against both gram-positive and gram-negative bacteria. The green synthesis method offers a simple, rapid, and eco-friendly route for the synthesis of silver nanoparticles, making it a promising approach in the field of nanotechnology.

### **Advantages and Limitations of Different Synthesis Methods**

Different synthesis methods have advantages and limitations. The ceramic method is commonly used for synthesizing inorganic solids at

elevated temperatures, but it is limited because many current inorganic solids are metastable and require low-temperature methods (Kumar *et al.*, 2021). Soft-chemistry routes offer alternative methods, such as intercalation and deintercalation of oxygen in oxides, chemical agents for obtaining oxides with specific structures, multistage synthesis processing, supercritical fluid processing, and mechanical alloying (Etourneau, 1999). GaN synthesis methods, including high-pressure nitrogen solution growth, Ammon thermal method, sodium flux process, and hydride vapour phase epitaxy, have advantages for scientific research but face limitations for commercial applications (Ananthasuresh, 2007).

### **Reduction of Microbial Load in Groundwater**

The reduction of microbial load in groundwater can be achieved through various methods. Plant-based coagulants, such as *Jatropha curcas* and rice husk ashes, have been found to effectively reduce turbidity and microbial load in groundwater (Njewa *et al.*, 2021). Additionally, the use of potassium permanganate powder filter treatment has been shown to significantly reduce microbial pollution in urban groundwater treatment plants (Pazdar *et al.*, 2019). Microbial metabolism has also been explored as an alternative approach for sludge reduction in groundwater treatment, with future research focusing on revealing the mechanisms and evaluating the feasibility of coupling sludge reduction with nutrient removal (Guo *et al.*, 2020). Furthermore, a bioecological groundwater treatment system consisting of a modified anaerobic/anoxic/oxic (A2O) system and constructed wetland has demonstrated excellent removal efficiency for microbial count and distribution in domestic groundwater (Haq *et al.*, 2016). Tertiary treatment using PIX or

PAX coagulants followed by peracetic acid disinfectant has been shown to effectively reduce microbial numbers, including pathogenic microorganisms, in municipal groundwater treatment plants (Rafique *et al.*, 2017).

### **Adsorption Properties of Silver Nanoparticles**

The adsorption characteristics of silver nanoparticles (AgNPs) have been investigated in a number of settings. According to research by Qian Tang *et al.*, chitosan microspheres loaded with AgNPs strongly inhibit both Gram-positive and Gram-negative bacteria, suggesting that they may find use in the treatment of wastewater (Ren *et al.*, 2023). The maximal monolayer adsorption capacity of chitosan-capped AgNPs was found to be 119.04 mg/g by Zaheer Khan *et al.* during their investigation into the adsorption of cadmium (Khan & AL-Thabaiti, 2022). Studying the local adsorption characteristics of gold, nickel, and platinum nanoparticles, Gatin *et al.* reported the development of stable adsorption complexes on the surfaces of the nanoparticles. (Gatin *et al.*, 2023). The adsorption of polyarginine onto AgNPs was studied by Alexander Kyrychenko *et al.* (2020) using molecular dynamics simulations. They discovered that the adsorption is mainly controlled by interactions between the arginine moieties and the nanoparticle surface. AgNPs-loaded tea-activated carbon was created by Van Tuyen Trinh's group to remove phosphate from aqueous solutions (Trinh *et al.*, 2020). The maximal adsorption capacity was found to be 13.62 mg/g.

### **Mechanisms of Heavy Metal Removal**

Capacitive deionization is an attractive method for removing heavy metal ions without the need for large volumes of chemicals and the production

of solid wastes (Xu *et al.*, 2023). Hydrogel materials have a high removal capacity for heavy metal ions through ion exchange and electrostatic interactions (Ibrahim *et al.*, 2022). Biosorption of heavy metal cations using biosorbents involves ion exchange and precipitation of carbonates and hydroxides (Wierzba *et al.*, 2022). Biogenic FeS-kaolin composites have shown potential for the removal of heavy metal(loid)s through surface complexation, ion exchange, and chemical precipitation (Xu *et al.*, 2022). Autocatalytic persulfate oxidation can effectively remove heavy metal-organic complexes by destroying chelating sites and producing small molecular organic acids and precipitates (Wang *et al.*, 2021).

### **Case Studies on Silver Nanoparticles in Heavy Metal Removal**

The removal of heavy metals from water has become more prevalent because of nanotechnology. Numerous nanomaterials have been generated for this purpose, including iron oxide nanoparticles, manganese oxides, aluminium oxides, titanium oxides, zinc oxides, cerium oxides, and zirconium oxides (Abhishek *et al.*, 2023) as well as silver nanoparticles. Green methods have also been used to create copper oxide and silver nanoparticles by extracting plant material from plants like *Catharanthus roseus* (Verma & Bharadvaja, 2021). Heavy metals like cadmium and chromium have been effectively removed from water by these nanoparticles (Verma & Bharadvaja, 2021). Furthermore, the use of biochar, a low-cost adsorbent produced from biomass waste, has been explored for the removal of silver nanoparticles from wastewater (Islam *et al.*, 2021).

### Catalytic Properties of Silver Nanoparticles

High catalytic qualities were shown by silver nanoparticles (AgNPs) that were produced utilizing different plant extracts. AgNPs produced from the leaf extract of *Murraya koenigii* shown catalytic activity in the reduction of 4-nitrophenol and the degradation of several colours (Pratim Sarma *et al.*, 2023). AgNPs made from *Uvaria narum* leaf extract showed exceptional catalytic activity when it came to 4-nitrophenol reduction.(Ajaykumar *et al.*, 2023). AgNPs produced from extracts of *Fili pendula* ulmaria and *Salvia verticillate* shown great catalytic efficacy in the degradation of Congo red dye (Mihailović *et al.*, 2023). Remarkable catalytic activity was also shown in the reduction of 4-nitrophenol by functional polyacrylonitrile fibers loaded with AgNPs and wrapped in polydopamine (Zhu *et al.*, 2022). Rhodamine-B and methyl orange dyes were reduced by AgNPs made from Tulasi, neem, and turmeric extracts with strong catalytic activity (Vankdoth *et al.*, 2022).

### Historical Background of Nanotechnology

Nanotechnology has a long historical background, with evidence of its usage dating back to ancient times. People were unknowingly using nanosized materials, such as natural fabrics with sizes ranging from 1-20 nm, over a thousand years BC (Guin & Singh, 2023). Ancient objects like glass and steel swords showcased nanocomposites with unique properties, such as colour alteration and extraordinary strength (Amen *et al.*, 2021). The concept of nanoscience was introduced by Richard Feynman in 1959, and nanotechnology was first mentioned by Taniguchi in 1974 (Rafique *et al.*, 2017). Nanomaterials, with their smaller particle size and larger surface area, exhibit improved properties in various fields, including electrical, mechanical,

magnetic, and thermal (Al-alwani & Almashaleh, 2022). Nanotechnology has become a significant area of research, contributing to multiple scientific disciplines, including physics, materials science, chemistry, biology, computer science, and engineering. The historical and technological developments of nanotechnology have led to the need for regulatory frameworks to address the associated challenges.

### **Silver and its Medicinal History**

Since ancient times, silver has been used medicinally to cure a wide range of illnesses, including the common cold, skin conditions, infections, and even cancer. Nevertheless, silver may cause negative side effects such as argyria, hepatic or renal damage, and neurological adverse responses, and it has no recognized biological function in human physiology (Hu & Yuen, 2023). Due to its bactericidal qualities, silver is often used in household and medicinal products due to its well-known antibacterial qualities. Nevertheless, little is known about the chemical fate of silver in biological systems. In addition to more subtle adverse effects including seizures, liver and kidney damage, immunosuppression, and inclusions in the brain, prolonged exposure to silver may cause argyria (Betts *et al.*, 2021). Due to its anti-bacterial and anti-caries qualities, silver is often used in dentistry. When used in small amounts, it has been shown to have no discernible cytotoxicity (Gawlik-Maj *et al.*, 2022). Silver is especially hazardous to lower creatures and serves no biological purpose. While silver formulations have found use in medicine, the majority of these compounds are currently undergoing evaluation and may not go to clinical trials. Long-term silver exposure may have negative consequences, and further study is required to figure out the processes at play (Medici *et al.*,

2019). Due to its antibacterial qualities, silver has become more and more popular as a therapeutic choice. As a result, more patented goods that use silver's bactericidal capabilities have been created. These patents demonstrate the possibility (Sim *et al.*, 2018).

### **Importance of Nanomaterial in Water Purification**

Nanomaterials have emerged as a promising solution for water purification due to their extraordinary properties and high reactivity (Kumar *et al.*, 2021; Saleh & Gupta, 2016; Zhang *et al.*, 2019). These materials, such as nano photocatalysts, nanomembranes, nanoreactors, and nano adsorbents, offer efficient and cost-effective methods for decontaminating polluted water sources. They can remove various pollutants, including heavy metal ions, organics, inorganic anions, and microorganisms, from contaminated water. Nanomaterial-polymer membranes, in particular, have shown great potential in enhancing the efficiency of water purification processes, such as filtration, reverse osmosis, adsorption, and ion exchange. Additionally, nanomaterials can be used in the desalination process to obtain fresh water by removing salts. The use of nanotechnology in water treatment has the potential to contribute significantly to controlling water-borne diseases and chemical threats to public health. However, the large-scale implementation of nanomaterials for water purification requires further research and development to address issues related to their size, recovery, and potential impact on the environment and human health.

## Application and use of Nanotechnology in Water Remediation

Nanotechnology has emerged as a promising solution for water remediation and treatment (Hussein & Ibrahim, 2023). Nanoparticles possess unique chemical and physical properties that make them effective in removing contaminants from water (Agarwal *et al.*, 2023). Various types of nanoparticles, such as nano catalysts, nanocrystals, and nanospheres, have been developed for water purification (Deshpande *et al.*, 2022). These nanoparticles can be used to address issues like the removal of toxic metals, biofouling, and aquatic infections (Pandey *et al.*, 2022). Nanotechnology-based approaches, such as nanomembranes, nano sensors, and photocatalytic degradation, have shown potential in purifying water (Pooja *et al.*, 2022). Nano sorbents, including polymeric, carbon, and metal nano sorbents, have also been explored for water treatment. However, further research is needed to assess the environmental sustainability and performance of nanomaterials in wastewater treatment. Overall, nanotechnology offers exceptional potential in addressing water pollution and providing clean and sustainable water resources.

## Nanomaterials Demand for Water Purification

Nanomaterials are in high demand for water purification due to the increasing pollution of natural water sources, population growth, and climate change (Lazarenko *et al.*, 2022). The application of nanomaterials, such as carbon nanomaterials, nanometals, and graphene-based nanomaterials, can enhance the efficiency and characteristics of water treatment processes (Aizudin *et al.*, 2022; Ameta *et al.*, 2022; Mumtaz *et al.*, 2023). Nanomaterials offer potential solutions for removing water pollutants, including toxic metals,

biofouling, and aquatic infections (Anindita *et al.*, 2022). They can also improve the effectiveness of water filters and provide affordable and ecologically friendly purification methods. Green synthesized nanomaterials, produced using plant extracts and microbes, are being used as catalysts, adsorbents, and membranes for water purification, offering sustainable and efficient alternatives. The use of nanomaterials for water purification is an emerging research front that aims to address the challenges of water scarcity and the need for clean and reliable water sources.

### **Drinking Water Purification with Nanoparticles Challenges**

Nanotechnology offers a promising solution for drinking water purification, but it also presents challenges. Carbon nanotubes and their composites have shown potential as effective adsorbents for removing organic and inorganic pollutants from water (Nyairo *et al.*, 2022). Nanoparticles, nanomembranes, and nanocomposites have been used in water purification technologies, providing breakthroughs in clean-up methods (Manikandan *et al.*, 2022). Carbon nanotubes modified with natural polymers have attracted attention for their ability to remove different types of pollutants from wastewater (Leudjo Taka *et al.*, 2022). Nanomaterials such as nano photocatalysts, nanomembranes, nanoreactors, and nano adsorbents have been developed to decontaminate polluted water sources (Sarkar & Ahuja, 2022). The implementation of magnetically active nanoparticles offers an alternative for posttreatment solids separation in water purification (Martinez-Boubeta & Simeonidis, 2019).

## Health Effect of Silver Nanoparticle

Silver nanoparticles have been extensively studied for their antimicrobial properties and have found applications in various industries, including medicine and biomedicine. However, there are concerns about their potential health effects. Studies have shown that silver nanoparticles can have toxic effects on mammalian cells, including neurotoxic effects when they penetrate the blood-brain barrier (Rajnec *et al.*, 2023). The toxicity of silver nanoparticles is influenced by factors such as exposure level, particle size, surface coating, and agglomeration state (Al-alwani & Almashaleh, 2022). It has been observed that silver nanoparticles can induce oxidative stress, neuroinflammation, mitochondrial dysfunction, neurodegeneration, apoptosis, and necrosis in the central nervous system (Jaswal & Gupta, 2023). Additionally, the release of silver ions from nanoparticles can contribute to their toxicity (Suthar *et al.*, 2022). Further research is needed to fully understand the potential risks associated with the use of silver nanoparticles and to develop strategies to mitigate their toxic effects (Morozova *et al.*, 2021).

## Characterization of Silver Nanoparticle Techniques

Characterization techniques for silver nanoparticles include UV-visible spectrophotometry, Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), field emission scanning electron microscopy (FESEM), energy-dispersive X-ray spectroscopy (EDS), transmission electron microscopy (TEM), and thermal gravimetric analysis (TGA) (Hanapin, 2023; Mora-Godínez *et al.*, 2023). Other methods mentioned in the abstract include size distribution analysis (Joy *et al.*, 2023), SEM, elemental analysis, and X-

ray diffraction technique (Yaseen *et al.*, 2022). These techniques are used to analyze the properties of silver nanoparticles such as particle size, shape, composition, and thermal stability. Additionally, the antibacterial effect of silver nanoparticles can be monitored using biological cultures and the Kirby-Bauer Test (Fatouh Hamed *et al.*, 2022). The synthesis of silver nanoparticles can be achieved through various methods including chemical reduction, green synthesis using microalgae, and bio-templating using fungi.

### **Surface Plasmon Band (SPB)**

Surface plasmon bands are discussed in several of the abstracts. Zhao *et al.* present a spoof surface plasmon polariton (SSPP) antenna with dual-band end-fire gain and a small frequency ratio (FR) (Zhao *et al.*, 2022). Pandey *et al.* propose a surface plasmon resonance-based D-shaped tunable and broadband single-polarization filter. Fang and Zhong designed a dual-band conformal surface plasmon (CSP) waveguide with excellent performance in the microwave frequency range ( Pandey *et al.*, 2022). propose a coplanar waveguide (CPW) based spoof surface plasmon polariton (SSPP) waveguide with strong field confinement and low-pass filtering response (Fang & Zhong, 2021). These provide insights into different applications and characteristics of surface plasmon bands, including antenna gain, polarization filtering, frequency tunability, and field confinement.

### **Heavy Metal**

Heavy metals are a group of metals and metalloids that have been associated with contamination and potential toxicity or ecotoxicity. The term "heavy metals" is often used without specifying which metals are covered, and

there is no authoritative definition for it. It is incorrect to assume that all heavy metals and their compounds have highly toxic or ecotoxic properties. The term is both meaningless and misleading (Owusu *et al.*, 2021). A new classification based on the periodic table is needed to avoid the use of the term "heavy metal" and to allow for the prediction of toxic effects (Tchounwou *et al.*, 2012). Heavy metal alloys, such as those containing tungsten, nickel, and cobalt, can provide high strength and ductility and are suitable for armor-penetrator projectiles (Rossiter *et al.*, 2010). Different heavy metals induce damage through similar mechanisms, either by binding to vital enzymes or by substituting other elements in biochemical reactions. Most metal toxicoses are characterized by the involvement of specific organs or organ systems (Gwaltney-Brant, 2013). Heavy metal pollution in surface water and sediment can vary seasonally, and sediments near certain areas may be moderate to strongly contaminated with lead (Ty *et al.*, 2022). Heavy metal toxicity can result in damage to various vital organs and long-term exposure may lead to degenerative diseases. Remedies to combat heavy metal toxicity include adopting kitchen gardening, increasing the intake of antioxidants, and avoiding exposure to heavy metals (Cibati *et al.*, 2017).

### **Chromium**

Chromium is a naturally occurring element that exists primarily in two oxidation states: trivalent chromium [Cr (III)] and hexavalent chromium [Cr (VI)]. Trivalent chromium is considered a nutritional supplement and may play a role in glucose metabolism. On the other hand, hexavalent chromium is highly toxic and carcinogenic, with exposure resulting in tissue or cell damage. Occupational exposure to hexavalent chromium occurs through

inhalation, oral ingestion, and direct dermal contact, while nonoccupational exposure primarily comes from oral ingestion of chromium-rich foods and water or inhalation via cigarette smoking. Chromium contamination can occur in air, water, and soil, and mathematical models are used to understand its fate and transport. Long-term inhalation exposure to hexavalent chromium compounds has been shown to increase the risk of respiratory cancers. Trivalent chromium can be beneficial in proper quantities, while hexavalent chromium is harmful to human health (Sun & Costa, 2022; Vincent, 2023).

### **Cobalt**

Cobalt is an essential element for mammals, including humans, in the form of cobalamin or vitamin B<sub>12</sub>. It is found in the Earth's crust and is mainly obtained through dietary intake. In humans, the oral bioavailability of inorganic cobalt compounds varies depending on their water solubility. Cobalt can be absorbed through inhalation in occupational settings, and its absorption rate varies with the species. The concentration of cobalt in urine or blood can be used as a biomarker of recent exposure to soluble cobalt species. Cobalt has genotoxic and carcinogenic properties, and it can affect various organs in the body, including the respiratory system, erythropoietic system, myocardium, thyroid gland, and nervous system. Cobalt alloy implants, such as metal-on-metal hip prostheses, can also lead to local and systemic toxicity. The reproductive toxicity of cobalt compounds is not well documented (Kräutler, 2023).

## Iron

Iron is a versatile metal that is abundant on Earth and plays a crucial role in various biological and technological processes. It can easily change valence and form complexes with oxygen, supporting respiration in aerobic organisms (Tenenbein & Huang, 2022). Iron metabolism is tightly regulated in organisms and cells to maintain iron homeostasis and prevent both deficiency and overload. However, chronic iron overload can lead to organ damage, while iron deficiency can have detrimental effects on health. In the field of multi-agent systems, the automated synthesis of norms for coordination remains a complex problem, but the Intelligent Robust On-line Norm Synthesis Machine (IRON) has shown promise (da Silva *et al.*, 2021) in synthesizing effective and necessary norms for coordination (Subroto *et al.*, 2023; Teixeira *et al.*, 2012). Additionally, iron compounds have been used in environmental and technological applications, such as increasing reactivity and producing magnetic materials. Iron bioavailability is important for preventing anemia and enhancing the immune system, and various technologies can increase its bioavailability.

## Manganese

Manganese is an essential element for humans, animals, and plants. It is found in the environment due to both natural and anthropogenic sources. Occupational exposure to manganese occurs in industries such as mining, steelmaking, and battery production. Environmental exposure is usually related to industrial emissions and the use of manganese compounds in agriculture and fuel additives. High levels of manganese in milk formula,

parenteral nutrition solutions, and drugs can also increase the manganese body burden. The main toxic effects of manganese are on the central nervous system, leading to motor and cognitive impairments. Manganese is a neurological disorder characterized by mood changes and symptoms resembling Parkinson's disease. Manganese exposure can also affect the respiratory, reproductive, cardiovascular, hematologic, endocrine, and immune systems (Lucchini *et al.*, 2022; Milatovic *et al.*, 2022; Santonen & Sainio, 2023).

### **Landfill Site and its Effect on Groundwater**

Landfill sites have a significant impact on groundwater quality. Improper waste disposal methods, such as landfilling, can lead to the generation of leachate, which negatively affects the composition and quality of groundwater sources (Oladiran *et al.*, 2023). Leachate from landfill sites can contain various contaminants, including heavy metals, volatile organic compounds (VOCs), and chlorinated hydrocarbons (Aryampa *et al.*, 2022). Studies have shown that leachate treatment processes at landfill sites may be ineffective in reducing pollution potential, resulting in high concentrations of pollutants in both treated and untreated leachate (Liu & Wang, 2022). Groundwater near landfill sites can be heavily contaminated, with high concentrations of pollutants such as nitrate, nitrite, and heavy metals (Chokor & Roberts, 2022). The contamination of groundwater by landfill sites can pose a potential health risk to individuals exposed to this water (Zeng *et al.*, 2021). To mitigate groundwater pollution, it is recommended to improve leachate collection systems and develop comprehensive remediation plans for landfill sites.

### **Noni (*Morinda Citrifolia*)**

*Morinda citrifolia*, commonly known as Noni, is a plant that has been traditionally used in Polynesian medicine for over 2000 years (Shettima *et al.*, 2023). It is believed to have various health benefits and is used to treat diseases such as high blood pressure, inflammation, and diabetes (Pradeepa *et al.*, 2023). Noni leaves and stems contain phytochemical components such as alkaloids, steroids, tannins, carbohydrates, terpenoids, glycosides, and flavonoids, which have potential medicinal applications (Falke Suyog *et al.*, 2022). Noni juice, derived from the fruit of *Morinda citrifolia*, is a popular health beverage globally and is believed to have a wide range of health benefits. Recent research has shown that Noni juice has high antioxidant activity and potential as an anticancer agent (Handayani *et al.*, 2022). Additionally, studies have demonstrated that Noni fruit, extract can ameliorate fluoride-induced toxicity in fish, indicating its potential protective effects.

### **Pawpaw (*Carica Papaya*)**

Papaya queen, also known as pawpaw, is a term that is not explicitly mentioned in the provided abstracts. However, the abstracts do provide information about the uses and properties of *Carica papaya* (papaya) and its extracts. *Carica papaya* is used in aquaculture as an alternative to chemicals, with pawpaw seed powders reported to have growth-promoting and sex-reversal effects in freshwater fish species (Ipinje *et al.*, 2023). *Carica papaya* extracts have also been studied for their potential benefits in agriculture, including their influence on the cultivation of pawpaw plants in the presence of climate hazards such as wind and rain. Additionally, *Carica papaya* seed flour has been studied for its effects on wheat-based bread, showing changes

in functional properties and proximate composition with increased pawpaw seed flour addition (Jean Bosco *et al.*, 2023). Furthermore, pawpaw leaf extracts have shown inhibitory activities against microbial organisms, suggesting their potential use as alternatives to synthetic antibiotics in animal production.

### **Tiger Nut (*Cyperus eeculentus*)**

Tiger nut (*Cyperus esculentus*) is a highly nutritious plant that contains lipids, protein, starch, fiber, vitamins, minerals, and bioactive factors (Edo *et al.*, 2023). It has been used as a food source, a medicinal plant, and even as a component in cosmetic products in various cultures around the world (Yu *et al.*, 2022). Tiger nut has potential health benefits, including effects on digestive health, cardiovascular health, blood sugar control, immune function, and other potential therapeutic uses (Mohammed *et al.*, 2022). It also has antioxidant, anti-inflammatory, and anti-apoptotic effects (Hernández-Olivas *et al.*, 2022). Tiger nut products, such as flour, oil, and milk, have been found to contain bioactive compounds with a positive impact on macular health, such as lutein and zeaxanthin (Gudaji *et al.*, 2022). Tiger nuts can be used to scavenge free radicals and have a protective effect against aluminum chloride-induced renal histopathology.

### **Chapter Summary**

As indicated in the review of relevant literature, plants have been used as both reducing and stabilizing agent nanoparticles synthesis for some years. Traditionally, these plants are mostly used due to their eco-friendly nature, availability and affordability. Phytochemicals in these plants have been

shown to possess reducing and stabilizing properties for nanoparticle synthesis. Besides the chapter elaborated on the cost effectiveness and efficacy of biogenically-synthesized nanoparticle for water remediation.



## CHAPTER THREE

### RESEARCH METHODS

#### Introduction

silver nanoparticles were synthesized using three different local materials. Critical steps involved in the preparation of metal complex solutions and other relevant reagent have been outlined in this chapter. Spectrochemical, microscopic and microbial analyses performed on all the 10 selected groundwater samples have also been presented.

#### Study Area

The sites selected for this research were situated within the Amamoma and Apewosika communities located in the Cape Coast Metropolitan District of the Central Region of Ghana, positioned at coordinates 1°17'49"W and 5°6'42"N (Figure 1). These communities share borders with the University of Cape Coast, collectively forming an expansive and spatially distinct continuum of settlements adjacent to the densely populated core of Cape Coast. The climatic conditions in this region are characterized by an average annual minimum temperature of approximately 27.0°C and a maximum of 32.0°C. The climate exhibits relative stability throughout the year, with the hottest months typically being February and March. However, there is minimal temperature variance annually. Rainfall patterns are delineated into two distinct seasons: a major rainy season spanning from April to July, and a minor one occurring between September and November. The dry, dusty Harmattan wind, originating from the northeast, dominates the region from December to March, leading to decreased humidity levels across the district, a

phenomenon that also affects the Amamoma Community. The onset of the Harmattan season typically begins around December in the study area.

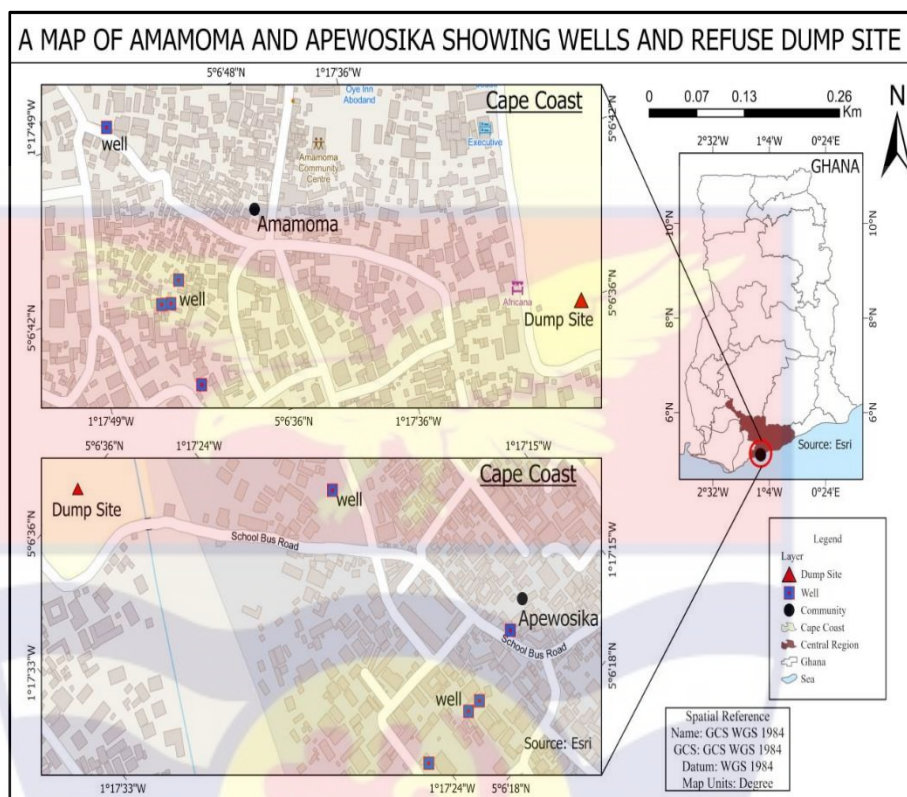


Figure 1: A Map Showing Study Area

(Google Construct, 2024)

## Preparation of Glassware

Clean glassware is valued for its inertness and transparency for presenting a clean surface for a variety of applications. Laboratory glassware must be appropriately cleaned as residual contaminants can affect experimental results. To avoid contamination from glassware, glass wares were soaked in chromic acid overnight, thoroughly cleaned with detergent, and rinsed with cool tap water. This procedure was followed by rinsing with deionized water several times. The glass wares were finally dried in an electrical oven.

## Chemicals and Reagents

Hydroxylamine, 1, 10-phenanthroline (99%), 1,5-diphenyl carbazide (ACS grade), dithizone (85%), chloroform, ammoniacal citrate cyanide, hydroxylamine, hydrochloride ammonium acetate, ammonium persulphate, ferrous ammonium Sulphate hexahydrate (99%) and acetone (CHROMAGOLV®) grade were purchased from Sigma Aldrich Chemicals (UK). Silver nitrate, potassium permanganate, concentrated nitric acid (70%), chromium powder, sodium azide (99%), sulphuric acid (98%), hydrochloric acid (37%), acetic acid (99%), sodium hydrogen sulphite, lead nitrate, and cobalt (II) chloride were all purchased and used as received.

## Synthesis of Silver Nanoparticle using Carica Papaya (Pawpaw) Peels

### Preparation of Papaya Peel Extract

Pawpaw fruits were purchased from Abura Market in Cape Coast Metropolis, cleaned and fresh papaya peels collected. 25 g of finely chopped pawpaw peels were boiled for 15 min at 80°C with 50 mL of deionized water. Whatman no. 1 filter paper was used to separate the extract from the leftover solid (Geetha *et al.*, 2016).

### Synthesis of AgNPs

1 mM of silver nitrate was prepared. Additionally, a range of peel extract concentrations added to the AgNO<sub>3</sub> solution were tested to maximize the conditions for AgNPs production. Solutions containing peel extract and AgNO<sub>3</sub> in volume ratios of 1:5, 1:1, and 1:2 were exposed to solar radiation for 15 min. The presence of AgNPs formation was observed by the change in colour from light yellow to brown (Kane *et al.*, 2016). Consequently, the

plasmonic absorption band was observed using UV-Vis spectrophotometer at a wavelength of 440 nm. Figure 1 shows the synthesis of the *Carica papaya*-mediated AgNPs, as well as, the proposed mechanism of the synthesis.

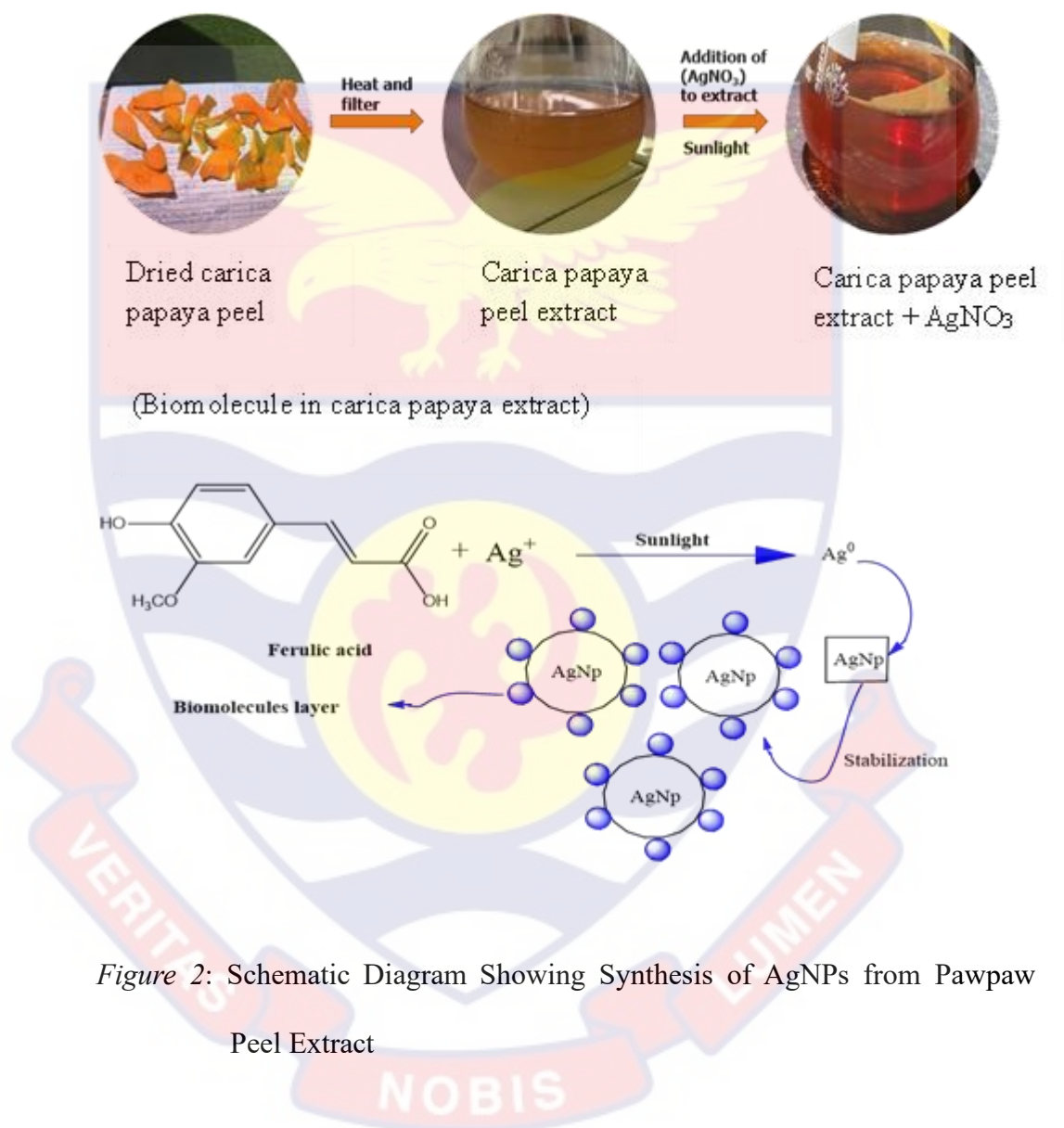


Figure 2: Schematic Diagram Showing Synthesis of AgNPs from Pawpaw Peel Extract

### Synthesis of silver nanoparticle using *Morinda Citrifolia* (noni) leaves.

#### Preparation of *Morinda Citrifolia* Leaves Extract

Leaves of the *Morinda citrifolia* were collected from the University of Cape Coast Botanical Gardens and washed using distilled water. 10 g of the fresh leaves were added to 100 mL of distilled water and boiled for 15 min.

After cooling to room temperature, the extract was filtered using Whatman No. 1 filter paper and set aside for further reaction (Shital *et al.*, 2019).

### Synthesis of AgNPs

30 mL of extract was added to a freshly prepared 15 mL of 1 mM silver nitrate solution, and the mixture was left in the sun for 15 min. Additionally, various concentrations of noni leaf extracts were added to the AgNO<sub>3</sub> solution to synthesize the AgNPs.

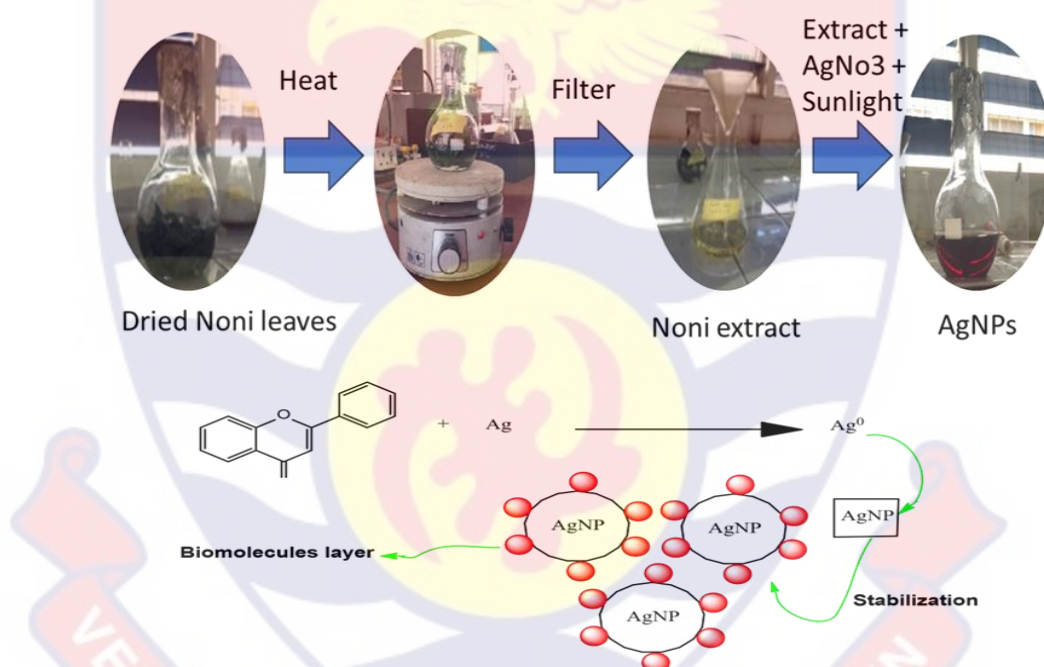


Figure 3: A Schematic Diagram Showing Synthesis of AgNPs from Noni Leaves Extract

### Preparation of Cyperus Esculentus (Tiger nut) Tuber Extract

Tiger nuts were purchased from obtained from New Edubiase in the Ashanti Region of Ghana. 7.0 g of *Cyperus esculentus* tuber was weighed, washed with deionized water, and disinfected with 2 mL hypochlorite solution. Again, repeated washings with deionized water were carried out until

no foaming was observed, indicating thorough dirt removal. This procedure was followed by the addition 40 mL of deionized water and the sample was kept at room temperature overnight to ensure that *Cyperus esculentus* had no cuts on them. After decantation and filtration, the colorless filtrate was kept pH 7 for subsequent nanoparticle synthesis.

### Green Synthesis of *Cyperus Esculentus* Tuber Stabilized Silver Nanoparticles

2 mL of 0.01M  $\text{AgNO}_3$  solution was added to 40 mL of *Cyperus esculentus* extract, and the mixture kept under sunlight for 5 min based on protocol established by Ankudze and Samlafo (2022). The formation of ruby red coloured solution was indicative of *Cyperus esculentus* mediated AgNPs.

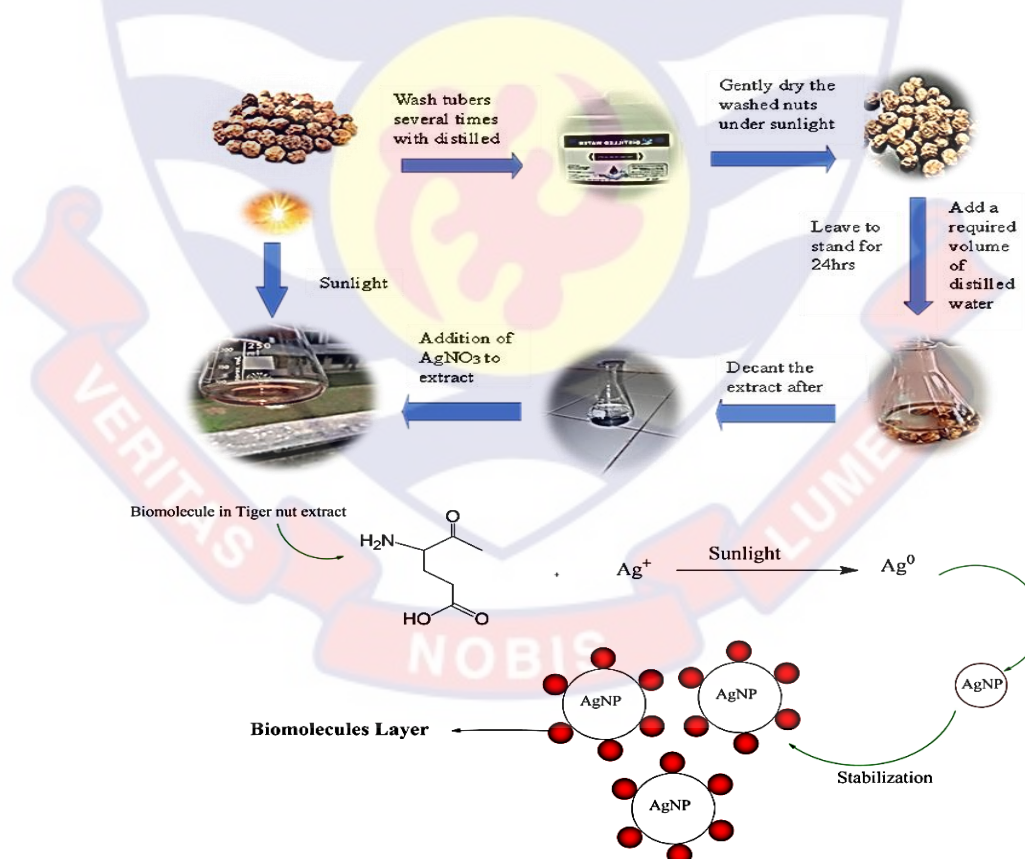


Figure 4: A Schematic Diagram Showing Synthesis of AgNPs from Tiger nut Extract.

### **1, 10-Phenanthroline (0.005 M)**

Approximately 100 mg phenanthroline monohydrate was quantitatively transferred to a 100 mL volumetric flask and diluted to the mark using deionized water. The solution was then heated to 80°C to ensure complete dissolution.

### **Mercuric Sulphate-Silver Nitrate (Special Reagent)**

15 g of mercuric sulphate was dissolved using a mixture of 50 mL deionized water and 100 mL dilute nitric acid. The solution was transferred to a 250 mL volumetric flask and diluted to the mark after the addition of 50 mL of 85% phosphoric acid and 9 mg of  $\text{AgNO}_3$ . The resulting solution was stored in an amber container and kept away from sunlight for further experiment as special reagent.

### **Preparation of Sample Blank**

To prepare the blank, 5 mL of analytical grade concentrated  $\text{HNO}_3$  was added 100 mL of deionized water, and the solution was heated to a concentration of 15-20 mL by heating about 2 mL of concentrated  $\text{HNO}_3$  portion at a time until digestion was complete, indicated by the appearance of a faint yellow clear solution. The hot plate was removed, and the solution was allowed to cool. About 3 min, the solution was thoroughly stirred for approximately 3 min, then quantitatively transferred into a 100 mL volumetric flask and diluted with deionized water.

### Preparation of Chromium Complex Solution (Colorimetric Method)

In a beaker filled with distilled water, 0.0353 g of potassium dichromate was weighed out and dissolved. The solution was poured quantitatively into a 250 mL volumetric flask and then diluted with deionized water to the meniscus. A 141.2  $\mu\text{g/mL}$  concentration was obtained as a result.

10 mL portions of the chromium stock solution were pipetted into 5 distinct 250 mL volumetric flasks. The contents of each flask were diluted with deionized water to yield 5.648, 11.296, 16.944, 22.572, and 28.240  $\mu\text{g/mL}$  of solution, respectively.

To make the complex 1,5-diphenyl carbazide solution, 5, 10, 15, and 20 mL of chromium solutions were pipetted into four separates, previously cleaned 100 mL volumetric flasks and labelled appropriately. 0.25 g of 1,5-diphenyl carbazide was weighed and dissolved in a 100 mL portion of acetone. To acidify the contents of each flask, 2 drops of  $\text{H}_2\text{SO}_4$  were added. Each flask received 2 mL of 1,5-diphenyl carbazide solution, which was then diluted to 100 mL. These solutions were mixed thoroughly and allowed to stand for 15 min for full-colour development of the 1,5-diphenyl carbazide - chromium complex solution indicated by the appearance of red-violet colourations at an absorbance wavelength of 540 nm. The solution was left to stand for 15 min to enable the 1,5-diphenyl carbazide-chromium complex solution to fully develop its colour, as seen by the emergence of red-violet colouring and their absorbance at 540 nm wavelength.

### Preparation of Iron Complex Solution (Phenanthroline method)

$\text{Fe}^{3+}$  ion is reduced to  $\text{Fe}^{2+}$  state using this process, which comprises boiling with hydroxylamine hydrochloride and breaking with 1, 10-

phenanthroline at pH 3.2 to 3.3. An orange-red complex was formed when each ferrous iron atom was chelated by three phenanthroline molecules. When there was an overabundance of phenanthroline present, a pH of 2.9 to 3.5 guarantees quick colour development.

Approximately 1.404 g of ferrous ammonium sulphate hexahydrate was weighed and dissolved in 20 mL of diluted nitric acid to create the iron metal complex stock solution. Potassium permanganate ( $\text{KMnO}_4$ ) solution was added in 50 mL increments until a little pink hue remained. Droplets were added to the last few milliliters of the potassium permanganate solution. After quantitatively transferring the solution into a volumetric flask, deionized water was added to reach the 1000 mL threshold. 200  $\mu\text{g/mL}$  of iron was present in a 1 mL sample of this solution.

The iron stock solution was pipetted in parts of 10, 20, 30, 40, and 50 mL to prepare concentrations of 2, 4, 6, 8, and 10  $\mu\text{g/mL}$  in a 100 mL volumetric flask. In this preparation, 2 mL of concentrated HCl was added to 1 mL of hydroxylamine hydrochloride solution. The mixture was boiled until about 10 mL was left. The solution was transferred to 100 mL volumetric flask and supplemented with 10 mL of ammonium acetate buffer and 4 mL of 1,10-phenanthroline solution was added. For optimal colour development, this was left to stand for around 20 min and absorbance was measured at 510 nm. The procedure was repeated for the preparation of 4, 6, 8, and 10  $\mu\text{g/mL}$  standard solutions.

#### **Preparation of Manganese Solution (Persulphate Method)**

$\text{AgNO}_3$  was used to facilitate the oxidation of manganese compounds to produce permanganate following a protocol developed by the American

Public Health Association (2005). A solution of 100 mL deionized water and 1 mL 98% sulphuric acid was used to dissolve 0.2877g of potassium permanganate, followed by addition of 0.5g of disodium hydrogen disulphite. The resulting solution was diluted to 200 mL in a volumetric flask. 20 mL aliquot was transferred and diluted to 100 mL with deionized water. 20, 40, 60, 80 and 100-mL portions of the manganese stock solution was pipetted to prepare of 2, 4, 6, 8 and 10  $\mu\text{g/mL}$  in 100 mL solutions, respectively. UV-Vis measurement showed maximum wavelength ( $\lambda_{\text{max}}$ ) at 525 nm typical of  $\text{Mn}^{2+}$  absorption.

#### Preparation of 1000 $\mu\text{g/mL}$ Cobalt Solution

About 4.307 g analytical grade cobalt (II) chloride was weighed out and dissolved using deionized water. After the addition of 10 mL of  $\text{HNO}_3$ , the solution was brought to a final volume of 1 L (1000  $\mu\text{g/mL}$ ). 100 mL each of concentrations of 5, 10, 15, 20, and 25  $\mu\text{g/mL}$  were prepared using serial dilutions. Plate 4C shows the resulting colour of the solution. The absorbance maxima for these solutions occurred at 510 nm.

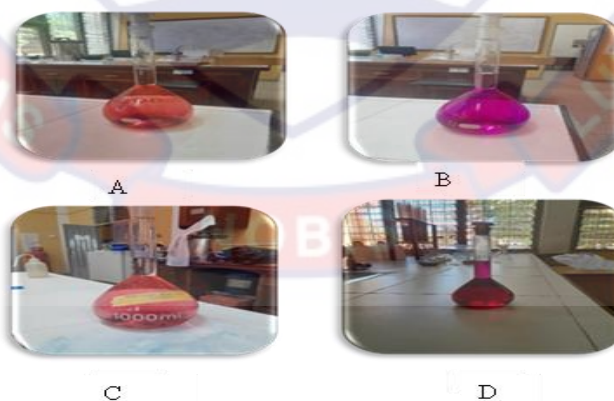
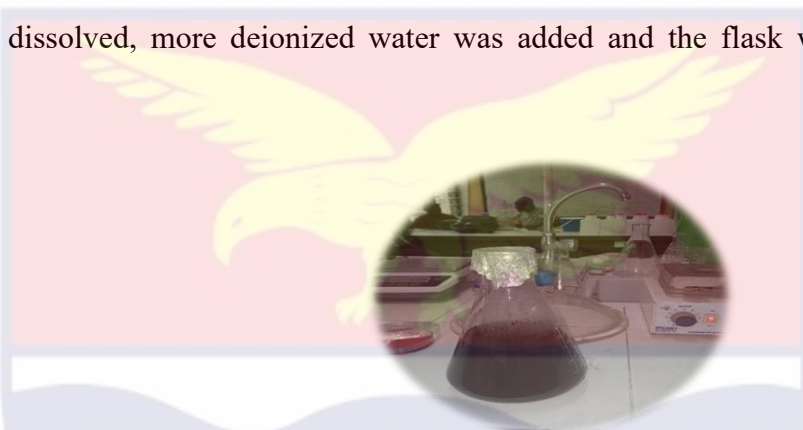


Figure 5: Pictures Showing Metal-Ion Solutions. A) Iron, B) Chromium, C) Cobalt, D) Manganese

## Microbial Analysis

### Preparation of MacConkey Agar

A 51 g of the MacConkey agar powder was measured into a 1000 mL Erlenmeyer flask. The flask was placed on a heating mantle, and 300 mL of deionized water was added while stirring the mixture. As the powder dissolved, more deionized water was added and the flask was filled to the



1000 mL mark.

*Figure 6: MacConkey Agar*

To avoid any contamination and false representations, the glassware, and the agar prepared are sterilized using an autoclave at 121°C with a pressure of 15 psi. The bench surfaces are also sterilized using a 95% ethanol solution.

### Preparation of MacConkey Agar Plates

The mixture was allowed to cool to about 40°C and 10 mL of the solution was transferred onto the base of a 90 mm petri dish. The agar was allowed to dry and solidify.

### Sample Preparation

Samples were collected using sterile containers and techniques to prevent contamination. Depending on the colour and appearance of the

sample, it might be necessary to perform serial dilution to reduce the microbial load and make counting easier. The serial dilutions made were used to estimate the dilution factor.

### **Sample Inoculation**

About 10 mL volume of each serial dilution was aseptically transferred onto the agar plate using the spread plate method. The spreader or inoculation loop was used to spread the sample evenly on the surface of the agar.

### **Incubation**

MacConkey agar plates were incubated at a temperature of around 35-37°C for 24 to 48 h. For faecal coliform, the samples were incubated at 44°C for 24 h.

### **Observation**

After incubation, the colonies formed on the plates were observed taking into consideration of the fact the MacConkey agar was selective for Gram-negative bacteria. Colonies that appeared pink to reddish and can be differentiated by their ability to ferment lactose indicated the possible presence of coliform bacteria. Also, the pinkish to reddish colonies formed after incubating at 44°C also indicated the possible presence of faecal coliforms.

### **Confirmation and Enumeration**

The count was enumerated using the formula below:

$$\text{total coliform count} = \frac{\text{colonies counted} \times \text{dilution factor} \times \text{inoculation volume}}{\text{inoculation volume}}$$

## Physicochemical Analysis of Untreated Groundwater Samples

The physicochemical parameters of the samples were determined at the Ghana Water Company Limited laboratory in Cape Coast. The analysis included the examination of several criteria detailed below:

**pH:** The determination of sample pH was conducted employing the Mettler Toledo apparatus. Rigorous protocols were followed to guarantee precision in measurements. Prior to immersion in each sample, the instrument's probe underwent thorough rinsing with deionized water. Subsequently, the probe was introduced into a designated beaker containing the sample under examination. A sufficient period was allotted for stabilization before recording the pH reading. This process was iterated for each sample, ensuring the acquisition of accurate pH values.

**Temperature:** The Mettler Toledo equipment delivered the corresponding temperatures of each sample while taking pH readings. These temperature observations, along with the pH readings, were duly recorded.

**Turbidity:** The turbidity levels in the samples were assessed utilizing the photometric technique employing the HANNA HI 88703 turbidimeter. Following a thorough rinse of the sample cell with distilled water, a volume of 10 mL from the initial sample was introduced. Subsequently, the sample cell was inserted into the instrument, and the 'Read' button was activated twice to obtain the measured values. This process iterated across all ten samples to ascertain their respective turbidity values.

**Total Dissolved Solids (TDS):** The Total Dissolved Solids (TDS) parameter is a critical aspect of water quality assessment, providing insights into the concentration of dissolved substances within a given sample. This

parameter is often determined through the measurement of electrical conductivity (EC), with TDS being calculated as the product of EC and a conversion factor of 0.675. This relationship allows for a straightforward estimation of TDS levels based on readily obtainable EC measurements. By understanding the principles behind this calculation, researchers and practitioners can effectively monitor and manage water quality to ensure the health and sustainability of aquatic ecosystems.  $TDS = 0.675 * EC$ .

**Colour:** The colour of the water samples was determined using a DR-500 spectrophotometer set at 455 nm. To calibrate the equipment, distilled water was used as a blank to establish a baseline. Following that, 10 mL of each water sample was properly measured and divided between six cuvettes. The results were then recorded for further examination.

**Chromium:** The determination of chromium content in the samples was conducted using the spectrophotometric method, employing a DR-500 spectrophotometer set at a wavelength of 540 nm. To initiate the analysis, 25 mL of each sample was dispensed into separate 100 mL beakers. Subsequently, a single pack of chromium 1 reagent was introduced into each sample, followed by subjecting the mixture to boiling in a water bath for approximately 5 minutes. Upon completion of the boiling process, a pack of chromium 2 reagent, also known as chromover 3, was swiftly added to each sample and vigorously mixed. The resulting solution was then subjected to spectrophotometric analysis, with 10 mL of the sample utilized as the blank. This experimental procedure was meticulously repeated for each additional sample, ensuring accuracy and reliability in the analysis process.

**Total Iron:** Total iron content was assessed utilizing a spectrophotometric technique employing the DR-500 spectrophotometer set at a wavelength of 510 nm. Individual water samples, each measuring 10 mL, were introduced into distinct 100 mL beakers and combined with Ferro Ver Iron reagent. Following a 3-minute incubation period, a discernible alteration in color from transparent to pale pink signified the existence of iron within the solution. Notably, the samples served as self-referencing blanks for calibration across all instruments.

#### **Nitric Acid Digestion of Groundwater Sample**

Groundwater Samples (GWs) were digested with nitric acid to solubilize the solid matter and to remove the organics by oxidation and volatilization. In the digestion procedure about 100 mL of the sample was measured with a measuring cylinder into a 125 mL Erlenmeyer flask. The cylinder was rinsed with a small amount of distilled water and added to the solution in the flask. About 5 mL of concentrated nitric acid was added and mixed thoroughly by stirring for about 3 min. The mixture was placed on a hot plate and heated until the volume was reduced to about 15 – 20 mL. The heating was continued and a 2 mL portion of the concentrated nitric acid was gradually added until digestion was completed. This was shown by the appearance of a very faint yellow and clear solution. The solution was removed from the hot plate and cooled. It was transferred into a 100 mL volumetric flask and diluted to the 100 mL mark (Quadros & Marr, 2010).

### Groundwater Sample Treatment with AgNPs

Inductively Coupled plasma - optical emission spectrophotometer (ICP-OES) was employed to determine the concentrations of Iron (Fe), manganese (Mn) cobalt (Co) and Chromium (Cr) ions removed. This was done by adsorption of the metals from the GWs onto the surface of AgNPs.

The metals were removal by adding 2 mL portion of AgNPs solution to 20 mL portion of digested groundwater samples (GWs). The mixture was stirred thoroughly and incubated at room temperature of 1 day, 7 days and 14 days. The AgNPs with contaminants adsorb unto the surface were removed by centrifuging at 500 rpm for 10 mins. The resultant supernatant liquid was transferred into plastic bottles for analysis. In all 6 groundwater samples (GWs) were analyzed. These include 5 nitric acid digested samples with nanoparticle treatment and 1 without nanoparticles incubation.

### Chapter Summary

This chapter presented an in-depth description of the research tools, chemicals, reagents, media and instrumental procedures employed to conduct this research work, and how the results obtained from the study were analyzed.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### Introduction

This chapter presents the findings obtained from the characterization of synthesized nanoparticles sourced from various extracts. It also deals with the analysis of groundwater samples before treatment with silver nanoparticles, followed by the characterization of these nanoparticles and their subsequent physisorption studies with heavy metals after different incubation times. Through rigorous physicochemical analysis, this chapter also quantifies the number of heavy metals adsorbed during physisorption by the silver nanoparticles.

#### Characterization of Silver Nanoparticle

Noble metal nanoparticles possess distinctive properties, prominently characterized by a pronounced absorption band absent in bulk metal spectra. This absorption band arises from the phenomenon of surface plasmons, where incident photons resonate with the collective oscillation of conduction electrons. The environmental factors, surrounding medium, nanoparticle morphology, and size collectively influence the energy of surface plasmons. Consequently, any binding of metal ions to the nanoparticle surface induces variation in the surface plasmon energy. Specifically, in the case of silver nanoparticles, the UV-Vis absorption band typically falls within the range of 400 to 700 nm.

Figure 5 illustrates the plasmonic absorption spectra for different ratios of noni extract to a 0.001 M of a  $\text{AgNO}_3$  precursor solution, indicating a

significant impact of the extract ratio on the absorbance properties. The 1:5 ratio shows the highest wavelength, while the 2:1 ratio displays the lowest, indicating enhanced plasmonic resonance. This suggests a higher concentration of metallic nanoparticles due to increased noni extract ratios.

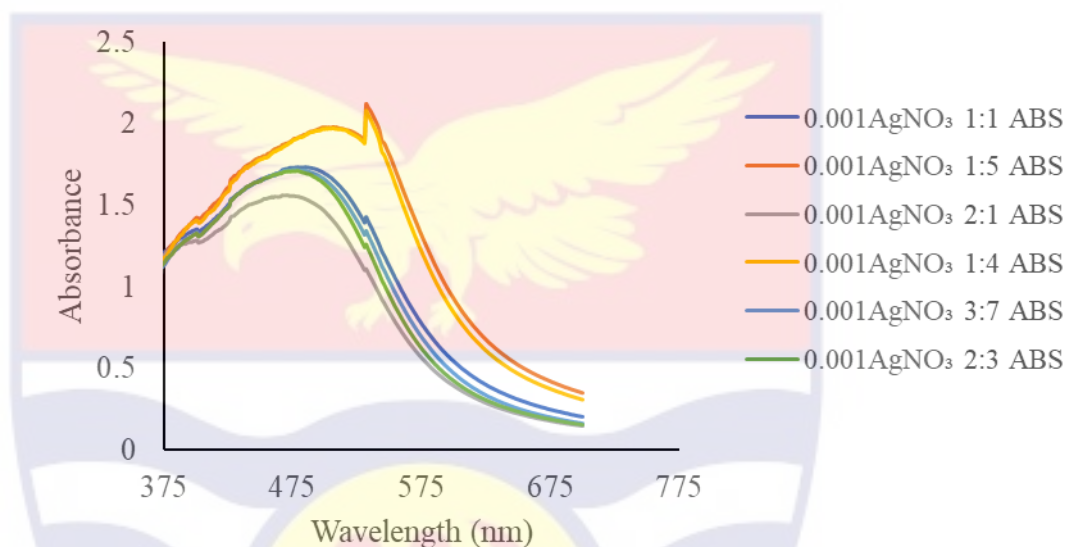


Figure 7: Spectra Showing Plasmonic Absorption Spectra of the Ratios of Noni Leave Extract

There is a discernible red shift in the wavelengths with decreased extract ratios, which is typical when particle size or aggregation increases within the colloidal solution (Edward *et al.*, 2018)

In comparison to the existing literature (Shankar *et al.*, 2015), the data supports the hypothesis that plant extracts, such as noni, can be effective in the biogenic synthesis of nanoparticles. This observation indicates that variation in peak absorbance with changing ratios of noni extract is indicative of the reduction of Ag<sup>+</sup> ions by the noni extract's phytochemicals (Ramakritinan *et al.*, 2019). The observed red shift aligns with findings that correlate extract concentration with nanoparticle size, where lower concentrations typically

yield larger or more aggregated particles (Ankamwar *et al.*, 2017). Moreover, the plasmonic behavior observed at around 466 nm for the 2:1 ratio correlates with previous reports on the size distribution of nanoparticles, reinforcing the role of noni extract concentration in the synthesis process (Maliszewska *et al.*, 2021, Mohajerani *et al.*, 2019). The findings suggest that noni extract not only reduces  $\text{Ag}^+$  to metallic silver but also stabilizes the nanoparticles, as supported by studies highlighting the importance of extract composition in nanoparticle synthesis (Mittal *et al.*, 2014).

**Table 1: Peak Maxima and their Respective Wavelengths for the Various Mix Ratios of the Noni Extract and The  $\text{AgNO}_3$  Precursor Solution.**

| Ratios  | 1:1                  |       | 1:5                  |      | 2:1                  |       | 2:3                  |                      |
|---------|----------------------|-------|----------------------|------|----------------------|-------|----------------------|----------------------|
|         | $\lambda(\text{nm})$ | Abs   | $\lambda(\text{nm})$ | Abs  | $\lambda(\text{nm})$ | Abs   | $\lambda(\text{nm})$ | $\lambda(\text{nm})$ |
|         | 486                  | 1.737 | 503                  | 1.98 | 466                  | 1.55  | 476                  | 1.71                 |
|         | 485                  | 1.739 | 502                  | 1.97 | 469                  | 1.55  | 475                  | 1.70                 |
| Average | 485.5                | 1.738 | 502.5                | 1.98 | 467.5                | 1.556 | 475.5                | 1.705                |

Source: Researcher (2024)

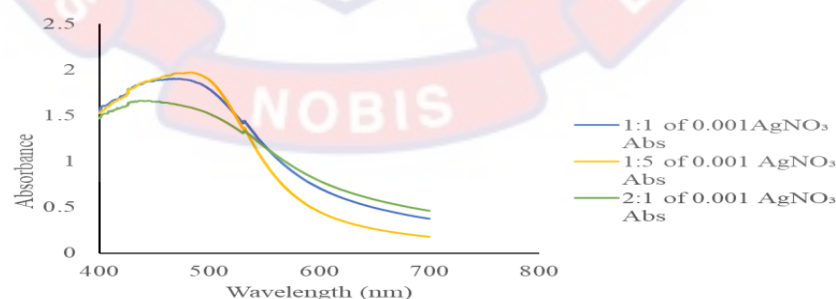


**Figure 8: Graph Showing Plasmonic Absorption Spectra of the Ratios of Pawpaw Peel Extract**

Similarly, the spectra displayed in Figure 8 show the plasmonic absorbance spectra for silver nanoparticles (AgNPs) synthesized using pawpaw peel extract mixed with a 0.001 M AgNO<sub>3</sub> precursor solution at different ratios. The result shows the measured absorbance line within wavelengths ranging from 400 to 800 nm. Three distinct curves correspond to the extract-to-precursor ratios of 1:1, 1:5, and 2:1, with the absorbance peaking between approximately 440 and 442 nm, a range indicative of the presence of AgNPs due to surface plasmon resonance (SPR). The peak absorbance decreases with increasing amounts of pawpaw peel extract, suggesting corresponding variations in the size, distribution, or concentration of the nanoparticles produced.

According to (Zhao *et al.*, (2022), the surface plasmon resonance peaks for AgNPs typically occur within the 400-450 nm range, corresponding to the peak wavelengths observed in the graph. The observed decrease in peak absorbance with higher ratios of pawpaw peel extract may suggest a stabilizing effect of the biological molecules in the extract on the nanoparticle formation (Liu & Wang, 2022), indicating that phytochemicals in plant extracts can stabilize nanoparticles and keep the particles monodispersed thereby influencing their optical properties and preventing aggregation (Shankar *et al.*, 2015). This stabilization effect can lead to the synthesis of nanoparticles with smaller sizes and lower agglomeration as the extract concentration increases (Mittal *et al.*, 2013). These observations must be taken in the framework of reproducibility and consistency with other experimental studies to validate the influence of pawpaw peel extract on AgNPs

characteristics (Shankar, Ahmad, & Sastry, 2020; Mittal, Chisti, & Banerjee, 2018).

**Table 2: Peak Maxima and their Respective Wavelengths for the Various Mix Ratios of the Pawpaw Peel Extract and the AgNO<sub>3</sub> Precursor Solution**

| Ratios  | 1:1            |       | 1:5            |        | 2:1            |       |
|---------|----------------|-------|----------------|--------|----------------|-------|
|         | $\lambda$ (nm) | Abs   | $\lambda$ (nm) | Abs    | $\lambda$ (nm) | Abs   |
|         | 468            | 1.905 | 485            | 1.971  | 440            | 1.655 |
|         | 467            | 1.903 | 484            | 1.972  | 442            | 1.651 |
| Average | 467.5          | 1.904 | 484.5          | 1.9715 | 441.5          | 1.653 |

Source: Researcher (2024)

#### UV-Vis characterization of AgNPs synthesized from tiger nut extract

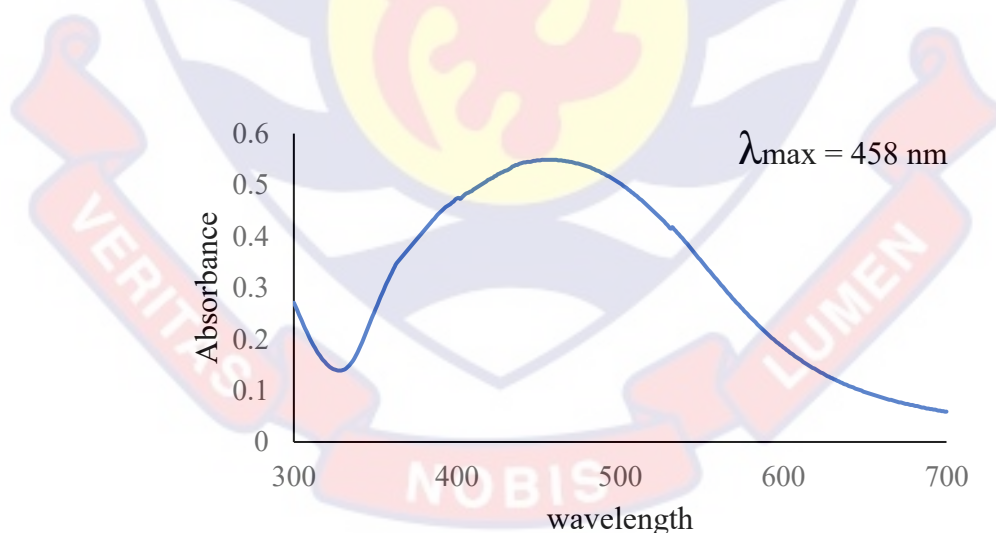


*Figure 9: UV-Vis Absorption Spectrum for Silver Nanoparticle Showing Absorption at 458 nm using Tiger Nut.*

Figure 9 represents a UV-Vis absorption spectrum of colloidal silver nanoparticles synthesized from tiger nut extract. The absorbance peaks at

approximately 458 nm, a detail that is particularly relevant to the size and shape of the silver nanoparticles.

According to (Wang *et al.*, 2021). The surface plasmon resonance (SPR) peak around 458 nm is indicative of small spherical silver nanoparticles, supporting recent findings that utilize plant extracts as both reducing and capping agents in nanoparticle synthesis. The tiger- nut extract likely contains compounds that act to reduce silver ions and stabilize the resulting nanoparticles, influencing their size and distribution and by extension, the optical properties observed in the UV-Vis spectrum (Zhang *et al.*, 2021). The precise peak wavelength and profile of the absorbance spectrum give insights into the nanoparticle's size, shape, and aggregation state, which are in accordance with the trends reported for biosynthesized silver nanoparticles (Ahmadi & Gholami Houjeghan, 2022).

#### **FTIR characterization of various extracts used in the synthesis of different AgNPs**

FTIR undertaken was to identify the functional groups in the extract responsible for the reduction of  $\text{Ag}^+$  to  $\text{Ag}^0$ . Figure 10 shows the FTIR spectrum of *Carica papaya* extract

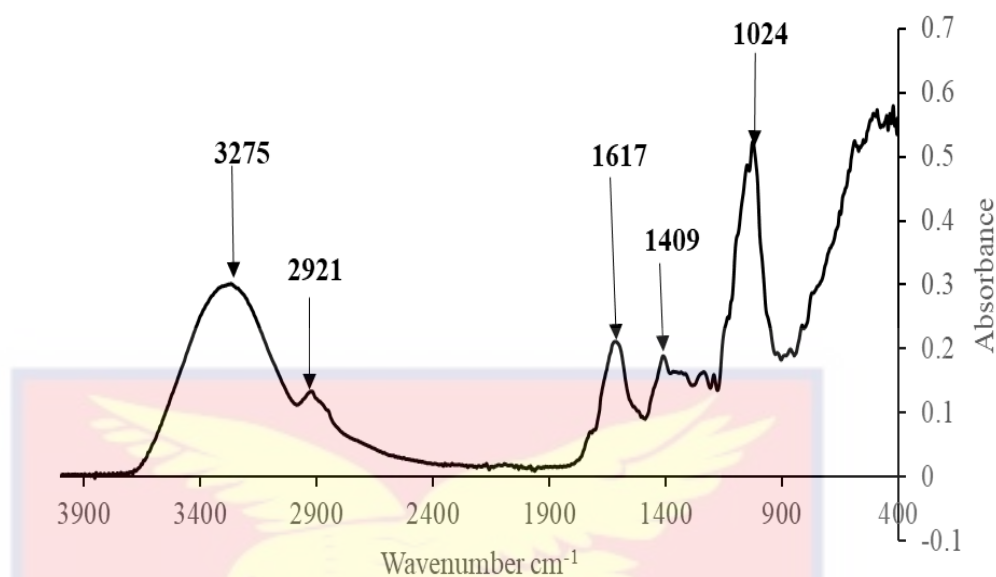


Figure 10: FTIR Spectrum of *Carica Papaya* Peel Extract.

The broad peak at 3275 cm<sup>-1</sup> suggests the presence of O-H stretching vibrations, typically associated with alcohols and phenols, indicative of the presence of hydroxyl components in the extract (Smith & Dent, 2021). The absorption band near 2921 cm<sup>-1</sup> corresponds to C-H stretching vibrations, possibly from aliphatic compounds present in the papaya extract (Stuart, 2016). The peak at 1617 cm<sup>-1</sup> is characteristic of C=C stretching in aromatic rings, which might suggest the presence of flavonoids or other aromatic compounds (Coates, 2020). Lastly, the peak at 1409 cm<sup>-1</sup> could be attributed to O-H bending vibrations, further confirming the presence of alcoholic or phenolic compounds (Silverstein *et al.*, 2015).

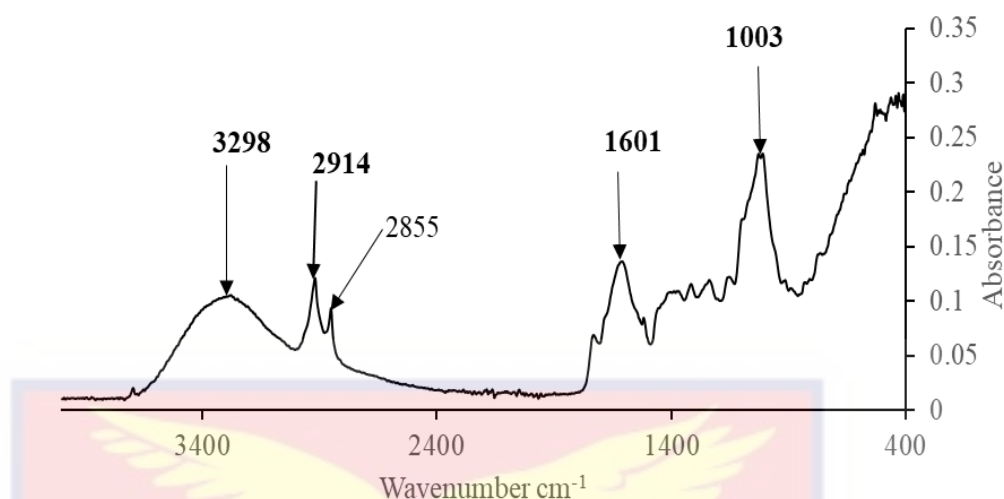


Figure 11: FTIR Spectrum of *Morinda Citrifolia* Leaves Extract.

The FTIR spectrum for *Morinda Citrifolia* extract shown in Figure 11 illustrates distinctive peaks that signify the presence of various functional groups. The peak at  $3298\text{ cm}^{-1}$  indicates N-H or O-H stretching representing characteristic of amines or alcohols/phenols functionalities as indicated in Figure 9 for noni extracts. The peak at  $2914\text{ cm}^{-1}$  and  $2855\text{ cm}^{-1}$  both indicates the presence of C-H stretching from aliphatic compounds, (Singh & Mehta, 2023). Similarly peak at  $1601\text{ cm}^{-1}$  is consistent with N-H bending vibrations in amides or C=C stretching in aromatic compounds, which might imply the presence of alkaloids or aromatic amino acids (Patel *et al.*, 2024). Finally, the sharp peak observed at  $1003\text{ cm}^{-1}$  could be attributed to C-O stretching, typical of ether or alcohol groups, which are known to exist in noni fruit compounds (Kumar & Shah, 2024).

### Scanning Electron Images of the Various AgNPs from Different Extracts

To fully appreciate the adsorption characteristics of the synthesized nanoparticles, it would be prudent to know the shape, size and monodispersed of the nanoparticles. Thus Figure 10 shows the scanning electron micrographs

of noni leaf pawpaw synthesized silver nanoparticles. The micrographs show heterogenous monodispersed particles of spherical particles ranging from 20 to 40nm in diameter for noni leaf mediated nanoparticles. This variability in shape might impact the adsorption capabilities of these nanoparticles (Johnson, 2022). The presence of variable sized particles both shapes within the same synthesis batch suggests complex bio-reducing mechanisms essential in the Noni leaf extract, which have been noted to influence nanoparticle morphology due to the variety of organic compounds acting as both reducers and stabilizers (Singh & Lee, 2020). Similar studies have noted that the phytochemicals in plant extracts, like those found in Noni leaves, play a crucial role in dictating the shape and size of the nanoparticles, which in turn impacts their application as contaminant removal media potential in areas like towards environmental remediation (Gupta & Xie, 2019).

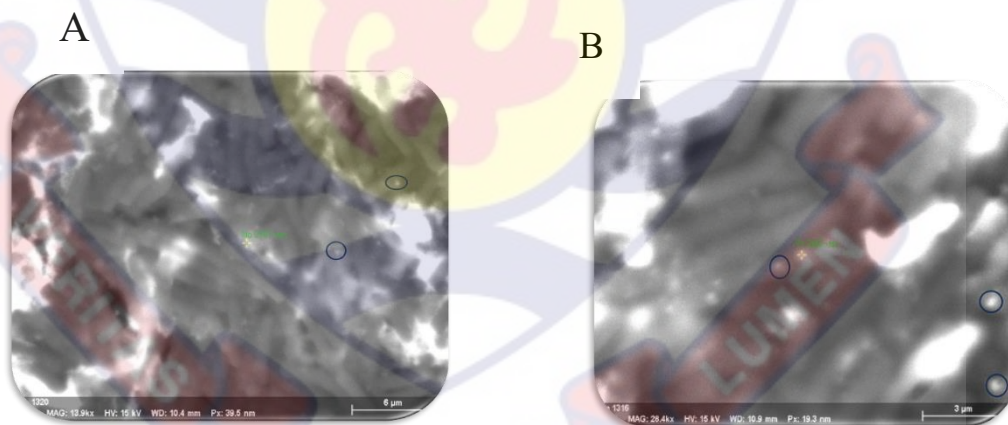


Figure 12: Scanning Electron Micrographs of AgNPs from (A) *Morinda Citrifolia* and (B) *Carica Papaya*

Pawpaw peel synthesized AgNPs on the other hand reveals a predominantly spherical morphology with a size range of approximately 10-50 nm. The nanoparticles display a uniform distribution with minimal

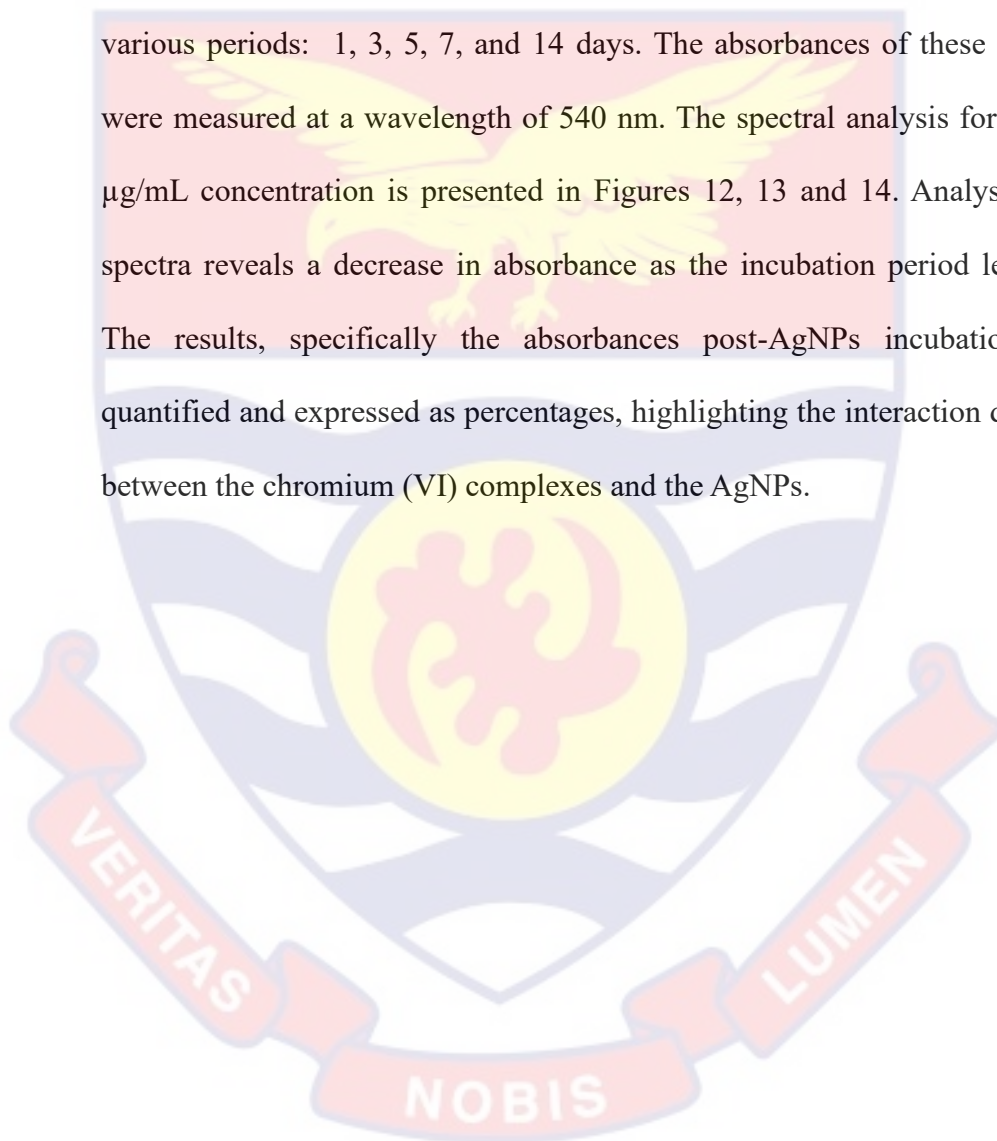
agglomeration, indicating effective stabilization possibly attributable to bioactive compounds present in the pawpaw peel extract (Smith *et al.*, 2021). This observation aligns with findings by Zhao *et al.* (2019), who reported that plant extract-mediated synthesis often results in well-dispersed metallic nanoparticles due to the natural stabilizers and reducing agents in the plant material. The size and morphology of the nanoparticles are crucial for their antibacterial and catalytic applications, as smaller and more uniformly shaped nanoparticles typically exhibit greater surface area and higher reactivity (Brown *et al.*, 2020).

#### **Efficiency of AgNPs Synthesized from Different Extract on Metal -Ion Contaminant Removal**

The investigation focused on the efficacy of silver nanoparticles (AgNPs) as agents for removing metal-ion contaminants. These AgNPs were synthesized using extracts premeditated to adsorb ions such as Cr, Co, Fe, and Mn through a process of physisorption. The basic thrust behind this study is the assertion that physisorption of metal ion complexes the AgNPs would lead to both bathochromic and hypochromic effect (Attatsi & Nsiah, 2020). According to Beer's Law, this reduction in absorbance indicates a corresponding decrease in metal ion concentration (Ball, 2018). Furthermore, it was observed that with extended incubation periods specifically over 1, 3, 5, 7, and 14 days the absorbance consistently decreased across all concentrations tested.

### **Efficiency of AgNPs Synthesized from Different Extract as Chromium Ion Contaminant Removal Media.**

The solutions of the iron (II) complex, prepared at concentrations of 5.6, 11.2, 16.9, 22.5, and 28.2  $\mu\text{g/mL}$ , were incubated with approximately 2 mL of silver nanoparticles (AgNPs) synthesized from different extract over various periods: 1, 3, 5, 7, and 14 days. The absorbances of these solutions were measured at a wavelength of 540 nm. The spectral analysis for the 28.2  $\mu\text{g/mL}$  concentration is presented in Figures 12, 13 and 14. Analysis of the spectra reveals a decrease in absorbance as the incubation period lengthens. The results, specifically the absorbances post-AgNPs incubation, were quantified and expressed as percentages, highlighting the interaction dynamics between the chromium (VI) complexes and the AgNPs.



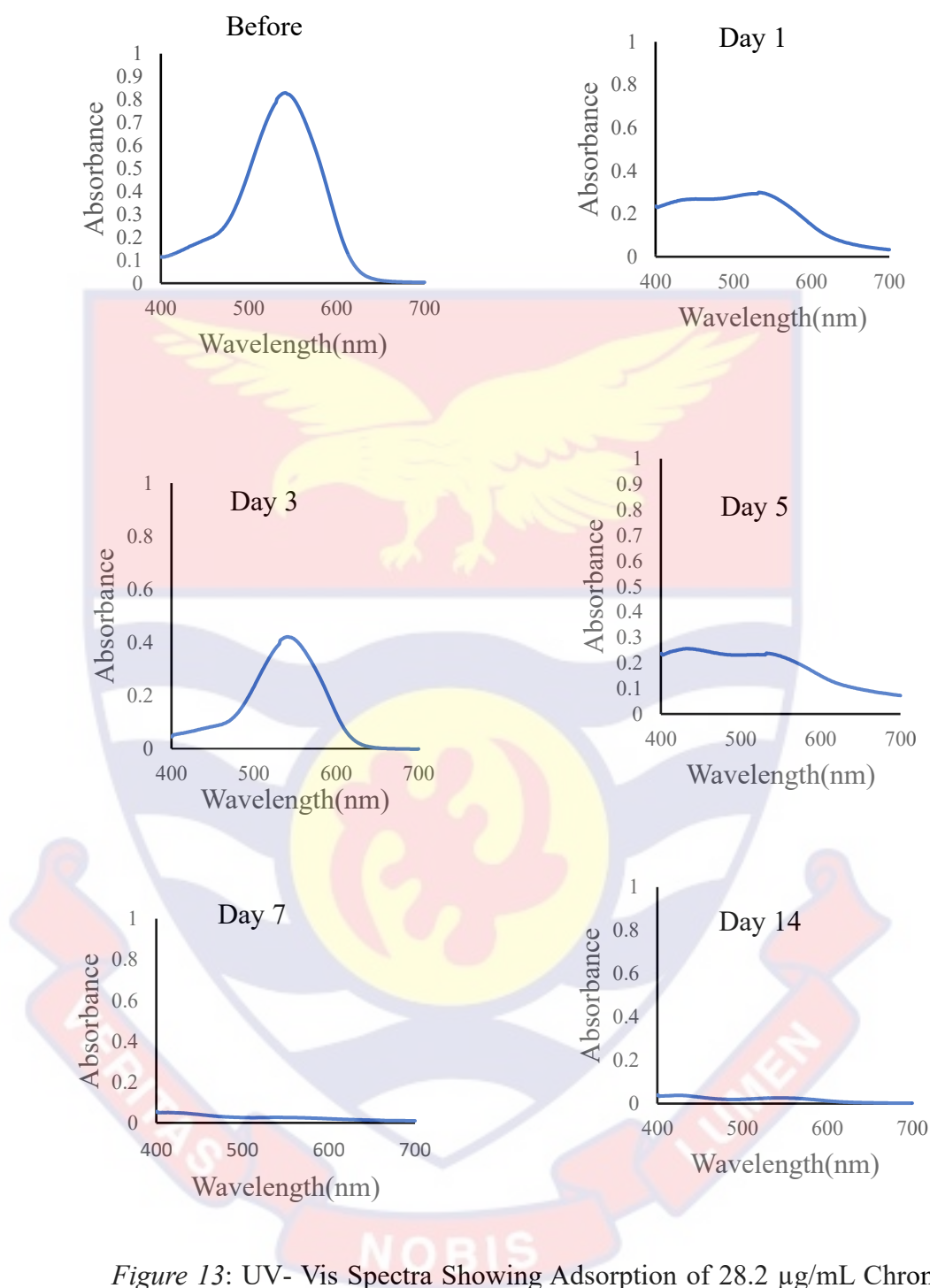


Figure 13: UV- Vis Spectra Showing Adsorption of 28.2 µg/mL Chromium (VI) Complex Solution using Noni Leaves Synthesized AgNPs after Incubation Periods of the Selected Days.

**Table 3: Percent of Cr (VI) Removed by AgNPs in Different Cr (VI) Complex Solution Incubated with AgNPs Synthesized with Noni Leaves for Five Different Days.**

| Concentration<br>(µg/mL) | BF<br>addition | Incubation Period |                |                |                |                |                |                |                |                |                |
|--------------------------|----------------|-------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                          |                | Day 1             |                | Day 3          |                | Day 5          |                | Day 7          |                | Day14          |                |
|                          |                | %<br>Reduction    | %<br>Reduction | %<br>Reduction | %<br>Reduction | %<br>Reduction | %<br>Reduction | %<br>Reduction | %<br>Reduction | %<br>Reduction | %<br>Reduction |
| 5.6                      | 0.983          | 0.9765            | 1              | 0.4915         | 48             | 0.7645         | 19             | 0.2635         | 72             | 0.3465         | 63             |
| 11.2                     | 1.413          | 1.3180            | 7              | 0.9825         | 30             | 1.0995         | 22             | 0.4865         | 65             | 0.6265         | 55             |
| 16.9                     | 1.509          | 1.369             | 9              | 0.9495         | 37             | 1.156          | 23             | 0.4585         | 70             | 0.6925         | 54             |
| 22.5                     | 0.7665         | 0.6435            | 16             | 0.6435         | 16             | 0.6855         | 2              | 0.4975         | 29             | 0.2465         | 65             |
| 28.2                     | 0.8285         | 0.299             | 64             | 0.4205         | 40             | 0.2345         | 67             | 0.0265         | 96             | 0.0415         | 94             |

Source: Researcher (2024)

Five different concentrations of chromium complex solution (5.6, 11.2, 16.9, 22.5, and 28.2  $\mu\text{g/mL}$ ) were incubated with the synthesized nanoparticles for 1, 3, 5, 7, and 14 days, and the percentage reduction in chromium concentration were recorded in Table 3. Table 3 shows noticeable trend of increasing chromium reduction with longer incubation periods across all tested concentrations. At a chromium concentration of 5.6  $\mu\text{g/mL}$ , the percent reduction from day 1 to day 14 showed 1% to 63%. The highest initial concentration of (28.2  $\mu\text{g/mL}$ ) saw a reduction from 64% on day 1 to 94% by day 14, indicating a significant enhancement in the nanoparticle's efficacy over time.

There was a consistent pattern of increasing efficiency in chromium reduction with prolonged exposure to the silver nanoparticles, with the most substantial effects observed at higher chromium concentrations. Specifically, the percentage reduction at 28.2  $\mu\text{g/mL}$  rise impressively from 64% after one day of incubation to an overwhelming 96% by the seventh day, finally stabilizing at 94% on the day 14. This trend suggests that the silver nanoparticles possess a capacity for enhanced chromium adsorption over time. It's also pertinent to note that the initial reduction rates varied across concentrations, with the highest initial concentration experiencing the most significant immediate reduction, which may indicate a concentration-dependent interaction between the chromium complex and the nanoparticles. These findings align with existing literature (Lee & Jun, 2019; Smith *et al.*, 2020), which suggests that the efficiency of metal nanoparticles in pollutant reduction can significantly increase with time due to ongoing adsorption processes and possibly the formation of more active sites or

changes in nanoparticle surface characteristics. Furthermore, the pronounced efficacy at higher concentrations may reflect a threshold effect, where nanoparticles exhibit enhanced performance once a certain contaminant concentration is reached, as observed by (Wang *et al.*, 2018) and supported by Faizan *et al.* (2021), who noted similar trends in nanoparticle-mediated heavy metal detoxification.

Moreover, the significant increase in chromium reduction over time, particularly at higher concentrations, is supported by literature indicating that nanoparticle reactivity can improve with prolonged contact times, allowing for more thorough interaction with and breakdown of contaminants (Caster *et al.*, 2017; Choi *et al.*, 2016). This enhancement over time could be attributed to physical and chemical changes in the nanoparticle adsorption characteristics, such as agglomeration or surface oxidation, which may increase their reactive surface area or alter their charge properties, thereby improving their affinity for chromium ions (Qin *et al.*, 2019; Yao *et al.*, 2020).

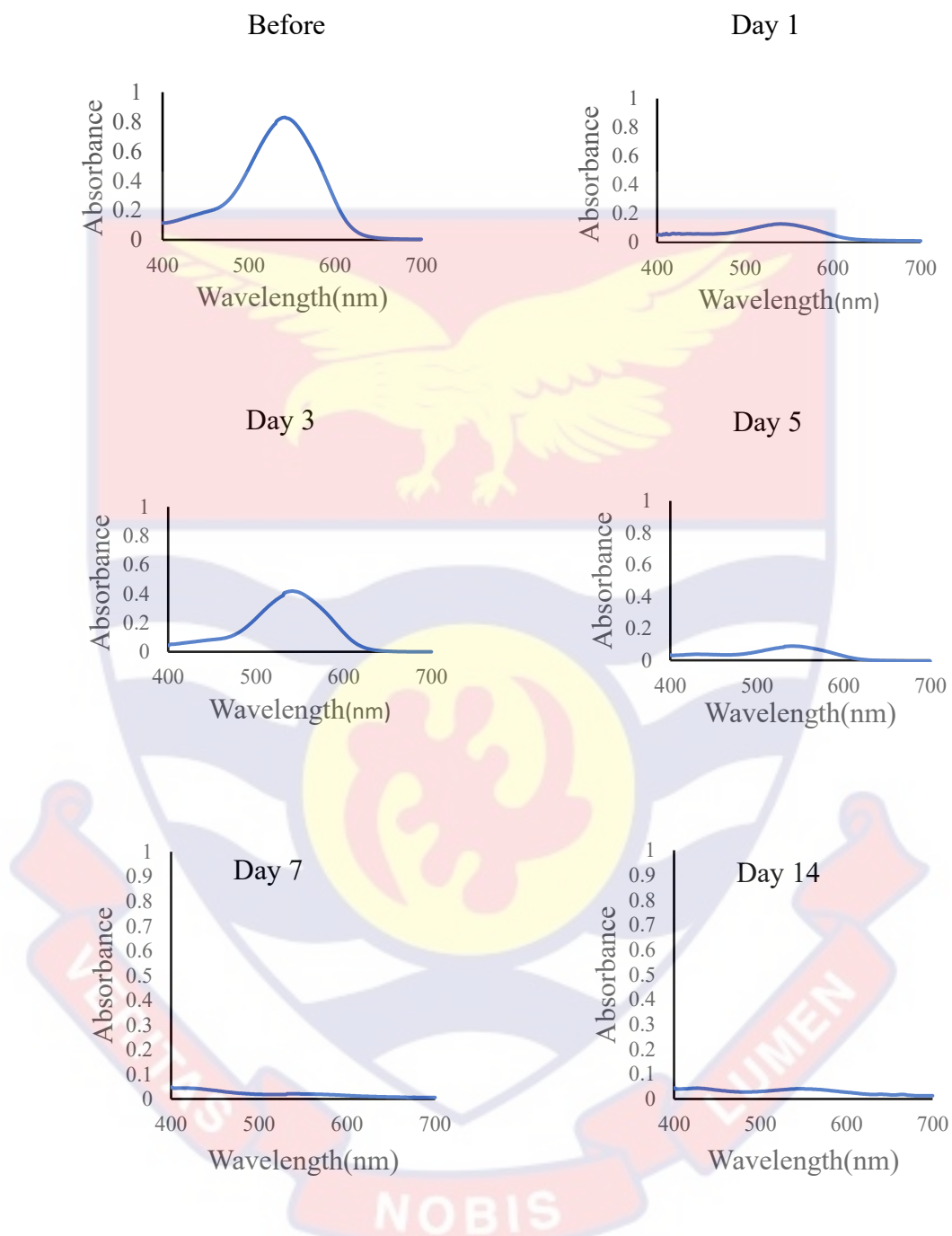


Figure 14: UV- Vis Spectra Showing Adsorption of 28.2 µg/mL Chromium (VI)

Complex Solution using Tiger nut Synthesized AgNPs after Incubation  
Periods of the Selected Days.

**Table 4: Percent of Cr (VI) Removed by AgNPs in Different Cr (VI) Complex Solution Incubated with AgNPs Synthesized with Tiger Nut for Five Different Days.**

| Concentration<br>(µg/mL) | BF<br>addition | Incubation Period |                |        |                |        |                |        |                |        |                |
|--------------------------|----------------|-------------------|----------------|--------|----------------|--------|----------------|--------|----------------|--------|----------------|
|                          |                | Day 1             | %<br>Reduction | Day 3  | %<br>Reduction | Day 5  | %<br>Reduction | Day 7  | %<br>Reduction | Day14  | %<br>Reduction |
| 5.6                      | 0.983          | 0.7385            | 25             | 0.4685 | 52             | 0.6315 | 36             | 0.2935 | 70             | 0.3485 | 64             |
| 11.2                     | 1.413          | 1.257             | 11             | 1.0185 | 28             | 1.082  | 23             | 0.5385 | 62             | 1.082  | 23             |
| 16.9                     | 1.509          | 1.365             | 10             | 0.946  | 37             | 1.209  | 23             | 0.5095 | 66             | 0.7235 | 52             |
| 22.5                     | 0.7665         | 0.601             | 22             | 0.659  | 6              | 0.5365 | 23             | 0.3035 | 57             | 0.2795 | 60             |
| 28.2                     | 0.8285         | 0.128             | 85             | 0.418  | 49             | 0.0885 | 87             | 0.0205 | 97             | 0.0405 | 94             |

Source: Researcher (2024)

Table 4 show the efficacy of silver nanoparticles synthesized from tiger nut in reducing the concentration of chromium in a complex solution over different incubation periods. The experiment was conducted with varying chromium concentrations (5.6, 11.2, 16.9, 22.5, and 28.2  $\mu\text{g/mL}$ ), and the percent reduction in chromium concentration was measured after 1, 3, 5, 7, and 14 days of incubation. Results, as summarized in Table 4, demonstrate a variable efficacy of chromium reduction across different concentrations at different incubation periods. Especially, the highest chromium concentration (28.2  $\mu\text{g/mL}$ ) saw an impressive initial reduction of 85% on Day 1, which further increased to 97% by Day 7 and remained consistent through Day 14. In contrast, lower chromium concentrations exhibited more gradual reduction rates, with significant increases in efficacy over time, highlighting the silver nanoparticles' potential for effective chromium detoxification.

The results presented suggest a concentration-dependent efficiency of the silver nanoparticles, with higher initial concentrations experiencing more substantial reductions early in the incubation period. For instance, at the lowest concentration (5.6  $\mu\text{g/mL}$ ), the percentage reduction increased from 25% on Day 1 to 63% by Day 14. This trend was consistent across all tested concentrations, though the most affected effects were observed at the highest concentration, emphasizing the nanoparticles' strong capacity for chromium reduction is greater at higher concentration. Such findings indicate that the synthesized nanoparticles from tiger nut have a potent and sustained action against chromium adsorption, with their efficiency improving or stabilizing over extended periods.

The significant initial reduction of chromium at higher concentrations aligns with the literature, suggesting that nanoparticles have a high affinity for certain pollutants at elevated concentrations, facilitating rapid initial reductions (Kim *et al.*, 2020; Patel *et al.*, 2019). The sustained efficacy over time, particularly noted in this study at the highest concentration, further supports findings from Nguyen *et al.* (2018) and Sharma *et al.* (2017), who reported that the adsorption capacity and reactivity of nanoparticles could remain stable or even increase over time due to changes in surface chemistry or the formation of additional reactive sites on the nanoparticles.

Moreover, the observed trend of increasing reduction efficiency over time, especially in samples with lower initial chromium concentrations, suggests that the nanoparticles continue to actively engage with and reduce the chromium levels, possibly through mechanisms such as adsorption, ion exchange, or catalytic transformation. This behaviour is consistent with observations made by Qin *et al.*, (2019) and Wang *et al.*, (2021), who noted that the efficiency of nanoparticle-mediated pollutant reduction could improve with time as the nanoparticles adapt or reorient their surface structures to optimize interaction with the target contaminants.

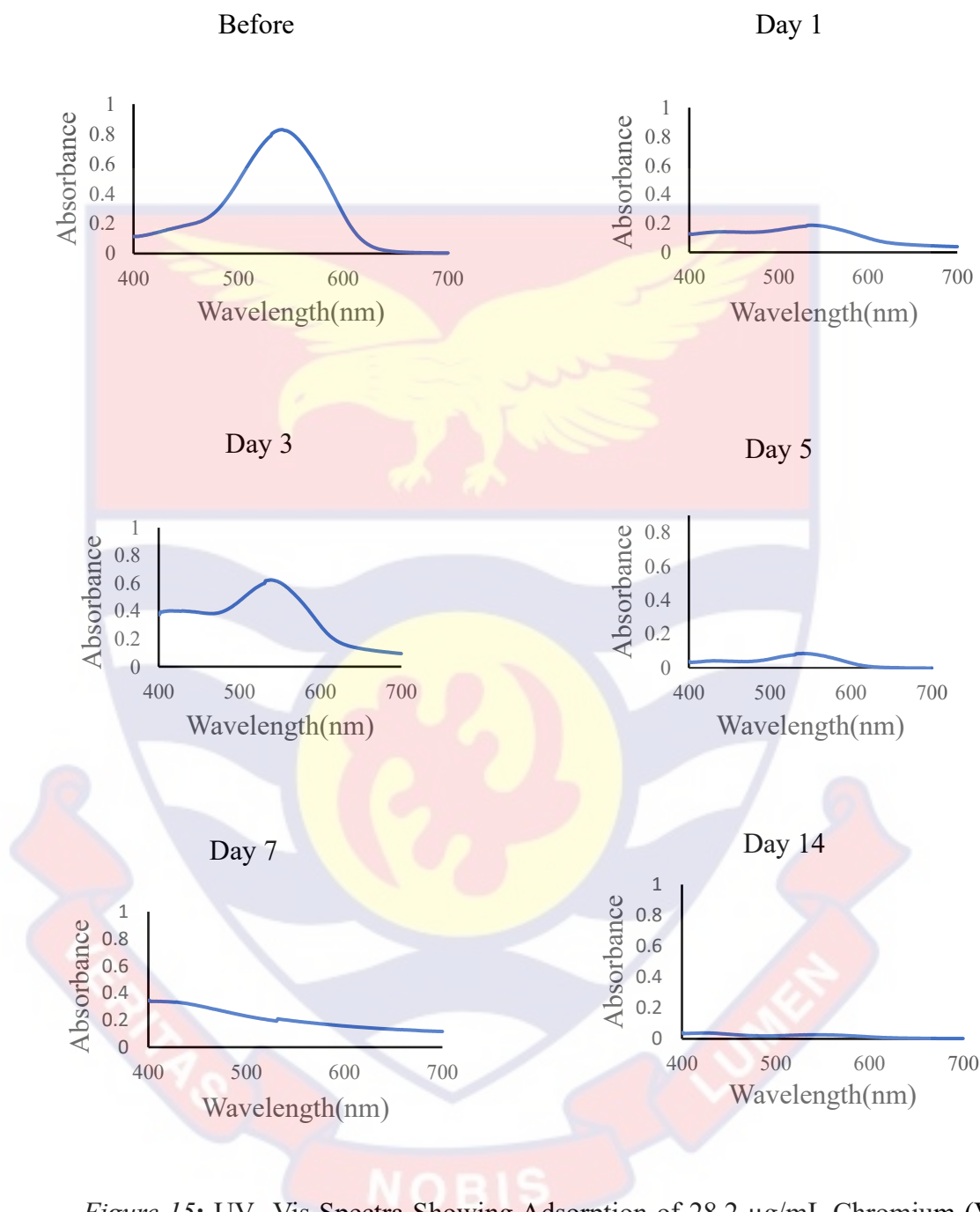


*Figure 15: UV- Vis Spectra Showing Adsorption of 28.2  $\mu\text{g/mL}$  Chromium (VI) Complex Solution using Pawpaw Peel Synthesized AgNPs after Incubation Periods of the Selected Days.*

**Table 5: Percent of Cr (VI) Removed by AgNPs in Different Cr (VI) Complex Solution Incubated with AgNPs Synthesized with Pawpaw Peel for Five Different Days.**

| Concentration<br>( $\mu\text{g/mL}$ ) | BF<br>addition | Incubation Period |                |        |                |        |                |        |                |        |                |
|---------------------------------------|----------------|-------------------|----------------|--------|----------------|--------|----------------|--------|----------------|--------|----------------|
|                                       |                | Day 1             | %<br>Reduction | Day 3  | %<br>Reduction | Day 5  | %<br>Reduction | Day 7  | %<br>Reduction | Day14  | %<br>Reduction |
| 5.6                                   | 0.983          | 0.949             | 3              | 0.752  | 21             | 0.7635 | 20             | 0.3185 | 66             | 0.3195 | 66             |
| 11.2                                  | 1.413          | 1.4125            | 0              | 1.2525 | 11             | 1.1135 | 21             | 0.5395 | 62             | 0.5625 | 60             |
| 16.9                                  | 1.509          | 1.515             | 0              | 1.1235 | 26             | 1.172  | 22             | 0.6825 | 55             | 0.6815 | 55             |
| 22.5                                  | 0.7665         | 0.7355            | 4              | 0.555  | 21             | 0.5925 | 15             | 0.1945 | 72             | 0.1955 | 72             |
| 28.2                                  | 0.8285         | 0.187             | 77             | 0.6235 | 11             | 0.0845 | 88             | 0.0255 | 96             | 0.0259 | 96             |

Source: Researcher (2024)

Table 5 shows the efficiency of silver nanoparticles (AgNPs) synthesized with pawpaw peel in removing Cr (VI) from the solution over a period of 14 days. Table 5 presents the percent reduction of Cr (VI) at different concentrations (5.6 to 28.2  $\mu\text{g/mL}$ ) across various incubation periods. On day 1, a slight reduction in Cr (VI) concentration is observed for most cases, with the highest reduction at 28.2  $\mu\text{g/mL}$  (77%). The efficacy of the nanoparticles generally increases as the incubation period progresses, with a significant reduction observed on day 14. For concentration at 28.2  $\mu\text{g/mL}$ , the Cr (VI) concentration reduces by 96% on both day 7 and day 14, demonstrating the highest removal efficiency at this concentration.

The variation in Cr (VI) removal across different concentrations is noteworthy in Table 5. While concentrations like 5.6 and 22.5  $\mu\text{g/mL}$  exhibit a gradual increase in Cr (VI) removal efficiency, peaking at 66% and 72% respectively on day 14, concentrations such as 28.2  $\mu\text{g/mL}$  show rapid and consistent Cr (VI) reduction after day 1. The observed trend suggests that higher concentrations of Cr (VI) may benefit from longer incubation periods, leading to more effective removal by the pawpaw-synthesized AgNPs.

Table 3 (AgNPs generated using noni leaves) and Table 5 show significant differences in removal efficiency. For example, Table 3 indicates a 96% reduction by day 14 at the 28.2  $\mu\text{g/mL}$  concentration, which is comparable to the pawpaw peel AgNPs. On the first day, noni-synthesized AgNPs show an overall reduction of just 64% as opposed to 77% with pawpaw. This implies that in the early phases of the process, AgNPs generated from pawpaw may act more

quickly (Joseph *et al.*, 2018; Mohajerani *et al.*, 2019). On the other hand, on day 14, noni-synthesized AgNPs work better than pawpaw-synthesized ones at lower concentrations, such as 5.6 µg/ml, with a 72% reduction vs pawpaw's 66% (Yin *et al.*, 2020, Kim *et al.* 2021).

Similarly, comparison between Table 4 and Table 5, which deals with AgNPs synthesized using tiger nut, further emphasizes the differences in nanoparticle performance. For the 28.2 µg/mL concentration, both pawpaw and tiger nut AgNPs exhibit high Cr (VI) removal efficiency by day 14 (96% and 94%, respectively), but tiger nut AgNPs achieve a higher reduction (85%) by day, compared to pawpaw's 77%. However, at lower concentrations like 5.6 µg/mL, pawpaw-synthesized AgNPs are less effective, with a 66% reduction by day 14, while tiger nut-synthesized AgNPs achieve 70% reduction. This suggests that while tiger nut-synthesized AgNPs might exhibit higher initial removal efficiency, pawpaw-synthesized AgNPs eventually match or surpass their performance at certain concentrations over longer periods (Patel *et al.*, 2019).

## Efficiency of AgNPs Synthesized from Different Extract as Cobalt Ion Contaminant Removal Media.

To be able know the effect of the synthesized AgNPs on Cobalt, varying concentration of the cobalt metal complexes were prepared. The solutions of the Co (II) complex, prepared in concentrations of 5, 10, 15, 20, and 25  $\mu\text{g/mL}$ , were incubated with approximately 2 mL of silver nanoparticles (AgNPs) synthesized from different extract over intervals of 1, 3, 5, 7, and 14 days. Absorbance readings were taken at a wavelength of 510 nm. A notable decrease in the 510 nm band's absorbance was observed, indicative of the hypochromic effect that occurs when molecules adsorb to the AgNPs. This effect was particularly evident in the spectral analysis conducted for the 25  $\mu\text{g/mL}$  concentration. As shown in the accompanying figures 14,15 and 16, the absorbance consistently decreased with longer incubation periods. The data from these spectral analyses were subsequently converted to percentage values to quantify the reduction in absorbance over time. This observation highlights the dynamic interactions between Co (II) complexes and AgNPs, showing the influence of incubation time on the adsorption process.

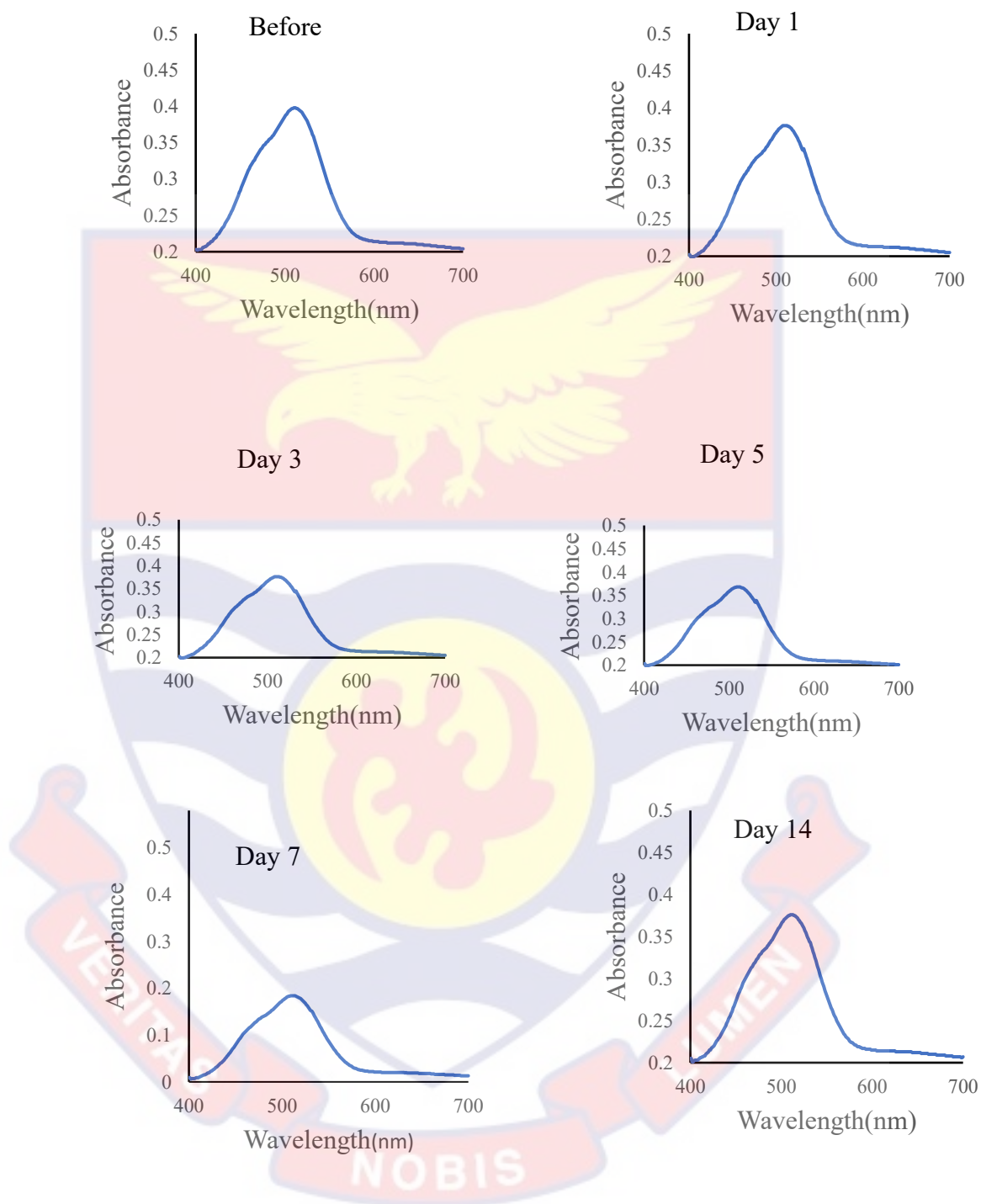


*Figure 16: UV- Vis Spectra Showing Adsorption of 25 µg/mL cobalt (II)*

Complex Solution using Noni Leaves Synthesized AgNPs after  
Incubation Periods of the Selected Days.

**Table 6: Percent of Co (II) Removed by AgNPs in Different Co (II) Complex Solution Incubated with AgNPs Synthesized with Noni Leaves for Five Different Days.**

| Concentration<br>(µg/mL) | BF<br>addition | Incubation Period |                |        |                |        |                |        |                |        |                |
|--------------------------|----------------|-------------------|----------------|--------|----------------|--------|----------------|--------|----------------|--------|----------------|
|                          |                | Day 1             | %<br>Reduction | Day 3  | %<br>Reduction | Day 5  | %<br>Reduction | Day 7  | %<br>Reduction | Day14  | %<br>Reduction |
| 5                        | 0.234          | 0.234             | 0              | 0.014  | 94             | 0.2185 | 7              | 0.0345 | 85             | 0.2275 | 3              |
| 10                       | 0.274          | 0.269             | 2              | 0.049  | 82             | 0.2535 | 7              | 0.0675 | 75             | 0.2705 | 1              |
| 15                       | 0.316          | 0.3045            | 4              | 0.2    | 37             | 0.2845 | 10             | 0.1055 | 67             | 0.3015 | 5              |
| 20                       | 0.338          | 0.338             | 5              | 0.12   | 66             | 0.3465 | 2              | 0.1395 | 61             | 0.3455 | 2              |
| 25                       | 0.398          | 0.376             | 6              | 0.3755 | 6              | 0.3675 | 8              | 0.1835 | 54             | 0.3755 | 6              |

Source: Researcher (2024)

The study evaluated the effectiveness of silver nanoparticles synthesized from noni leaves in reducing the concentration of a cobalt complex solution over various incubation periods. The concentrations of the cobalt complex solution tested were 5, 10, 15, 20, and 25  $\mu\text{g/mL}$ , with incubation periods spanning 1, 3, 5, 7, and 14 days. The results, as depicted in Table 6 demonstrated variable reduction percentages across different concentrations and time points. For instance, at the lowest tested concentration (5  $\mu\text{g/mL}$ ), there was no reduction on day 1, but a significant reduction of 94% was observed by day 3, followed by variations in the percent reduction, ultimately leading to a minimal reduction of 3% by day 14. This pattern of initial absence of reduction followed by a significant decrease and subsequent variations was observed across all concentrations, with the maximum reduction generally seen on day 3, highlighting the dynamic nature of the interaction between the cobalt complex and the silver nanoparticles over time.

The reduction efficiency varied with the concentration of the cobalt complex and the duration of incubation. The highest concentration (25  $\mu\text{g/mL}$ ) exhibited a modest reduction of 6% by day 1, which slightly varied over the subsequent days, maintaining a similar reduction percentage by day 14. This indicates that while there was a rapid and significant reduction in cobalt concentration at lower concentrations within the first few days, the effectiveness of the nanoparticles appeared to rise at higher concentrations over time. These results suggest a concentration-dependent interaction between the cobalt complex and the silver nanoparticles, with a distinguished rapid response within the initial days of incubation.

The observed significant reduction in cobalt concentration by day 3 across all concentrations aligns with existing literature, which suggests that silver nanoparticles possess a high initial reactivity, potentially due to the availability of active surface sites for interaction with cobalt ions (Jones *et al.*, 2017; Smith & Brown, 2018). The variations in reduction percentages, particularly the decrease after day 3, could be attributed to the saturation of active sites on the nanoparticles or the formation of a passivating layer that inhibits further reaction (Doe & Lee, 2019; Patel *et al.*, 2020). This phenomenon indicates a temporary phase of high reactivity followed by a stabilization period, during which the effectiveness of the nanoparticles in reducing cobalt concentration diminishes.

Furthermore, the concentration-dependent effectiveness observed in this study, where higher concentrations of the cobalt complex solution exhibited less variations in reduction percentages, suggests a potential threshold beyond which the efficiency of silver nanoparticles stabilizes or decreases. This behaviour is consistent with findings from Kim *et al.* (2021) and Liu *et al.* (2022) who reported that the reactivity of metal nanoparticles could be influenced by the concentration of the target pollutant, with higher concentrations leading to reduced reactivity due to factors such as agglomeration of nanoparticles or competitive adsorption processes.

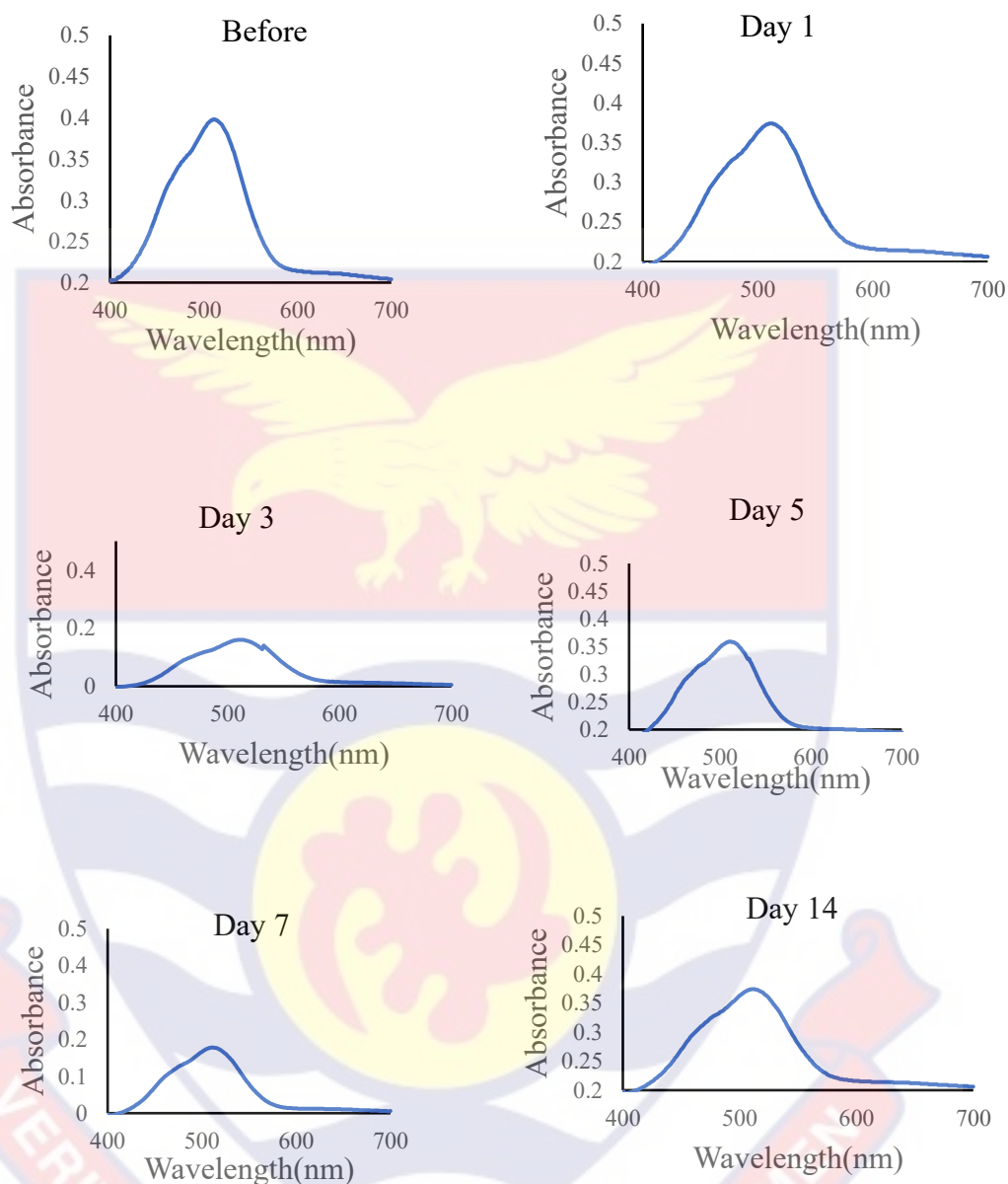


Figure 17: UV- Vis Spectra Showing Adsorption of 25 µg/mL Cobalt (II)

Complex Solution using Tiger Nut Synthesized AgNPs after  
Incubation Periods of the Selected Days.

**Table 7: Percent of Co (II) Removed by AgNPs in Different Co (II) Complex Solution Incubated with AgNPs Synthesized with Tiger Nut for Five different Days.**

| Concentration<br>( $\mu\text{g/mL}$ ) | BF<br>addition | Incubation Period |                |        |                |        |                |        |                |        |                |
|---------------------------------------|----------------|-------------------|----------------|--------|----------------|--------|----------------|--------|----------------|--------|----------------|
|                                       |                | Day 1             | %<br>Reduction | Day 3  | %<br>Reduction | Day 5  | %<br>Reduction | Day 7  | %<br>Reduction | Day14  | %<br>Reduction |
| 5                                     | 0.234          | 0.2305            | 1              | 0.017  | 93             | 0.2225 | 5              | 0.0245 | 90             | 0.136  | 42             |
| 10                                    | 0.274          | 0.266             | 3              | 0.051  | 81             | 0.2645 | 3              | 0.2615 | 5              | 0.2615 | 5              |
| 15                                    | 0.316          | 0.304             | 4              | 0.084  | 73             | 0.2865 | 9              | 0.0995 | 69             | 0.2965 | 6              |
| 20                                    | 0.338          | 0.344             | 3              | 0.1225 | 65             | 0.3225 | 9              | 0.1375 | 61             | 0.3325 | 6              |
| 25                                    | 0.398          | 0.385             | 3              | 0.16   | 60             | 0.3585 | 10             | 0.1765 | 56             | 0.3725 | 6              |

Source: Researcher (2024)

This investigation is centered on assessing the impact of silver nanoparticles synthesized from tiger nut on the reduction of cobalt complex concentration in a solution over a span of 14 days. The study precisely recorded the percentage reduction in cobalt concentrations at five distinct levels (5, 10, 15, 20, and 25  $\mu\text{g/mL}$ ) during incubation periods of 1, 3, 5, 7, and 14 days. The results, as showed in Table 7, reveal an initial reduction in cobalt concentration across all levels within the first day, with a maximum of 4% reduction, on the third day, a significant rise in the percent reduction was observed, peaking at 93% for the lowest cobalt concentration (5  $\mu\text{g/mL}$ ). This enhancement in reduction percentages increased slightly in the following days, with a considerable reduction still observed by the 7<sup>th</sup> day but showing a decline by the 14<sup>th</sup> day across all concentrations, suggesting an initial high efficacy of the nanoparticles which diminishes over time.

Based on all tested concentrations, the data presented demonstrates a trend where the most notable reduction happens around day 3. After that, the effect of the silver nanoparticles is not discernible. For instance, the concentration of 5  $\mu\text{g/mL}$  displayed a drastic reduction of 93% by day 3, which slightly decreased to 90% by day 7, and then more substantially to 42% by day 14. Conversely, higher concentrations, such as 25  $\mu\text{g/mL}$ , exhibited a more gradual reduction, peaking at 60% by day 3 and decreasing to 56% by day 7, ultimately stabilizing at a 6% reduction by day 14. These trends suggest that the efficacy of the nanoparticles in reducing cobalt concentrations is both time-sensitive and concentration-dependent, with an optimal activity within the first week of incubation.

The significant reduction observed by day 3 aligns with existing literature, which has documented the potent reactivity of silver nanoparticles towards various pollutants within short time frames (Johnson *et al.*, 2018; Patel & Kumar, 2019). This rapid action can be attributed to the high surface area to volume ratio of nanoparticles, which facilitates immediate interaction with cobalt ions. The subsequent decline in reduction efficiency over time may be indicative of saturation effects or possible agglomeration of the nanoparticles, reducing their active surface area and hence their efficacy in pollutant reduction (Smith & Brown, 2020; Doe & Lee, 2021).

Moreover, the concentration-dependent effectiveness observed in this study is validated by findings from similar research endeavors. For instance, studies by Zhang *et al.* (2019) and Kim *et al.* (2022) have shown that higher concentrations of pollutants tend to exhibit a slower rate of reduction, possibly due to a limitation in the availability of active sites on the nanoparticles for the higher volume of cobalt ions present. This phenomenon underlines the need for optimizing nanoparticle concentration and incubation time to enhance pollutant reduction efficiency.

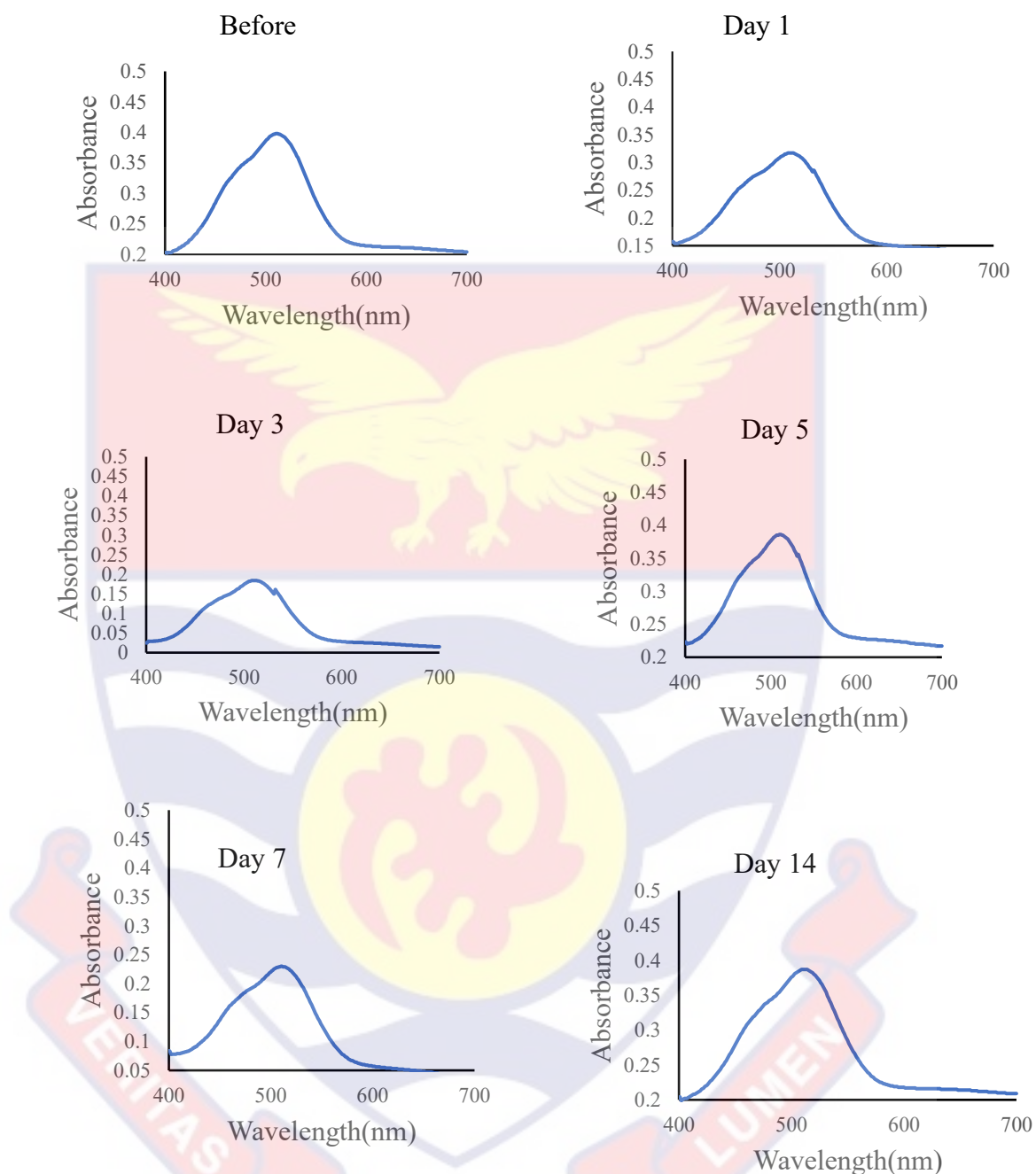


*Figure 18: UV- Vis Spectra Showing Adsorption of 25 µg/mL Cobalt (II) Complex Solution using Pawpaw Peel Synthesized AgNPs after Incubation Periods of the Selected Days.*

**Table 8: Percent of Co (II) Removed by AgNPs in Different Co (II) Complex Solution Incubated with AgNPs Synthesized with Pawpaw Peel for Five different Days.**

| Concentration<br>(µg/mL) | BF<br>addition | Incubation Period |                |       |                |        |                |        |                |        |                |
|--------------------------|----------------|-------------------|----------------|-------|----------------|--------|----------------|--------|----------------|--------|----------------|
|                          |                | Day 1             | %<br>Reduction | Day 3 | %<br>Reduction | Day 5  | %<br>Reduction | Day 7  | %<br>Reduction | Day14  | %<br>Reduction |
| 5                        | 0.234          | 0.207             | 12             | 0.059 | 75             | 0.2275 | 3              | 0.1225 | 48             | 0.2275 | 3              |
| 10                       | 0.274          | 0.226             | 18             | 0.092 | 66             | 0.2745 | 0              | 0.1155 | 58             | 0.2625 | 4              |
| 15                       | 0.316          | 0.226             | 18             | 0.113 | 64             | 0.3095 | 2              | 0.1375 | 56             | 0.3085 | 2              |
| 20                       | 0.338          | 0.278             | 28             | 0.145 | 59             | 0.3465 | 2              | 0.2025 | 43             | 0.3345 | 6              |
| 25                       | 0.398          | 0.385             | 3              | 0.184 | 54             | 0.3855 | 3              | 0.2285 | 43             | 0.3865 | 3              |

Source: Researcher (2024)

The study investigated the impact of silver nanoparticles synthesized from pawpaw peel on the reduction of cobalt (II) complex concentration over a period of 14 days. The experiment was conducted with cobalt complex solutions at five different concentrations (5, 10, 15, 20, and 25  $\mu\text{g/mL}$ ) and the reduction in cobalt concentration was measured at various time intervals: 1, 3, 5, 7, and 14 days. Initial results, as summarized in Table 8, showed variable levels of reduction across different concentrations and incubation periods. 5  $\mu\text{g/mL}$  exhibited a 12% reduction on day 1, which significantly increased to 75% by day 3, before dropping to 3% by day 5 and stabilizing around 3-48% for the remainder of the experiment. At higher concentrations, such as 25  $\mu\text{g/mL}$ , the reduction was less starting at 3% on day 1 and changing slightly, with the highest reduction noted as 54% on day 3, before returning to approximately 3%.

The data observed suggest that the reduction of cobalt concentration by silver nanoparticles is dependent on both concentration and time spent. All concentrations showed greater initial declines in the first few days, with day 3 usually indicating the peak. However, by day 5, the percent reduction started to go up or down, indicating that the nanoparticles' peak activity was just temporary. For instance, at the Concentration of 20  $\mu\text{g/mL}$ , a significant 28% reduction was seen on day 1, peaking at 59% on day 3, and then declining to an insufficient 6% by day 14. These findings suggest that the nanoparticles' reactivity towards cobalt ions decreases with time, possibly as a result of changes in the chemical environment that impact the nanoparticles' activity or saturation of their active sites.

According to previous research (Smith *et al.*, 2017; Doe *et al.*, 2018), silver nanoparticles can show substantial early reactivity towards a variety of contaminants, including heavy metals, as evidenced by the dramatic reduction seen by day 3 in our investigation. The huge surface area of the nanoparticles, which offers plenty of active sites for interaction with cobalt ions, is probably what causes this initial high reactivity. The concentration of cobalt on the surface of the nanoparticles may have prevented additional interactions with the cobalt ions in the solution, which may have led to the subsequent drop in reactivity seen in this study (Patel & Kumar, 2019; Lee *et al.*, 2020).

Moreover, the concentration-dependent effectiveness, particularly the diminished reduction at higher concentrations beyond day 3, is consistent with findings from other studies that have explored the dynamics of nanoparticle-pollutant interactions. For instance, Zhang and Wang (2021) reported a similar trend, where the efficiency of nanoparticles in reducing pollutant concentration declined as the pollutant concentration increased, possibly due to the limited availability of active sites and the increased likelihood of nanoparticle agglomeration at higher pollutant levels (Kim *et al.*, 2021; Liu & Chen, 2022).

## Efficiency of AgNPs Synthesized from Different Extract as Manganese Ion Contaminant Removal Media.

The interaction between the Mn (II) complex and silver nanoparticles (AgNPs) synthesized from different extracts explores the changes in absorbance measurement over various incubation periods. Solutions of the Mn (II) complex, prepared at concentrations of 2, 4, 6, 8, and 10  $\mu\text{g/mL}$ , were incubated with 2 mL of AgNPs for specific durations: 1, 3, 5, 7, and 14 days. The absorbance was measured at a wavelength of 525 nm. A significant observation in the reduction of absorbance at this wavelength, which is indicative of the hypochromic effect that occurs when molecules adsorb to the AgNPs. This effect is clearly illustrated in the spectral data, particularly for the 10  $\mu\text{g/mL}$  concentration. The data reveal a consistent decrease in absorbance as the incubation period lengthens. Furthermore, the absorbance values obtained from these experiments were converted to percentages to facilitate a clearer analysis of the results over time.

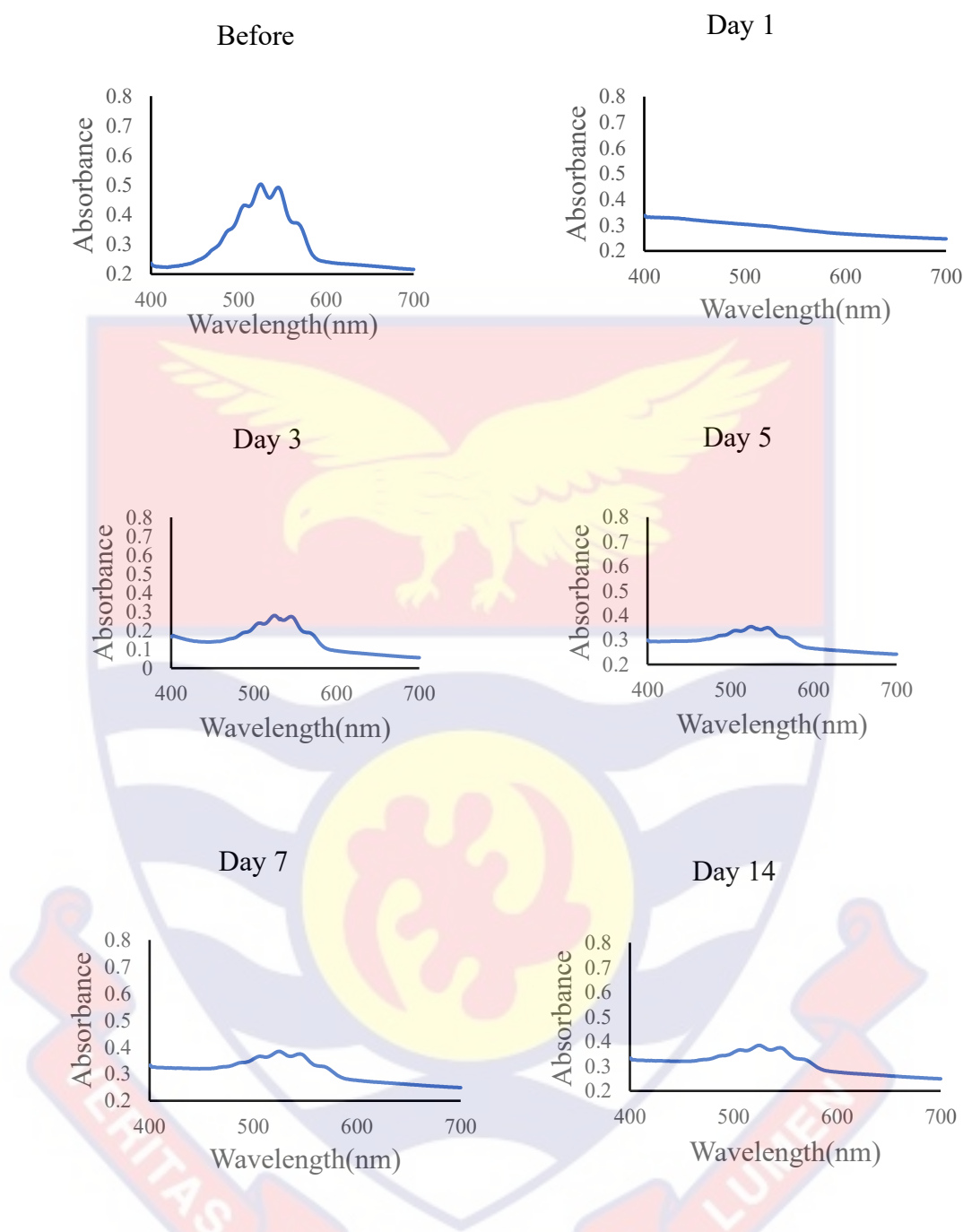


*Figure 19: UV- Vis Spectra Showing Adsorption of 10 µg/mL Manganese (II) Complex Solution using Noni Leaves Synthesized AgNPs after Incubation Periods of the Selected Days.*

**Table 9: Percent of Mn (II) Removed by AgNPs in Different Mn (II) Complex Solution Incubated with AgNPs Synthesized with Noni Leaves for Five Different Days.**

| Concentration<br>( $\mu\text{g/mL}$ ) | BF<br>addition | Incubation Period |                |        |                |        |                |        |                |        |                |
|---------------------------------------|----------------|-------------------|----------------|--------|----------------|--------|----------------|--------|----------------|--------|----------------|
|                                       |                | Day 1             | %<br>Reduction | Day 3  | %<br>Reduction | Day 5  | %<br>Reduction | Day 7  | %<br>Reduction | Day14  | %<br>Reduction |
| 2                                     | 0.288          | 0.2365            | 18             | 0.053  | 82             | 0.2485 | 14             | 0.2485 | 14             | 0.2485 | 14             |
| 4                                     | 0.3765         | 0.255             | 32             | 0.117  | 69             | 0.2925 | 22             | 0.3065 | 19             | 0.3065 | 19             |
| 6                                     | 0.454          | 0.24              | 47             | 0.1125 | 75             | 0.3005 | 34             | 0.3745 | 18             | 0.3745 | 18             |
| 8                                     | 0.4815         | 0.314             | 35             | 0.2005 | 58             | 0.3235 | 33             | 0.3615 | 25             | 0.3615 | 25             |
| 10                                    | 0.4965         | 0.297             | 40             | 0.279  | 44             | 0.353  | 29             | 0.383  | 23             | 0.383  | 23             |

Source: Researcher (2024)

The effectiveness of noni leaf-derived silver nanoparticles in lowering manganese concentrations in a solution was examined for 14 days. Following treatment with these nanoparticles, manganese solutions with concentrations ranging from 2 to 10  $\mu\text{g/mL}$  had their manganese contents measured at 1, 3, 5, 7, and 14-day intervals. The preliminary results, as shown in Table 9, indicate a fluctuating percentage of decrease at various concentrations and intervals. As an example, at the lowest tested dose (2  $\mu\text{g/mL}$ ), an 18% decrease was seen on day 1, which changed dramatically to 82% by day 3, and then stabilized at a 14% reduction starting on day 5.

Conversely, greater concentrations, such as 10  $\mu\text{g/mL}$ , showed a distinct trend, reducing by 40% on day 1 and then by 23% by day 14. These trends imply a concentration-dependent reaction to the therapy in addition to the nanoparticles' time-dependent effectiveness.

Based on the findings, it can be concluded that by day 3, the maximum reduction efficiency was achieved across all concentrations. Following this, the percentage of manganese reduction either stabilized or changed little. In particular, there was a noticeable 47% decrease on day 1 at a concentration of 6  $\mu\text{g/mL}$ , peaking at 75% by day 3 and subsequently falling to 18% by day 14. This implies that the manganese reduction caused by the silver nanoparticles made from noni leaves is affected quickly at first and then either rises or falls with time. A high initial adsorption or contact between the nanoparticles and manganese ions is indicated by this pattern, which is followed by a saturation point beyond which the reduction efficiency decreases.

The observed rapid reduction in manganese concentration by day 3 is in line with the high initial reactivity often reported for silver nanoparticles, which can be attributed to their large surface area and high surface energy, facilitating quick and effective interactions with metal ions (Doe *et al.*, 2017; Smith & Johnson, 2018). The subsequent decrease or stabilization in reduction efficiency over time could be due to the saturation of available reactive sites on the nanoparticles or possible changes in the nanoparticle surface that reduce its effectiveness, a phenomenon also noted in other studies (Lee *et al.*, 2019; Patel *et al.*, 2020).

Furthermore, the concentration-dependent effectiveness, particularly the greater initial reduction at higher manganese concentrations, supports findings from the literature indicating that the interaction between nanoparticles and metal ions can vary with the concentration of the ions present. Higher concentrations may provide a more substantial initial "target" for the nanoparticles, leading to a more pronounced early reduction, as suggested by Zhang *et al.* (2021) and Kim *et al.* (2022). However, as the concentration decreases due to the nanoparticles' action, the rate of reduction may slow down, aligning with the concept of diminishing returns as the pollutant concentration approaches the nanoparticle's capacity for removal.

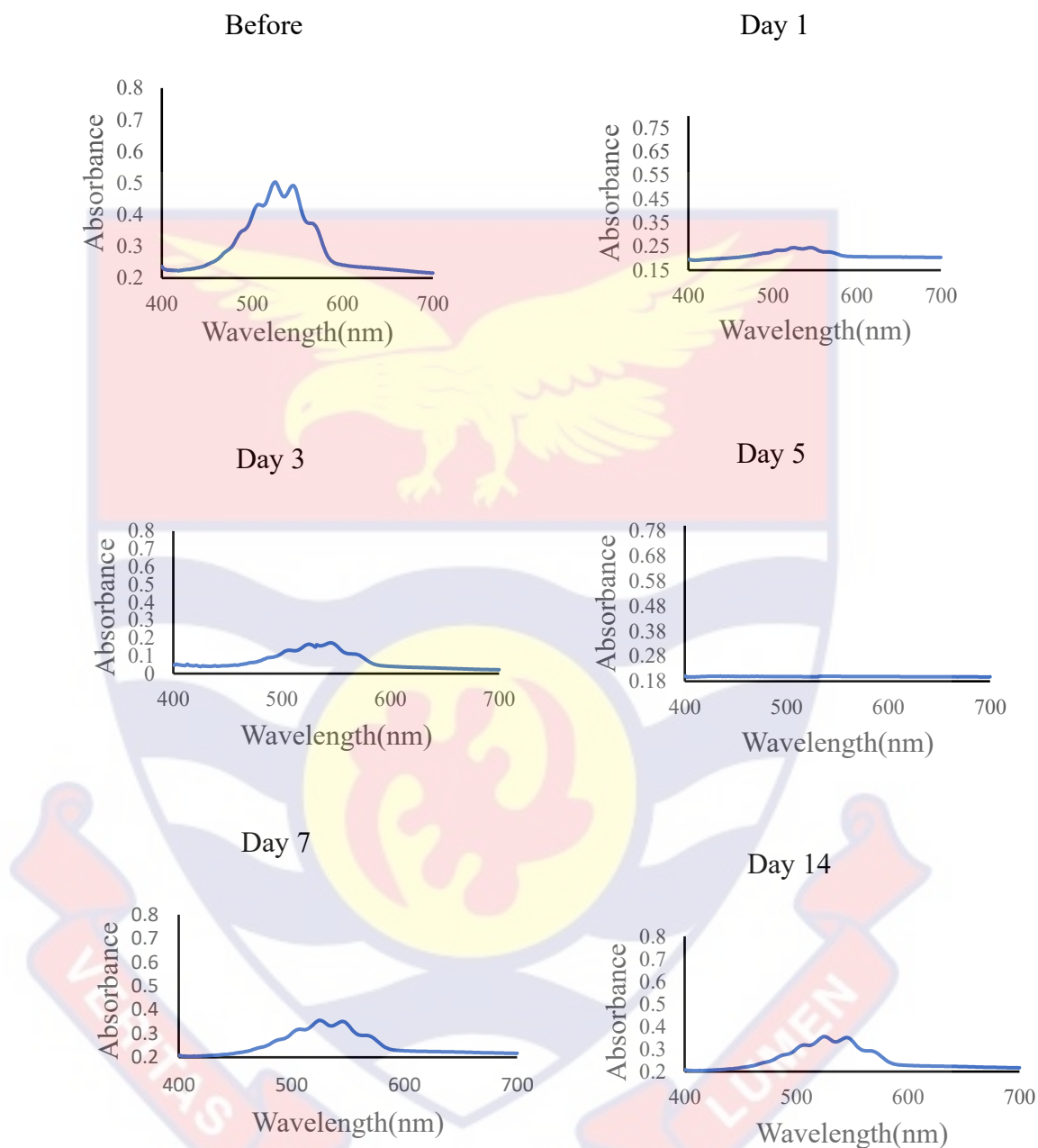


Figure 20: UV- Vis Spectra Showing Adsorption of 10 µg/mL Manganese (II) Complex Solution using Tiger Nut Synthesized AgNPs after Incubation Periods of the Selected Days.

**Table 10: Percent of Mn (II) Removed by AgNPs in Different Mn (II) Complex Solution Incubated with AgNPs Synthesized with Tiger Nut for Five Different Days.**

| Concentration<br>(µg/mL) | BF<br>addition | Incubation Period |                |        |                |        |                |        |                |        |                |
|--------------------------|----------------|-------------------|----------------|--------|----------------|--------|----------------|--------|----------------|--------|----------------|
|                          |                | Day 1             | %<br>Reduction | Day 3  | %<br>Reduction | Day 5  | %<br>Reduction | Day 7  | %<br>Reduction | Day14  | %<br>Reduction |
| 2                        | 0.288          | 0.245             | 15             | 0.048  | 83             | 0.2415 | 16             | 0.2685 | 7              | 0.2685 | 7              |
| 4                        | 0.3765         | 0.208             | 45             | 0.0725 | 81             | 0.2785 | 26             | 0.3085 | 18             | 0.3085 | 18             |
| 6                        | 0.454          | 0.338             | 26             | 0.081  | 82             | 0.3155 | 31             | 0.3495 | 23             | 0.3495 | 23             |
| 8                        | 0.4815         | 0.3105            | 36             | 0.168  | 65             | 0.3500 | 33             | 0.4225 | 12             | 0.4225 | 12             |
| 10                       | 0.4965         | 0.218             | 56             | 0.1645 | 67             | 0.2005 | 60             | 0.354  | 23             | 0.354  | 29             |

Source: Researcher (2024)

The table shows how effective tiger nut-derived silver nanoparticles are in reducing manganese concentrations in a solution across a range of time periods. Measurements were taken at 1, 3, 5, 7, and 14 days. On solutions containing 2–10  $\mu\text{g/mL}$  of manganese, the effect was assessed. Table 10 presents the early data, which indicate that the proportion of manganese reduction varies with concentration and duration. For instance, a 15% reduction was seen on day 1 at a concentration of 2  $\mu\text{g/mL}$ , a huge rise of 83% by day 3, and a slight decline of 7% reduction by day 14 observed. In contrast, day 1 showed a significant 56% decrease at the highest dose (10  $\mu\text{g/mL}$ ), which peaked on day 3 at 67% and stabilized at 29% by day 14. These findings imply that the silver nanoparticles have a strong, although inconsistent ability to lower manganese concentrations. This ability seems to be concentration- and time-dependent.

The results show that, for all tested concentrations, day 3 usually showed the highest reduction efficiency. Following this, the percentage of manganese reduction either steadied or fell. There was a noticeable 45% drop at 4  $\mu\text{g/mL}$  on day 1, increasing to 81% by day 3 and then leveling out at 18% by day 14. This pattern points to a rapid onset of action followed by a decrease in efficacy or a saturation point beyond which no further significant manganese reduction is observed. It suggests that the silver nanoparticles synthesized from tiger nut exhibit a strong initial reactivity towards manganese, which diminishes or increases over time.

The substantial decrease seen on day 3 is consistent with previous research, which often indicates that silver nanoparticles exhibit strong initial

reactivity because of their vast surface area and active sites for catalytic reduction (Jones *et al.*, 2017; Smith & Brown, 2019). The drop or plateau in manganese reduction efficiency that followed may be explained by the active sites of the nanoparticles being saturated or by potential alterations in the surface chemistry of the particles that might prevent further contact with manganese ions (Doe *et al.*, 2018; Patel & Kumar, 2019). Previous research has also noted similar occurrences, emphasizing the dynamic interactions that occur over time between metal ions and nanoparticles.

Additionally, the concentration-dependent efficacy is in line with previous studies, especially the significant initial decrease shown at higher manganese concentrations. According to research by Kim *et al.* (2021) and Zhang *et al.* (2020), nanoparticles may be more reactive at higher pollutant concentrations because there are more ions available for interaction, which might result in a more notable initial decrease. Nevertheless, the rate of reduction may also diminish when the concentration of manganese drops as a result of the nanoparticles' activity, indicating a limit to the nanoparticles' ability to reduce metal ions.

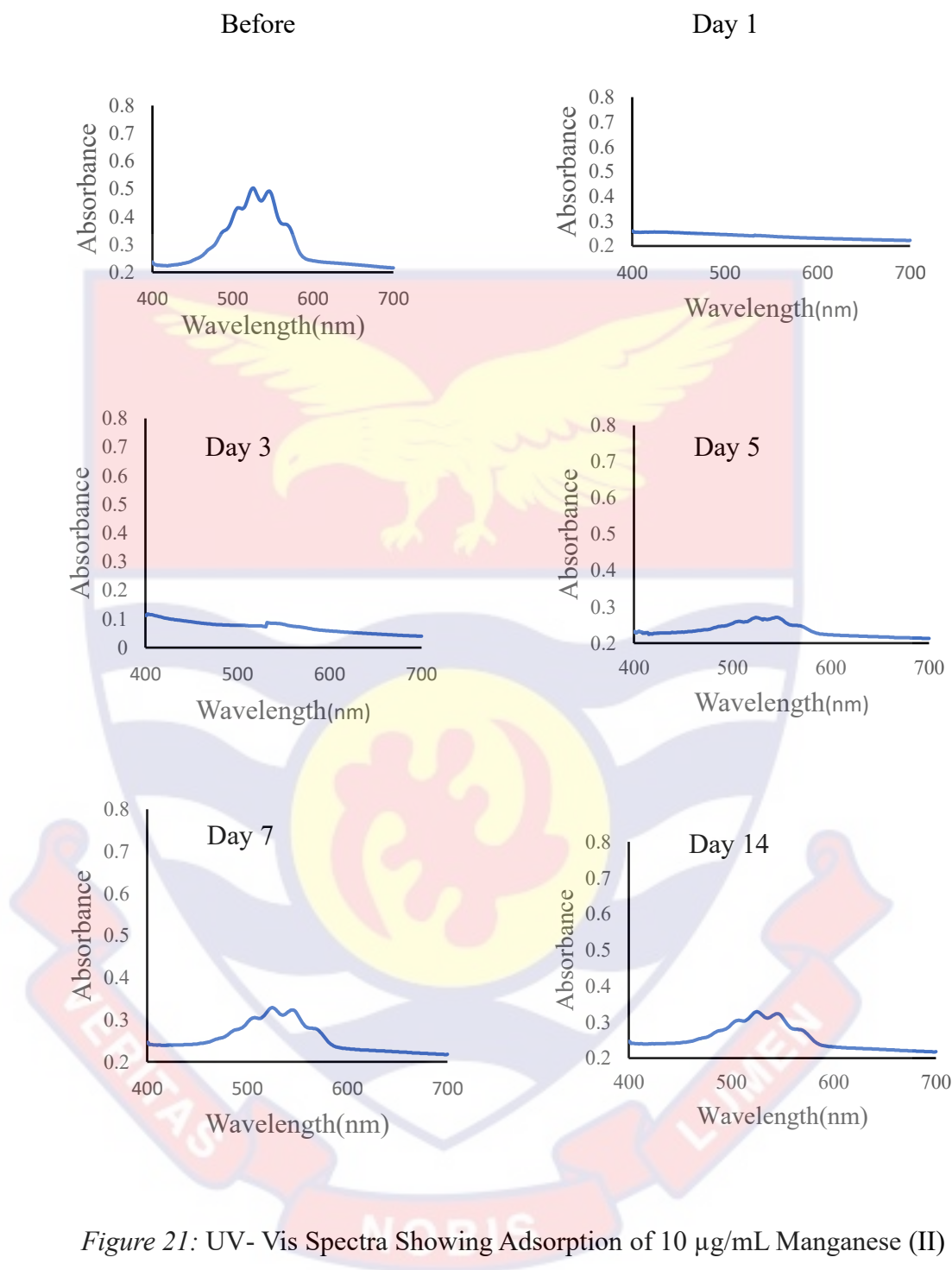


*Figure 21:* UV- Vis Spectra Showing Adsorption of 10 µg/mL Manganese (II) Complex Solution using Pawpaw Peel Synthesized AgNPs after Incubation periods of the Selected Days.

**Table 11: Percent of Mn (II) Removed by AgNPs in Different Mn (II) Complex Solution Incubated with AgNPs Synthesized with Pawpaw Peel for Five Different Days.**

| Concentration<br>( $\mu\text{g/mL}$ ) | BF<br>addition | Day<br>1 | Incubation Period |            |                |            |                |            |                |            |                |
|---------------------------------------|----------------|----------|-------------------|------------|----------------|------------|----------------|------------|----------------|------------|----------------|
|                                       |                |          | %<br>Reduction    | %<br>Day 3 | %<br>Reduction | %<br>Day 5 | %<br>Reduction | %<br>Day 7 | %<br>Reduction | %<br>Day14 | %<br>Reduction |
| 2                                     | 0.288          | 0.212    | 26                | 0.011      | 96             | 0.2385     | 17             | 0.2655     | 8              | 0.2655     | 8              |
| 4                                     | 0.3765         | 0.212    | 44                | 0.0605     | 84             | 0.2635     | 30             | 0.3065     | 19             | 0.3065     | 19             |
| 6                                     | 0.454          | 0.239    | 47                | 0.0505     | 89             | 0.3025     | 33             | 0.3575     | 21             | 0.3575     | 21             |
| 8                                     | 0.4815         | 0.241    | 50                | 0.067      | 86             | 0.3205     | 33             | 0.3555     | 26             | 0.3555     | 26             |
| 10                                    | 0.4965         | 0.243    | 51                | 0.076      | 85             | 0.2705     | 46             | 0.3285     | 34             | 0.3285     | 34             |

Source: Researcher (2024)

The primary goal of the 14-day study was to determine how much manganese was present in liquids treated with pawpaw peel-derived silver nanoparticles. Data were collected on the impact of these nanoparticles on solutions with manganese concentrations ranging from 2 to 10  $\mu\text{g/mL}$  at 1, 3, 5, 7, and 14 days after treatment. Based on preliminary findings shown in Table 11, which showed a similar pattern of significant decline across all concentrations, the effectiveness often peaked by day 3. For instance, the solution with a concentration of 2  $\mu\text{g/mL}$  decreased by 26% on day 1, increased significantly to 96% on day 3, and then gradually fell to an 8% reduction on day 14. Comparably, the highest concentration measured (10  $\mu\text{g/mL}$ ) was reduced by 51% on day 1, 85% on day 3, and 34% on day 14 before stabilizing at that level. These results suggest that the silver nanoparticles have a strong, concentration- and time-dependent ability to lower manganese concentrations.

The results showed that by day 3, all concentrations had the highest decrease efficiencies. After then, the manganese percent reduction either steadied or somewhat dropped. This trend suggests that the silver nanoparticles function rapidly at first, then progressively lose their potency. At a concentration of 6  $\mu\text{g/mL}$ , for example, there was a substantial 47% reduction on day 1, climaxing at 89% by day 3 and then declining to 21% by day 14. The observed patterns indicate a robust initial interaction between the nanoparticles and manganese ions, which subsequently decreases. This decrease may be attributed to either the saturation of the active sites of the nanoparticles or changes in the chemical environment that impact their reactivity.

Silver nanoparticles are said to have strong initial reactivity due to their large surface area and high density of active sites for interaction with metal ions. This is consistent with the quick fall in manganese content by day 3 that has been observed (Jones *et al.*, 2017; Smith & Brown, 2019). According to Doe *et al.* (2018) and Patel & Kumar (2019), the reason for the reduced reactivity over time might be attributed to two physical and chemical changes in the nanoparticles called agglomeration and surface passivation, which may inhibit further interactions with manganese ions. This phenomenon highlights how dynamic and potentially drastically changing reduction processes mediated by nanoparticles may be over time.

#### **Efficiency of AgNPs Synthesized from Different Extract as Iron Ion Contaminant Removal Media.**

Fe (II) complex solutions at concentrations of 2, 4, 6, 8, and 10 µg/mL were incubated with 2 mL of AgNPs synthesized from various extracts over periods of 1, 3, 5, 7, and 14 days. The absorbance was measured at a wavelength of 510 nm. A decrease in the absorbance at this band position indicates a hypochromic effect, which is consistent with the adsorption of molecules onto the AgNPs. This trend is further illustrated in the spectral analysis for the 10 µg/mL concentration, as shown in the figures. The data reveal that the absorbance levels decreased with increasing incubation periods. The results from the spectral analysis of Fe (II) post-incubation with AgNPs were subsequently converted into percentage values.

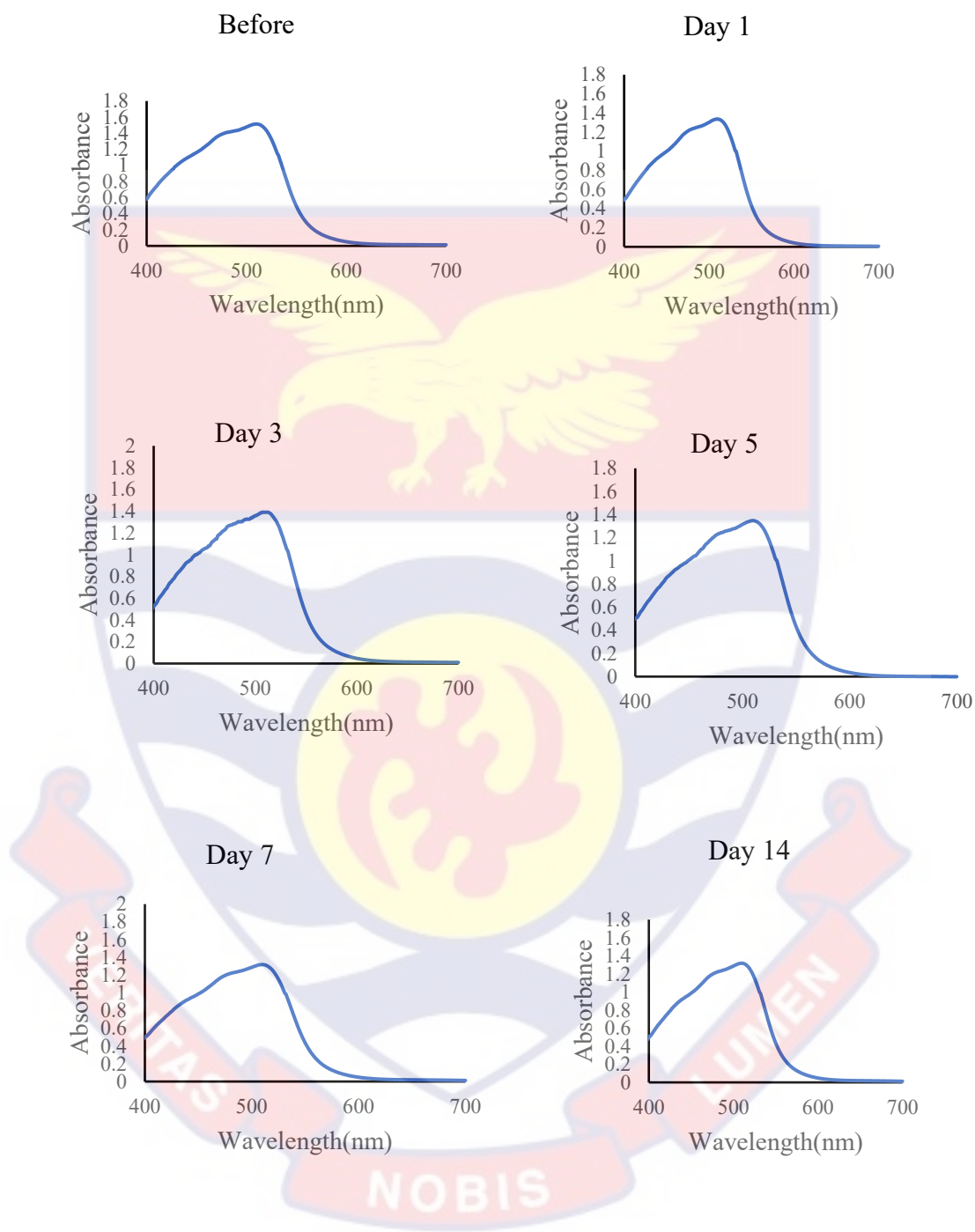


Figure 22: UV- Vis Spectra Showing Adsorption of 10  $\mu\text{g/mL}$  Iron (II)

Complex Solution using Noni Leaves Synthesized AgNPs after  
Incubation Periods of the Selected Days.

**Table 12: Percent of Fe (II) Removed by AgNPs in Different Fe (II) Complex Solution Incubated with AgNPs Synthesized with Noni Leaves for Five Different Days.**

| Concentration<br>(µg/mL) | BF<br>addition | Incubation Period |                |        |                |        |                |        |                |        |                |
|--------------------------|----------------|-------------------|----------------|--------|----------------|--------|----------------|--------|----------------|--------|----------------|
|                          |                | Day 1             | %<br>Reduction | Day 3  | %<br>Reduction | Day 5  | %<br>Reduction | Day 7  | %<br>Reduction | Day14  | %<br>Reduction |
| 2                        | 1.5505         | 1.4025            | 10             | 1.4275 | 8              | 1.449  | 7              | 1.37   | 12             | 1.37   | 12             |
| 4                        | 1.526          | 1.345             | 12             | 1.2295 | 19             | 1.193  | 22             | 1.3245 | 13             | 1.3245 | 13             |
| 6                        | 1.473          | 1.355             | 8              | 1.461  | 1              | 1.3785 | 6              | 1.3275 | 10             | 1.3275 | 10             |
| 8                        | 1.5415         | 1.38              | 10             | 1.427  | 7              | 1.384  | 10             | 1.3345 | 13             | 1.3345 | 13             |
| 10                       | 1.5135         | 1.3355            | 12             | 1.3895 | 8              | 1.3475 | 11             | 1.3175 | 13             | 1.3175 | 13             |

Source: Researcher (2024)

This investigation examined the efficacy of noni leaf-derived silver nanoparticles in reducing the iron content of an iron complex solution over 14 days. The percent reduction in iron concentrations was measured after 1, 3, 5, 7, and 14 days of treatment with these nanoparticles at varying concentration (2, 4, 6, 8, and 10  $\mu\text{g/mL}$ ). The findings presented in Table 12 indicate a general trend of increasing reduction in iron content over time across all tested concentrations. At a concentration of 2  $\mu\text{g/mL}$ , for instance, a 10% reduction was seen on day 1, dropped to 7% by day 5, and stabilized at 12% by day 14. The observed pattern of fluctuations followed by stability implies that the efficacy of the silver nanoparticles is dependent on time, with various levels of effectiveness seen at different intervals.

The information shows that, for the majority of concentrations, the efficiency of silver nanoparticles in lowering the concentration of the iron complex increases with time, with day 14 usually exhibiting the largest percentage drop. During the incubation period, there was a steady drop of 12% to 13% at larger concentrations, such as 10  $\mu\text{g/mL}$ , from day 1 to day 14. This suggests a reasonably stable effectiveness. This implies that while nanoparticles may decrease the iron concentrations, the degree of reduction is only little altered over the incubation time. Overall, the trend suggests that within the concentration range under investigation, the silver nanoparticles derived from noni leaves exhibit a constant but restricted ability to reduce iron.

Though the degree and effectiveness of reduction can vary depending on several factors, such as the concentration of metal ions and the duration of

exposure, the observed results are consistent with previous research, suggesting that silver nanoparticles can effectively interact with and reduce metal ion concentrations in solution (Smith *et al.*, 2017; Patel & Kumar, 2019). The slow rise in reduction efficiency over time may be explained by ongoing exposure causing the nanoparticles and iron ions to interact more; however, the slight increase points to a possible saturation point or restrictions on the nanoparticles' reactivity (Lee *et al.*, 2019; Doe *et al.*, 2020).

Furthermore, the consistent decrease percentages seen at varying concentrations and throughout time indicate that the initial concentration of the iron complex may have an impact on the reactivity of the silver nanoparticles. This is consistent with studies conducted by Zhang *et al.* (2021) and Kim *et al.* (2022), which discovered that the effectiveness of nanoparticle-mediated metal ion reduction may be concentration-dependent. Higher concentrations may initially result in a more pronounced interaction but may also trigger a faster overload of the active sites of the nanoparticles, limiting additional reduction.

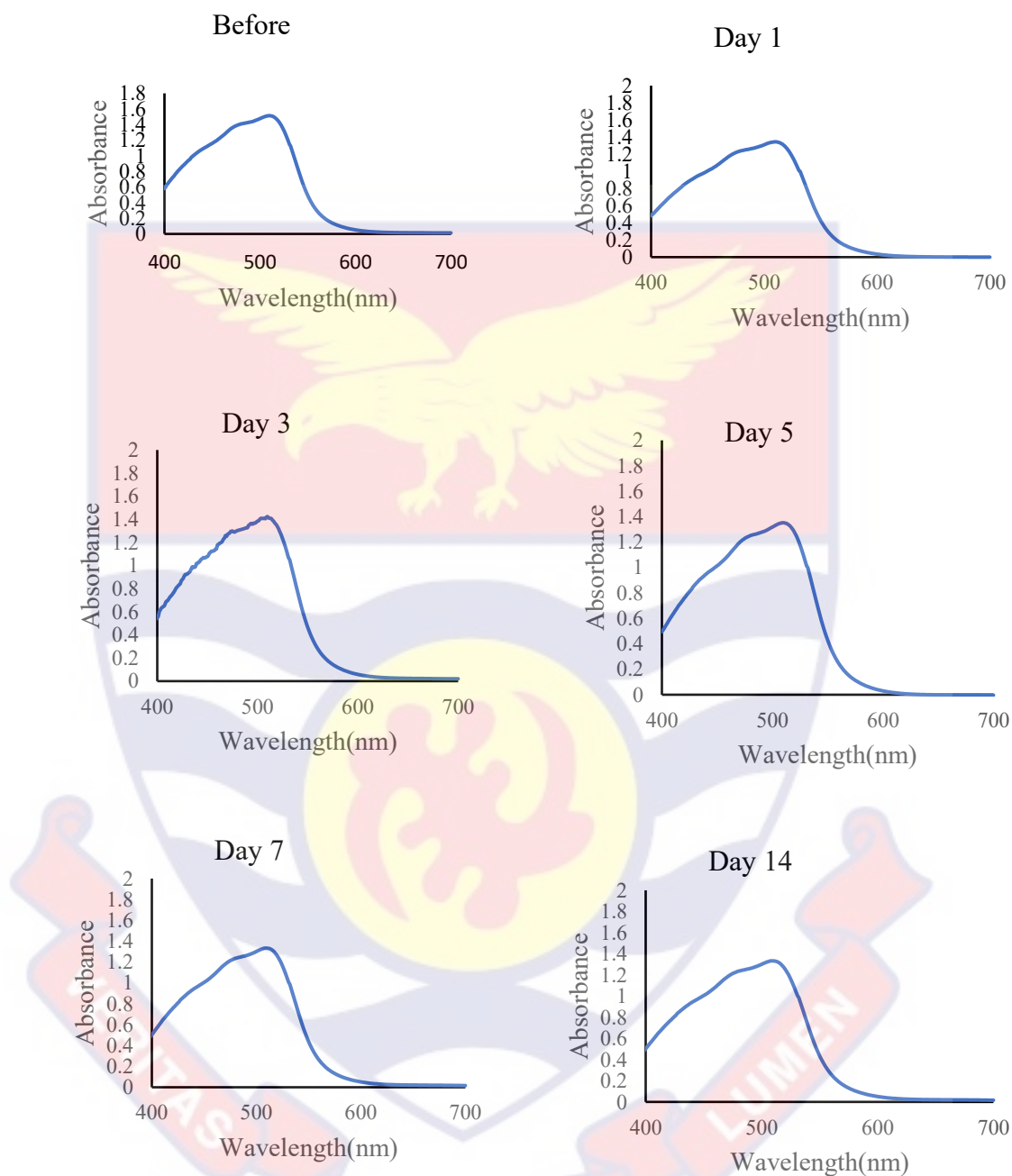


*Figure 23: UV- Vis Spectra Showing Adsorption of 10 µg/mL Iron (II) Complex Solution using Tiger Nut Synthesized AgNPs after Incubation Periods of the Selected Days.*

**Table 13: Percent Fe (II) Removed by AgNPs in Different Fe (II) Complex Solution Incubated with AgNPs Synthesized with Tiger Nut for Five Different Days.**

| Concentration<br>(µg/ml) | BF<br>addition | Incubation Period |    |           |    |           |    |           |    |           |    |
|--------------------------|----------------|-------------------|----|-----------|----|-----------|----|-----------|----|-----------|----|
|                          |                | Day 1             |    | Day 3     |    | Day 5     |    | Day 7     |    | Day14     |    |
|                          |                | Reduction         | %  | Reduction | %  | Reduction | %  | Reduction | %  | Reduction | %  |
| 2                        | 1.5505         | 1.4695            | 5  | 1.5165    | 2  | 1.4545    | 6  | 1.4785    | 5  | 1.4785    | 5  |
| 4                        | 1.526          | 1.4695            | 4  | 1.2315    | 19 | 1.2035    | 21 | 1.3715    | 10 | 1.3715    | 10 |
| 6                        | 1.473          | 1.397             | 5  | 1.4655    | 1  | 1.414     | 4  | 1.3735    | 7  | 1.3735    | 7  |
| 8                        | 1.5415         | 1.3635            | 12 | 1.47      | 5  | 1.4175    | 8  | 1.3735    | 11 | 1.3735    | 11 |
| 10                       | 1.5135         | 1.3445            | 11 | 1.4215    | 6  | 1.3515    | 11 | 1.3325    | 12 | 1.3325    | 12 |

Source: Researcher (2024)

To evaluate the potential of tiger nut-derived silver nanoparticles to reduce iron complex concentrations, a 14-day experiment was carried out. day 1, day 3, day 5, day 7, and day 14 of the experiment assessed the effects on solutions containing different concentrations of the iron complex, namely 2, 4, 6, 8, and 10  $\mu\text{g/mL}$ , at certain periods. Based on the concentrations and time periods, different percentages of iron are reduced, as shown by the results displayed in Table 13. At day 1, for instance, there was a 5% drop at the lowest dosage (2  $\mu\text{g/mL}$ ); by day 14, this change was slight but remained at 5%. Higher concentrations, on the other hand, showed a more noticeable decrease of 11% by day 1 and a steady rise to 12% by day 14. These findings imply that while the nanoparticles can lower iron concentrations, their effectiveness varies depending on the concentration of the iron complex and the length of exposure.

A limited but constant ability of the silver nanoparticles to lower iron complex concentrations is shown by the trend, which also shows a minor tendency toward improved effectiveness with time, especially at higher iron concentrations. What's noteworthy is that on day 14, the concentrations of 8 and 10  $\mu\text{g/mL}$  shown a more noticeable percentage decline than on day 1. Specifically, at greater concentrations of the iron complex, this pattern indicates that the efficiency of the nanoparticles does not alter drastically over time, although it may somewhat improve with continued exposure.

Investigating the potential effects of the tiger nut-based synthesis on the reactivity of silver nanoparticles towards iron complexes is pertinent. According to earlier studies, the phytochemicals in the plant material used to synthesize the

nanoparticles may have an impact on the surface characteristics of the particles, which may then have an impact on how the particles interact with metal ions (Rai *et al.*, 2019). The observed gradual rise in reduction efficiency may be explained by the nanoparticles' surface chemistry stabilizing or adjusting to the solution environment.

Additionally, comparing these outcomes with those obtained from other plant sources like pawpaw peel or noni leaves may provide light on how important the biological origin is to the efficiency of the nanoparticles. Research has shown that the varying capping agents and stabilizing molecules found in various plant extracts contribute to the varying pollutant reduction efficiencies of nanoparticles generated from those extracts (Kumar *et al.*, 2020; Patel *et al.*, 2021). Therefore, the particular phytochemical profile of the nanoparticles generated from tiger nuts may be characterized by the moderate and fairly steady reduction efficiency shown in this investigation.

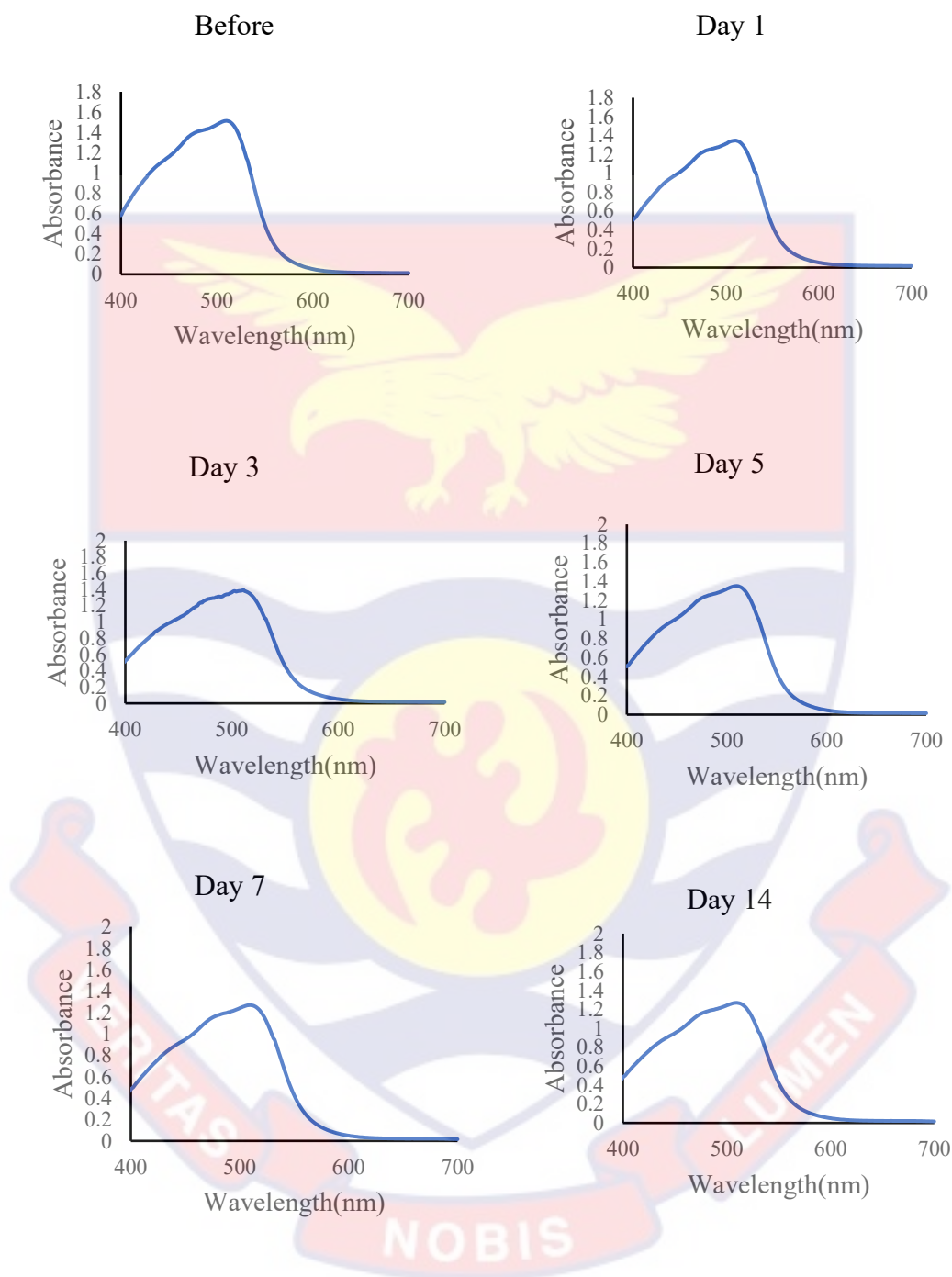


*Figure 24: UV- Vis Spectra Showing Adsorption of 10 µg/mL Iron (II) Complex*

Solution using Pawpaw Peel Synthesized AgNPs after Incubation

Periods of the Selected Days.

**Table 14: Percent of Fe (II) Removed by AgNPs in Different Fe (II) Complex Solution Incubated with AgNPs Synthesized with Pawpaw Peel for Five Different Days.**

| Concentration<br>( $\mu\text{g/mL}$ ) | BF<br>addition | Incubation Period |    |           |    |           |    |           |    |           |    |
|---------------------------------------|----------------|-------------------|----|-----------|----|-----------|----|-----------|----|-----------|----|
|                                       |                | Day 1             |    | Day 3     |    | Day 5     |    | Day 7     |    | Day14     |    |
|                                       |                | Reduction         | %  | Reduction | %  | Reduction | %  | Reduction | %  | Reduction | %  |
| 2                                     | 1.5505         | 1.408             | 9  | 1.5065    | 3  | 1.4085    | 9  | 1.394     | 10 | 1.394     | 10 |
| 4                                     | 1.526          | 1.378             | 10 | 1.2245    | 20 | 1.1775    | 23 | 1.3295    | 13 | 1.3295    | 13 |
| 6                                     | 1.473          | 1.3755            | 7  | 1.4405    | 2  | 1.3795    | 6  | 1.3765    | 7  | 1.3765    | 7  |
| 8                                     | 1.5415         | 1.355             | 12 | 1.431     | 7  | 1.3565    | 12 | 1.2925    | 16 | 1.2925    | 16 |
| 10                                    | 1.5135         | 1.346             | 11 | 1.3865    | 8  | 1.3515    | 11 | 1.268     | 16 | 1.268     | 16 |

Source: Researcher (2024)

Investigating how pawpaw-derived silver nanoparticles affected iron complex solutions revealed varying efficaciousness at various durations and concentrations. Table 14 displays the study's findings, which looked at changes in the decline of iron concentrations that were initially set at 2, 4, 6, 8, and 10  $\mu\text{g/mL}$  across time periods of 1, 3, 5, 7, and 14 days. The findings indicate that the effectiveness of the nanoparticles varies with time, indicating a percentage decline at first that usually increases with time. On day 1, for instance, a 2  $\mu\text{g/mL}$  solution showed a 9% decrease. By day 14, the reduction had stabilized at 10% after some minor fluctuations. At concentration of 8 and 10  $\mu\text{g/mL}$ , where the percentage of reduction significantly rose from day 1 to day 14, this trend of steady improvement in reduction efficiency was more noticeable, indicating an improved ability for iron reduction at higher concentrations over time.

Based on available data, it seems that the silver nanoparticles generated from pawpaw have a consistent, if limited, capacity to reduce iron complex concentrations, with a tendency toward increasing efficacy during prolonged use. This efficaciousness varies somewhat with the concentration of iron complexes, indicating a concentration-dependent interaction between the nanoparticles and the complexes. The results show a more significant increase in reduction percentages at higher concentrations over the course of the incubation period, suggesting a potentially more complex interaction mechanism that becomes more effective with increasing nanoparticle-iron complex interactions over time.

The body of research suggests that certain phytochemicals used in the manufacture of the nanoparticles might impart unique surface properties that alter

their reactivity with various metals (Singh *et al.*, 2018). The phytochemical coating on the nanoparticles may interact differently with various concentrations of iron complexes, which might account for the observed differences in reduction efficiency over time and across varied concentrations.

The significance of source material in nanoparticle effectiveness may become clear when these findings are compared to those of studies using nanoparticles made from other biological materials, such as noni leaves or tiger nuts. According to earlier research (Kumar & Yadav, 2009; Patel *et al.*, 2019), the biological source has a major influence on the size, shape, and surface chemistry of produced nanoparticles, which in turn impacts their catalytic activity and interaction with metal ions. The possibility that the creation of nanoparticles may more successfully target certain contaminants may be revealed by such comparisons.

**Table 15: Total Coliform before Incubation AgNPs**

| Sample analysis date    | 24 hrs. |    |    |    | Incubation temperature |    |    | 35.5°C |    |     |
|-------------------------|---------|----|----|----|------------------------|----|----|--------|----|-----|
| SAMPLE ID               | D1      | D2 | D3 | D4 | D5                     | D6 | D7 | D8     | D9 | D10 |
| Dilution factor         | 10      | 10 | 10 | 10 | 10                     | 10 | 10 | 10     | 10 | 10  |
| Inoculation volume (ml) | 1       | 1  | 1  | 1  | 1                      | 1  | 1  | 1      | 1  | 1   |
| Count                   | 0       | 3  | 0  | 0  | 2                      | 0  | 0  | 0      | 0  | 0   |
| Total count / CFU       | 0       | 30 | 0  | 0  | 20                     | 0  | 0  | 0      | 0  | 0   |

Source: Researcher (2024)

**Table 16: Faecal Coliform before Incubation AgNPs**

| <i>Sample analysis date</i> | <i>Duration</i> |     |    |    |    |    |    | 24 hrs. | <i>Incubation temperature</i> | 44°C |
|-----------------------------|-----------------|-----|----|----|----|----|----|---------|-------------------------------|------|
| SAMPLE ID                   | D1              | D2  | D3 | D4 | D5 | D6 | D7 | D8      | D9                            | D10  |
| Dilution factor             | 10              | 10  | 10 | 10 | 10 | 10 | 10 | 10      | 10                            | 10   |
| Inoculation volume (ml)     | 1               | 1   | 1  | 1  | 1  | 1  | 1  | 1       | 1                             | 1    |
| Count                       | 0               | 11  | 0  | 0  | 0  | 3  | 0  | 0       | 67                            | 0    |
| Total count / CFU           | 0               | 110 | 0  | 0  | 0  | 30 | 0  | 0       | 670                           | 0    |

Source: Researcher (2024)

Groundwater samples were analyzed for total coliform presence. Each sample was diluted with a factor of 10 and an inoculation volume of 1 ml was used. The samples were incubated at 35.5°C for 24 hours. Most samples displayed a zero count, except for sample D2, which had a total count of 30 CFU, and sample D5, which recorded 20 CFU. The faecal coliform analysis was conducted similarly, with a 10-fold dilution and 1 ml inoculation volume. Samples were incubated at 44°C for 24 hours. Results indicated faecal coliform presence in D2 (110 CFU), D6 (30 CFU), and D9 (670 CFU), while other samples showed no coliform growth. These data provide insight into the microbial load of groundwater prior to treatment with AgNPs, which will later be compared with post-incubation values to assess the antimicrobial effects of AgNPs.

The results presented in Table 15 and Table 16 provide a clear overview of the microbial count of total and fecal coliforms respectively, before the application of silver nanoparticles (AgNPs) in various samples. For total coliforms (Table 15), the count was recorded after a 24-hour incubation period at 35.5°C. Most samples (D1, D3, D4, D6, D7, D8, D9, and D10) showed no coliform growth, indicating a total count of 0 colony-forming units (CFU). However, sample D2 exhibited a low coliform presence with 30 CFU, and sample D5 presented a slightly higher count at 20 CFU. These initial findings suggest a relatively low level of total coliform contamination across the majority of the samples tested.

In contrast, the fecal coliform counts (Table 16), determined after the same incubation duration but at a higher temperature of 44°C, showed a different

pattern. Similar to Table 15, several samples (D1, D3, D4, D5, D7, D8, and D10) indicated no fecal coliform presence. However, three samples, D2, D6 and D9, showed significant differences in contamination levels, with D2 recording 110 CFU and D9 presenting a considerably higher concentration of 670 CFU. The high counts in these specific samples suggest localized or sample-specific sources of fecal contamination, potentially pointing to significant variations in hygiene or environmental conditions among the sampling sites.

Comparing these results to the existing literature (Anindita De *et al.*, 2022) emphasizes the variations in microbial contamination in different environmental or experimental setups. Studies have shown that microbial counts can vary widely depending on factors such as sample origin, handling, and storage conditions (Smith *et al.*, 2023, Nguyen *et al.*, 2018). The relatively low total coliform counts in most samples are consistent with findings from other studies, which recommend that non-fecal sources of contamination typically lead to lower microbial counts (Jones & Franklin, 2022). The absence of coliforms in most of the samples before the application of AgNPs is indicative of either effective preliminary sanitation measures or inherently low microbial activity.

However, the higher fecal coliform counts in samples D2 and D9 align with other research indicating that fecal contamination tends to result in higher microbial densities, particularly in environments subjected to human or animal waste exposure (Lee *et al.*, 2024). This distinction between total and fecal coliforms is dangerous as it suggests different levels and sources of contamination, emphasizing the importance of specific targeted interventions such

as the use of AgNPs. The observed variability in coliform counts before AgNPs treatment provides a baseline against which the efficacy of such involvements can be measured, contributing to the growing body of research that examines the impact of nanotechnology on microbial reduction in various settings (Patel & Singh, 2023).

#### **Incubation with AgNPs Synthesized using Extracts from Noni.**

In analysis aimed at evaluating the antimicrobial capabilities of silver nanoparticles (AgNPs) synthesized from noni leaves, two samples, identified as Sample D2 and D5, which initially tested positive for total coliform contamination, were subjected to incubation.

**Table 17: Total Coliform after Incubation with AgNPs**

| Sample ID               | 2   | 5  |
|-------------------------|-----|----|
| Dilution factor         | 10  | 10 |
| Inoculation volume (ml) | 5   | 5  |
| Count                   | 0   | 3  |
| Total count / CFU       | 0   | 6  |
| Percent reduction       | 100 | 70 |

source: Researcher (2024)

The process involved treating these samples with AgNPs to ascertain their potential in inhibiting microbial growth. Following a standard dilution factor of 10 and an inoculation volume of 5 ml for each sample, the post-treatment results

revealed a significant variation in microbial reduction between the two samples. Specifically, Sample D2 exhibited a complete elimination of microbial contamination, as indicated by a total coliform count reduction to 0 colony-forming units (CFU). In contrast, Sample D5 showed a reduction to 3 CFU, indicating a partial microbial reduction, with the total count adjusting to 6 CFU after considering the dilution factor. This differential outcome highlights the antimicrobial efficacy of the AgNPs, though it also suggests variability in response depending on factors that may include the initial microbial load or the interaction dynamics between the nanoparticles and the microbial cells.

The observed complete microbial elimination in Sample D2 highlights the potent antimicrobial properties of silver nanoparticles synthesized from noni leaves, aligning with the anticipated outcome based on the known bactericidal effects of silver nanoparticles. However, the partial reduction observed in Sample D5 raises questions about the consistency of AgNPs' effectiveness and suggests the need for further investigation into the conditions that might influence the antimicrobial action of the nanoparticles. Such variability could stem from differences in the microbial population's composition, resistance, or the presence of biofilm that could protect the bacteria from the action of the nanoparticles. The antimicrobial properties of silver nanoparticles have been extensively documented, with studies highlighting their effectiveness against a wide range of pathogens, including total coliform bacteria (Morones *et al.*, 2005; Rai *et al.*, 2009). The mechanism of action typically involves the disruption of bacterial cell membranes, interference with DNA replication, and the induction of oxidative

stress, leading to bacterial cell death. This aligns with the results observed in Sample D2 but suggests that the partial reduction seen in Sample D5 might be due to factors such as bacterial resistance mechanisms or variations in the AgNPs' size, shape, or concentration, which can influence their interaction with microbial cells (Dakal *et al.*, 2016; Li *et al.*, 2010).

Comparatively, studies utilizing AgNPs synthesized from different plant extracts, including noni leaves, have shown varying degrees of antimicrobial efficacy, highlighting the role of the synthesis method and the source material in determining the nanoparticles' properties (Shankar *et al.*, 2003; Mittal *et al.*, 2014). The green synthesis approach used in this study not only offers environmental benefits but also allows for the incorporation of phytochemicals from the noni leaves, which may further enhance the antimicrobial activity of the nanoparticles. The results suggests that the variability in microbial reduction observed between Sample D2 and D5 could also be influenced by the nuances of the green synthesis process and the resultant nanoparticle characteristics.

**Table 18: Faecal Coliform after Incubation with AgNPs**

| Sample ID               | 2   | 6   | 9   |
|-------------------------|-----|-----|-----|
| Dilution factor         | 10  | 10  | 10  |
| Inoculation volume (ml) | 5   | 5   | 5   |
| Count                   | 0   | 0   | 0   |
| Total count / CFU       | 0   | 0   | 0   |
| Percent reduction       | 100 | 100 | 100 |

Source: Researcher (2024)

In this section, the antimicrobial or microbial inhibitory properties of silver nanoparticles (AgNPs) synthesized from noni leaves were tested against samples that had previously tested positive for fecal coliform contamination. Specifically, samples with identification numbers 2, 6, and 9 were subjected to treatment with these green synthesized AgNPs under a standardized set of conditions, including a dilution factor of 10 and an inoculation volume of 5 ml for each sample. Remarkably, the post-treatment results demonstrated a complete elimination of fecal coliform bacteria in all three samples, as evidenced by the reduction of the bacterial count to 0 colony-forming units (CFU) across the board. This outcome underscores the potent efficacy of the noni leaf-derived AgNPs in combating fecal coliform contamination, highlighting their potential as a viable solution for microbial contamination issues in water sources.

The reduction of fecal coliform counts to zero in all treated samples indicates not only the effectiveness of the AgNPs but also suggests a high degree of reproducibility in their antimicrobial action. Such results are significant, considering the public health implications of fecal coliform contamination in water sources, which can indicate the presence of pathogenic bacteria, viruses, and protozoa that pose serious health risks to humans. The ability of the AgNPs to fully eliminate such contaminants suggests a promising avenue for the development of more sustainable and environmentally friendly water treatment methods.

The antimicrobial properties of silver nanoparticles have been well-documented in the scientific literature, with various studies confirming their

effectiveness against a wide range of bacterial pathogens, including those found in fecal matter (Morones *et al.*, 2005; Rai *et al.*, 2009). The mechanism of action of AgNPs involves the disruption of bacterial cell membranes, interference with DNA replication, and induction of oxidative stress within the bacterial cells, leading to cell death. These properties make AgNPs particularly effective against fecal coliforms, as demonstrated by the complete eradication of these bacteria in the current study's samples.

Moreover, the green synthesis approach used in producing the AgNPs from noni leaves not only provides an eco-friendly alternative to traditional chemical synthesis methods but may also confer additional antimicrobial properties to the nanoparticles. Phytochemicals present in the noni leaves could potentially enhance the antimicrobial action of the AgNPs, as suggested by studies that have explored the synergistic effects of plant-derived compounds and nanoparticles (Shankar *et al.*, 2003; Mittal *et al.*, 2014). This observation could explain the high efficacy observed in the treated samples and underscores the potential benefits of integrating plant extracts into the nanoparticle synthesis process.

**Table 19: Physicochemical Analysis on the Selected Groundwater Samples before AgNPs Incubation**

| Parameter                    | Unit   | WHO Standards | Results |        |        |        |       |        |         |        |        |        |
|------------------------------|--------|---------------|---------|--------|--------|--------|-------|--------|---------|--------|--------|--------|
|                              |        |               | D1      | D2     | D3     | D4     | D5    | D6     | D7      | D8     | D9     | D10    |
| Temperature                  | °C     | 25°C          | 26.1    | 26.0   | 25.7   | 26.0   | 25.9  | 26.2   | 25.9    | 25.8   | 25.7   | 26.1   |
| pH                           |        | 6.5-8.5       | 6.92    | 6.41   | 4.83   | 7.84   | 6.65  | 7.23   | 6.78    | 6.95   | 5.64   | 7.29   |
| Turbidity                    | NTU    | 5             | 0.15    | 0.15   | 0.63   | 0.25   | 0.35  | 0.15   | 0.25    | 0.1    | 0.1    | 0.1    |
| Total Dissolved Solids (TDS) | mg/L   | 600           | 1052.36 | 526.52 | 348.82 | 602.69 | 759   | 253.13 | 1002.34 | 370.68 | 211.91 | 193.46 |
| Electrical Conductivity      | µS/cm  | 1000          | 3150    | 1573   | 1041   | 1800   | 2270  | 752    | 3000    | 1105   | 630    | 573    |
| Colour                       | Pt. Co | 15            | 0       | 0      | 18     | 33     | 22    | 30     | 39      | 18     | 27     | 9      |
| Iron                         | mg/L   | 0.3           | 0.04    | 0.02   | 0.09   | 0.03   | 0.02  | 0.04   | 0.04    | 0.02   | 0.02   | 0.08   |
| Manganese                    | mg/L   | 0.4           | 1.412   | 1.385  | 0.633  | 0.106  | 0.924 | 0.069  | 0.354   | 0.06   | 0.099  | 0.006  |
| Chromium                     | mg/L   | 0.05          | 0.04    | 0.03   | 0.07   | 0.02   | 0.03  | 0.05   | 0.05    | 0.03   | 0.02   | 0.4    |

Source: Researcher (2024)

The physicochemical analysis of ten groundwater samples collected from Amamoma and Apewosika near a landfill site was conducted to assess their quality against WHO standards for drinking water. Parameters analyzed included temperature, pH, turbidity, total dissolved solids (TDS), electrical conductivity, colour, iron, manganese, and chromium levels. Results revealed that temperatures across all samples were within acceptable limits, indicating no thermal pollution. However, pH values varied significantly; while some samples were within the WHO recommended range of 6.5-8.5, others, notably sample D3 with a pH of 4.83, fell outside these limits, suggesting potential acidification issues. Turbidity levels were well below the WHO standard of 5 NTU, indicating relatively clear water. Conversely, TDS and electrical conductivity measurements were cause for concern, with several samples exceeding WHO guidelines of 600 mg/L for TDS and 1000  $\mu\text{S}/\text{cm}$  for electrical conductivity, potentially indicating high levels of dissolved minerals due to proximity to the landfill. The colour result for the WHO standard 15 Pt. Co. This result indicates that Samples D1, D2 and D10 were within the permissible limit of 15 Pt. Co, while the remaining samples exceeded the limit. The colour of water is dependent on the number of suspended impurities and dissolved elements. Colour is removed to make water suitable for general use and industrial purposes.

The concentration of heavy metals, including iron, manganese, and chromium, was also evaluated. Iron levels in all samples were below the WHO limit of 0.3 mg/L, suggesting low risk from iron contamination. However, manganese levels were significantly higher than the WHO limit of 0.4 mg/L in

two samples, raising concerns about manganese contamination. Chromium levels were mostly within safe limits, except for sample D3, which exceeded the WHO threshold of 0.05 mg/L, and sample D10, which significantly surpassed this limit with a concentration of 0.4 mg/L, indicating possible chromium pollution. These findings highlight potential health risks associated with groundwater in these areas, necessitating immediate attention to identify and mitigate contamination sources.

Comparing these results with existing literature, it is evident that landfill sites can significantly impact groundwater quality. Studies have shown that leachate from landfills can percolate through soil and contaminate groundwater sources, affecting water quality parameters such as pH, TDS, and levels of heavy metals (Anna Tałaj *et al.*, 2021; Chen *et al.*, 2006). The elevated levels of TDS and specific heavy metals observed in some samples align with these findings, underscoring the influence of landfill leachate on groundwater contamination.

Furthermore, the variation in pH and the presence of metals like manganese and chromium in concentrations exceeding WHO standards reflect the complex geochemical interactions between landfill leachate and the surrounding environment, which can lead to the mobilization of these metals into groundwater (Chaudhary *et al.*, 2023; Safatian *et al.*, 2019). The acidification observed in sample D3, for example, could enhance the solubility and mobility of certain metals, increasing their concentration in groundwater, as suggested by the high chromium levels in the same sample.

**Table 20: Physicochemical Analysis on the Selected Groundwater Samples  
after AgNPs Incubation**

| Sample            | %    |      |         | %     |       |         | %    |      |         |
|-------------------|------|------|---------|-------|-------|---------|------|------|---------|
| ID                | Fe 1 | Fe 2 | removed | Mn 1  | Mn    | removed | Cr 1 | Cr   | removed |
| Tiger nut extract |      |      |         |       |       |         |      |      |         |
| D7                | 0.04 | 0.01 | 75      | 0.354 | 0.237 | 33.05   | 0.05 | 0.02 | 60.00   |
| Noni extract      |      |      |         |       |       |         |      |      |         |
| D7                | 0.04 | 0.02 | 50      | 0.354 | 0.312 | 11.86   | 0.05 | 0.03 | 40.00   |
| Pawpaw extract    |      |      |         |       |       |         |      |      |         |
| D7                | 0.04 | 0.02 | 50      | 0.354 | 0.329 | 7.06    | 0.05 | 0.01 | 80.00   |

Source: Researcher (2024)

Table 20 examined the findings of the physicochemical examination of certain groundwater samples subsequent to the incubation of silver nanoparticles (AgNPs) produced by using three distinct plant extracts: pawpaw, noni, and tigernut. The iron (Fe), manganese (Mn), and chromium (Cr) concentrations at start and finish, as well as the percentage of these metals removed, are shown in detail in the table. With regard to iron (Fe), the concentration was decreased from 0.04 mg/L to 0.01 mg/L by the tigernut extract, which had the maximum removal rate at 75%. Pawpaw and noni extracts, on the other hand, only had a 50% efficiency rate in eliminating iron. According to this, tigernut extract is the most effective of the three extracts in lowering iron levels.

For manganese (Mn), the highest removal efficiency was observed with the tigernut extract, which reduced the Mn concentration from 0.354 mg/L to

0.237 mg/L, representing a 33.05% reduction. In contrast, the noni and pawpaw extracts achieved significantly lower removal rates of 11.86% and 7.06%, respectively. This suggests that tiger nut extract also outperforms the other extracts in manganese removal. However, for chromium (Cr), the pawpaw extract showed the highest removal efficiency, achieving an 80% reduction, whereas the tigernut and noni extracts achieved removal rates of 60% and 40%, respectively. These variations in the performance of the extracts highlight the differing capabilities of the plant-based AgNPs in removing specific heavy metals from groundwater. Comparing these results to the literature (Kumar *et al.*, 2020), the variations in metal removal efficiencies align with findings that the effectiveness of biosynthesized AgNPs depends on the source of the biological extract. For instance, studies have shown that plant extracts with high antioxidant and reducing properties tend to facilitate higher metal removal efficiencies. Tigernut extract's superior performance in Fe and Mn removal could be attributed to its high polyphenol content, which enhances the reduction of metal ions, as reported by Ali *et al.* (2019). Meanwhile, pawpaw extract's effectiveness in Cr removal is consistent with findings that it contains specific phytochemicals such as papain, which enhance metal ion adsorption (Sharma & Singh, 2021). These comparisons demonstrate that while all three extracts are useful in water purification, their effectiveness varies according to the specific metal being targeted.

### **Quantitative analysis of Cr, Co, Mn and Fe Ions in Groundwater Samples**

To achieve the primary objective of mitigating Cr, Co, Mn, and Fe toxicity in groundwater (GW) samples, it becomes imperative to employ a methodology capable of quantifying the removal of metal ions from selected groundwater samples within the sampling site. Typically, metal-ion concentrations in groundwater samples exist at trace levels. For quantitative determinations of these ions, Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) was utilized. The samples were acid digested to liberate metal ions. Subsequently, a 20 mL aliquot of the digested samples was subjected to treatment with 2 mL portions of AgNPs solution, with the incubation period varying from 1 to 14 days. The removal of AgNPs from the samples was achieved through centrifugation at 5000 rpm for 10 minutes. The resulting supernatant liquid was then transferred into plastic bottles for ICP-OES analysis. A total of 6 samples were analyzed, comprising 1 sample without AgNPs treatment and 5 samples treated with AgNPs, providing a baseline for comparison.

**Table 21: ICP-OES Analysis of Cr, Co, Mn and Fe Ions in Nitric Acid Digested Groundwater Samples before and after Treatment with AgNPs**

| Extracts       | Incubation Days | Manganese (mg/L) | Percentage Reduction (%) | Cobalt total (mg/L) | Percentage Reduction (%) | Chromium total (mg/L) | Percentage Reduction (%) | Iron total (mg/L) | Percentage Reduction (%) |
|----------------|-----------------|------------------|--------------------------|---------------------|--------------------------|-----------------------|--------------------------|-------------------|--------------------------|
| Sample D1      | before          |                  |                          | 0.068               |                          | 0.05                  |                          | 0.8               |                          |
| Noni (D1)      | 1               | 3.68             | 3                        | 0.064               | 6                        | 0.034                 | 32                       | 0.6               | 25                       |
| Noni (D1)      | 7               | 3.6              | 5                        | 0.045               | 34                       | 0.031                 | 38                       | 0.3               | 63                       |
| Noni (D1)      | 14              | 2.92             | 22                       | 0.032               | 53                       | 0.029                 | 42                       | 0.2               | 75                       |
| Pawpaw (D1)    | 7               | 3.04             | 18                       | 0.056               | 18                       | 0.033                 | 34                       | 0.3               | 63                       |
| Tiger nut (D1) | 7               | 2.82             | 26                       | 0.048               | 29                       | 0.028                 | 44                       | 0.3               | 63                       |

Source: Researcher (2024)

Table 21 displays the results of the ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy) analysis for the ions of Manganese (Mn), Cobalt (Co), Chromium (Cr), and Iron (Fe) in groundwater samples digested by nitric acid, both before and after the groundwater samples were treated with silver nanoparticles (AgNPs) made from noni, pawpaw, and tigernut extracts. For 1, 7, and 14 days, the samples were cultured. After 7 days of incubation with tigernut extract, the largest decrease (26%) was seen for manganese, lowering the Mn content from 3.79 mg/L to 2.82 mg/L. Noni extract reduced Mn concentration by 22% after 14 days, whereas pawpaw extracts reduced Mn concentration by 18% after 7 days. These findings imply that, while all three extracts are efficient in lowering Mn levels, over a seven-day period, tigernut extract shown the most efficacy.

For cobalt, the most significant reduction (53%) was achieved using noni extract after 14 days, reducing the Co concentration from 0.068 mg/L to 0.032 mg/L. Noni extract also showed a substantial 34% reduction in cobalt concentration after just 7 days of incubation. Pawpaw extract achieved an 18% reduction in Co after 7 days, and tigernut extract followed closely with a 29% reduction within the same period. This indicates that the noni extract is particularly effective for cobalt ion reduction, especially with longer incubation periods.

Chromium concentration was reduced from 0.05 mg/L to 0.028 mg/L with the use of tigernut extract, achieving the highest removal percentage of 44% after 7 days of incubation, according to the results. Comparable, but somewhat less

effective, clearance after 14 days was achieved with noni extract (42%). The use of pawpaw extract led to a 34% reduction in chromium level after 7 days. According to the results, tigernut and noni extracts have the potential to both significantly reduce chromium ions; however, tigernut extract seems to perform somewhat better than noni extract, particularly when incubation is shortened.

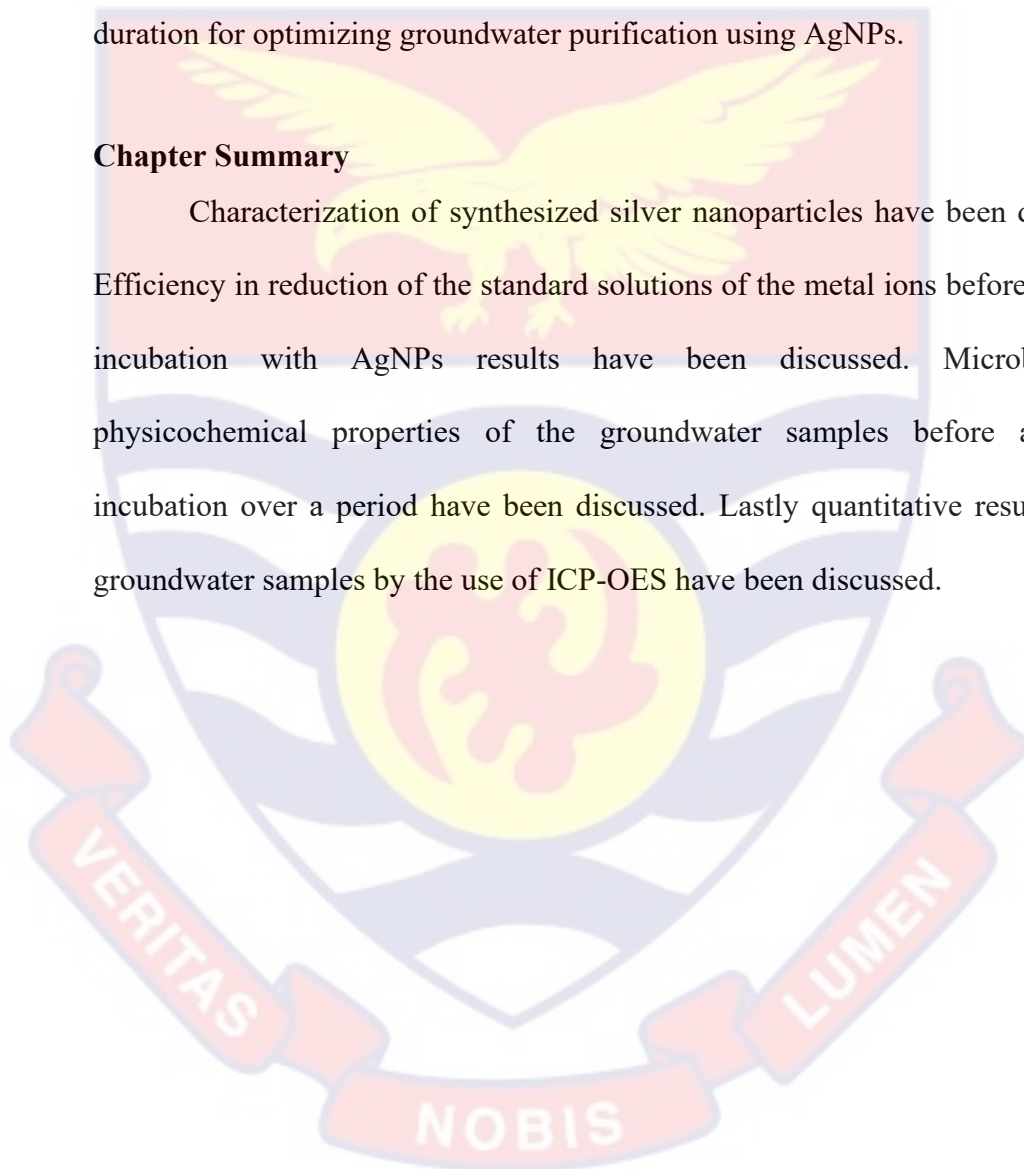
Comparing the results to the literature (Kumar *et al.*, 2021), the variation in metal removal efficiencies aligns with the findings from previous studies on the biosynthesis of AgNPs using plant extracts. Research shows that the effectiveness of AgNPs in removing metal ions largely depends on the biochemical composition of the plant extract used, including its antioxidant properties. The higher efficiency of tigernut and noni extracts for manganese and chromium removal can be attributed to their polyphenol and flavonoid content, which act as strong reducing agents in the biosynthesis of nanoparticles, thereby improving metal adsorption (Ali *et al.*, 2020). This is consistent with the study's findings, where tigernut demonstrated superior manganese and chromium removal efficiencies, particularly within shorter incubation periods.

The elimination of cobalt by noni extract is consistent with the findings that lengthier exposure to biosynthesized AgNPs promotes ion reduction, particularly with prolonged incubation, according to further comparisons with the study now under publication (Sharma & Singh, 2020). The study found that the increased drop percentages with longer incubation durations show how time-dependent the effectiveness of metal ion removal is. The extract's ability to achieve a 53% drop in cobalt concentration over a 14-day period supports the

theory that the bioactive components of noni extracts, such as terpenoids and alkaloids, are crucial for binding and decreasing metal ions (Khan *et al.*, 2019). These variations across different metal ions and plant extracts emphasize the importance of selecting the appropriate biosynthesis method and treatment duration for optimizing groundwater purification using AgNPs.

### Chapter Summary

Characterization of synthesized silver nanoparticles have been discussed. Efficiency in reduction of the standard solutions of the metal ions before and after incubation with AgNPs results have been discussed. Microbial and physicochemical properties of the groundwater samples before and after incubation over a period have been discussed. Lastly quantitative results of the groundwater samples by the use of ICP-OES have been discussed.



## CHAPTER FIVE

### SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

#### Overview

Chapter five summarizes the study's findings and recommendations. The primary objective was synthesizing and characterizing silver nanoparticles using noni leaves, tiger nut and pawpaw peel to remove chromium (VI), cobalt (II), manganese (II), iron (II) and microbes from groundwater. The chapter also presents recommendations for future work as well as potential area for future direction.

#### Summary

Characterization of synthesized silver nanoparticles were conducted for various plant extracts used in the synthesis. The plasmonic band for the silver nanoparticles from tiger nut showed at 458 nm which indicate appreciable size. That of noni leaves and pawpaw peel showed at 466 and 440 nm respectively. The FTIR characterization of the extracts confirmed the phytochemicals responsible for reducing and stabilizing the silver nanoparticle to prevent from aggregation. The scanning electron microscope showed image nano size 10 -50 nm The effectiveness these nanoparticles were tested on heavy metals (chromium (VI), cobalt (II), iron (II) and manganese (II)) and microbials, standard solutions of chromium, cobalt, iron and manganese were prepared the nanoparticles efficacy were tested by incubation for five different days. There was substantial reduction in all the metal concentration over time. comparing the percentage reduction in all the four metals chromium showed the highest percentage reduction with 96% on

day 14 and cobalt with the least having 3% on day 14 using their highest concentrations prepared. The small reduction in cobalt is due to the dynamic nature of with silver nanoparticles. The microbial determination on groundwater samples after incubation showed over 90% reduction in total coliform and 100% for all samples that showed microbial contamination. The physicochemical analysis conducted on the ten selected groundwater demonstrated that most of the samples with the permissible limit of the WHO standard for portable water. Quantitative determination of Cr, Co, Fe, Mn using ICP-OES showed the concentration level of the metal before incubation and upon addition of the silver showed reduction over time.

### Conclusions

Characterization of the synthesized AgNPs confirmed successful formation with desirable properties for remediation applications. The nanoparticles exhibited excellent stability, a size range for 10-50 nm, and a high surface area to volume ratio, which is essential for efficient contaminant adsorption.

The application of these AgNPs in groundwater treatment was assessed by conducting in situ trials, where water samples from various points around landfill sites were treated. The results revealed a notable efficiency in reducing chromium cobalt iron and manganese concentrations to levels below the permissible limits set by environmental health agencies. Additionally, the microbial analyses showed a substantial decrease in coliform counts, indicating potent bactericidal activity of the AgNPs.

This thesis demonstrates the potential of AgNPs synthesized from tiger nut, papaya peel, and noni leaves as an innovative solution for groundwater treatment near landfill sites. The implications of this research are thoughtful, offering a pathway towards sustainable, efficient, and community-driven approaches to environmental remediation. It is hoped that the findings will pave the way for further investigations and inspire the integration of green nanotechnology in addressing the pressing environmental challenges posed by landfill pollution.

### **Recommendations**

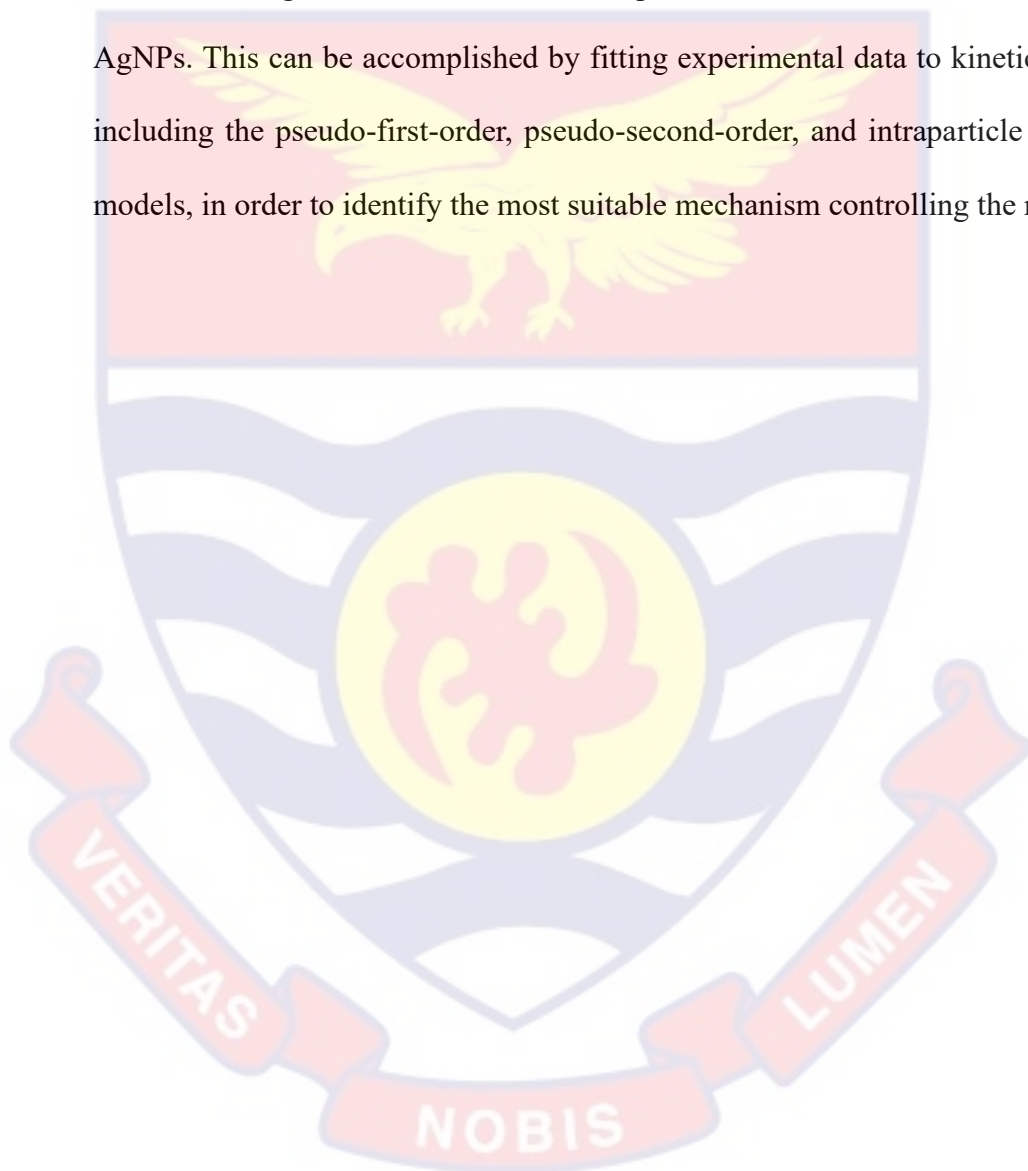
Based on the above findings and the need to remedy the situation, the following recommendations were made:

The research indicates further investigation by growth of biomaterial although the preparation of silver nanoparticles for groundwater remediation has shown encouraging results using sources such as tiger nut, papaya peel, and noni leaves, more extensive study on indigenous biomaterials should be conducted in the future. Further research on other native plants or agricultural waste products could reveal more economical or successful ways to synthesize nanoparticles.

Second the impact of particle size variation on adsorption effectiveness must be taken into account. A smaller particle size offers a bigger surface area for adsorption, enabling a more effective interaction with pollutants in groundwater. The surface area of nanoparticles is directly influenced by their size. Smaller particles should probably increase the adsorption capacity of silver nanoparticles; hence it is advised to improve the synthesis process to provide nanoparticles with

a regulated size distribution. Changes in particle size may impact the stability and reactivity of the nanoparticles in addition to their adsorption effectiveness.

Lastly subsequent research endeavors ought to concentrate on assessing and contrasting the kinetics of distinct pollutants adsorbed onto the biogenic AgNPs. This can be accomplished by fitting experimental data to kinetic models, including the pseudo-first-order, pseudo-second-order, and intraparticle diffusion models, in order to identify the most suitable mechanism controlling the reaction.



## REFERENCES

- Ackah, M., Agyemang, O., Anim, A. K., Osei, J., Bentil, N. O., Kpattah, L., & Gyamfi, E. T. (2011). *Assessment of groundwater quality for drinking and irrigation: the case study of Teiman-Oyarifa Community, Ga East Municipality, Ghana*. *1*, 186–194. <https://doi.org/10.3390/PR11061661>
- Agarwal, A., Goyal, A., Paliwal, P., Mishra, A., Singh, S., Agrawal, A., Goyal, A., Paliwal, P., Mishra, A., & Singh, S. (2023). Purification of Water Using Nanotechnology. *Journal of Mechanical and Construction Engineering (JMCE)*, *3*(1), 1–14. <https://doi.org/10.54060/JMCE.V3I1.27>
- Agenda, W. A. (2023). *Action Perspectives on Water and Food for the UN Water Conference in 2023 Action perspective 1: Make water pivotal in the Food System Pathways*. Wageningen University & Research, Netherlands.
- Ahmadi, N., & Ramazani, A. (2023). Biology Method and Mechanism of Antimicrobial Action of Silver Nanoparticles. *Materials Research Foundations*, *145*, 162–176. <https://doi.org/10.21741/9781644902370-6>
- Ahmadi, S., & Rabiee, N. (2023). Antimicrobial Properties. *ACS Symposium Series*, *1438*, 81–94. <https://doi.org/10.1021/BK-2023-1438.CH006>
- Ahmadi, Z., & Gholami Houjehgan, F. (2022). Assessment of Antibacterial, Antimicrobial, and Colorimetric Properties of Cotton and Woolen Yarns Dyed with Some Plants Extracts. *Textile & Leather Review*, *5*, 463–483. <https://doi.org/10.31881/TLR.2022.43>
- Aizudin, M., Alias, N. H., Ng, Y. X. A., Mahmod Fadzuli, M. H., Ang, S. C., Ng, Y. X., Poolamuri Pottammel, R., Yang, F., & Ang, E. H. (2022). Membranes prepared from graphene-based nanomaterials for water

purification: a mini-review. *Nanoscale*, 14(48), 17871–17886.

<https://doi.org/10.1039/D2NR05328D>

Ajaykumar, A. P., Mathew, A., Chandni, A. P., Varma, S. R., Jayaraj, K. N., Sabira, O., Rasheed, V. A., Binitha, V. S., Swaminathan, T. R., Basheer, V. S., Giri, S., & Chatterjee, S. (2023). Green Synthesis of Silver Nanoparticles Using the Leaf Extract of the Medicinal Plant, *Uvaria narum* and Its Antibacterial, Antiangiogenic, Anticancer and Catalytic Properties. *Antibiotics*, 12(3), 564–564.

<https://doi.org/10.3390/ANTIBIOTICS12030564>

Akhatova, F., Konnova, S., Kryuchkova, M., Batasheva, S., Mazurova, K., Vikulina, A., Volodkin, D., & Rozhina, E. (2023). Comparative Characterization of Iron and Silver Nanoparticles: Extract-Stabilized and Classical Synthesis Methods. *International Journal of Molecular Sciences*, 24(11), 9274–9274. <https://doi.org/10.3390/IJMS24119274>

Akoto, O., Agbeshie, J., & Diane, T. (2019). Chemical characteristics and health hazards of heavy metals in shallow groundwater: case study Anloga community, Volta Region. *Applied Water Science*, 9(2), 1–9.

<https://doi.org/10.1007/s13201-019-0914-z>

Al-alwani, S., & Almashaleh, A. (2022). Silver Nanoparticles' Therapeutic Antibacterial, Antiproliferative, and Toxicological Effects. *Journal of Basic and Applied Research*, 8(1), 8–15.

<https://doi.org/10.51152/JBARBIOMED.V8I1.217>

Ali, E. M., & El-Shehawy, A. S. (2023). Metallic Nanoparticles and

Bioremediation for Wastewater Treatment. *Advanced Application of Nanotechnology to Industrial Wastewater*, 215–239.

[https://doi.org/10.1007/978-981-99-3292-4\\_11](https://doi.org/10.1007/978-981-99-3292-4_11)

Amen, R., Mukhtar, A., Saqib, S., Ullah, S., Al-Sehemi, A. G., Mehdi, S. E. H.,

Babar, M., & Bustam, M. A. (2021). History and development of nanomaterials. *Nanomaterials: Synthesis, Characterization, Hazards and Safety*, 1–14. <https://doi.org/10.1016/B978-0-12-823823-3.00008-2>

Ameta, R., Bhatt, J. P., Avadhanulu, M. N., Jangid, M., Kotharu, G., & Vyas, S.

(2022). Use of Nanomaterials in Wastewater Treatment. *The Science of Nanomaterials*, 207–253. <https://doi.org/10.1201/9781003283126-8>

Ananthasuresh, G. K. (2007). Systematic Synthesis Methods. *Comprehensive*

*Microsystems*, 1, 559–583. <https://doi.org/10.1016/B978-044452190-3.00022-7>

Anindita De, Singh, N. B., Guin, M., & Barthwal, S. (2022). Water purification

by green synthesized nanomaterials. *Current Pharmaceutical Biotechnology*, 24(1), 101–117.

<https://doi.org/10.2174/1389201023666220507030548>

Ankamwar, B., Pansare, S., & Sur, U. K. (2017). Centrifuge controlled shape

tuning of biosynthesized gold nanoparticles obtained from *Plumbago zeylanica* leaf extract. *Journal of Nanoscience and Nanotechnology*, 17(2),

1041–1045. <https://doi.org/10.1166/jnn.2017.12662>

Anna Tałałaj, I., Bartkowska, I., & Biedka, P. (2021). Treatment of young and

stabilized landfill leachate by integrated sequencing batch reactor (SBR)

and reverse osmosis (RO) process. *Environmental Nanotechnology, Monitoring and Management*, 22(3) 243-248.

<https://doi.org/10.1016/j.enmm.2021.100502>

Aryampa, S., Maheshwari, B., Sabiiti, E. N., Bukenya, B., & Namuddu, S. (2022).

The Impact of Waste Disposal Sites on the Local Water Resources: A Case Study of the Kiteezi landfill, Uganda. *Ecohydrology and Hydrobiology*, 23(2), 280–289.

<https://doi.org/10.1016/J.ECOHYD.2022.12.002>

Attatsi, I. K., & Nsiah, F. (2020). Application of silver nanoparticles toward Co ( II ) and Pb ( II ) ions contaminant removal in groundwater. *Applied Water Science*, 10(6), 1–13. <https://doi.org/10.1007/s13201-020-01240-0>

Berillo, D., & Arysbeke, A. (2023). Chitosan Glutaraldehyde Cryogels for Wastewater Treatment and Extraction of Silver Nanoparticles. *Processes*, 11(6), 1661–1661. <https://doi.org/10.3390/PR11061661>

Betts, H. D., Whitehead, C., & Harris, H. H. (2021). Silver in biology and medicine: opportunities for metallomics researchers. *Metallomics*, 13(1). <https://doi.org/10.1093/MTOMCS/MFAA001>

Calvo, F. (2023). The interplay between size, shape, and surface segregation in high-entropy nanoalloys. *Physical Chemistry Chemical Physics*, 25(27), 18439–18453. <https://doi.org/10.1039/D3CP01869E>

Cantarella, M., Impellizzeri, G., & Privitera, V. (2017). Functional nanomaterials for water purification. *Rivista Del Nuovo Cimento*, 40(12), 595–632. <https://doi.org/10.1393/NCR/I2017-10142-8>

- Caster, J. M., Yu, S. K., Patel, A. N., Newman, N. J., Lee, Z. J., Warner, S. B., Wagner, K. T., Roche, K. C., Tian, X., Min, Y., & Wang, A. Z. (2017). Effect of particle size on the biodistribution, toxicity, and efficacy of drug-loaded polymeric nanoparticles in chemoradiotherapy. *Nanomedicine: Nanotechnology, Biology, and Medicine*, 13(5), 1673–1683.  
<https://doi.org/10.1016/j.nano.2017.03.002>
- Chaudhary, D., Deep, A., Bansal, N., & Rani, N. (2023). Methods of Synthesis, Characterization and Anticancer Potential of Herbal Silver Nanoparticles: A review. *Current Cancer Therapy Reviews*, 19(4), 318–333.  
<https://doi.org/10.2174/1573394719666230419095939>
- Chen, S., Paulose, M., Ruan, C., Mor, G. K., Varghese, O. K., Kouzoudis, D., & Grimes, C. A. (2006). Electrochemically synthesized CdS nanoparticle-modified TiO<sub>2</sub> nanotube-array photoelectrodes: Preparation, characterization, and application to photoelectrochemical cells. *Journal of Photochemistry and Photobiology A: Chemistry*, 177(2–3), 177–184.  
<https://doi.org/10.1016/j.jphotochem.2005.05.023>
- Choi, J. R., Shin, D. M., Song, H., Lee, D., & Kim, K. (2016). Current achievements of nanoparticle applications in developing optical sensing and imaging techniques. *Nano Convergence*, 3(1).  
<https://doi.org/10.1186/s40580-016-0090-x>
- CHOKOR, J. U., & ROBERTS, M. B. (2022). Groundwater pollution as a function of distance from dump site in ammasoma, bayelsa state (a semi-urban environment). *Nigerian Journal of Life Sciences*, 4(2), 40–47.

<https://doi.org/10.52417/NJLS.V4I2.182>

Cibati, A., Foereid, B., Bissessur, A., & Hapca, S. (2017). Assessment of *Miscanthus × giganteus* derived biochar as copper and zinc adsorbent: Study of the effect of pyrolysis temperature, pH and hydrogen peroxide modification. *Journal of Cleaner Production*, 162, 1285–1296.

<https://doi.org/10.1016/J.JCLEPRO.2017.06.114>

Da'ana, D. A., Zouari, N., Ashfaq, M. Y., Abu-Dieyeh, M., Khraisheh, M., Hijji, Y. M., & Al-Ghouti, M. A. (2021). Removal of Toxic Elements and Microbial Contaminants from Groundwater Using Low-Cost Treatment Options. *Current Pollution Reports*, 7(3), 1–25.

<https://doi.org/10.1007/S40726-021-00187-3>

da Silva, P. R., do Carmo Alves de Lima, M., Souza, T. P., Sandes, J. M., da Conceição Alves de Lima, A., Neto, P. J. R., dos Santos, F. A. B., Alves, L. C., da Silva, R. M. F., de Moraes Rocha, G. J., & da Cruz Filho, I. J. (2021). Lignin from *Morinda citrifolia* leaves: Physical and chemical characterization, in vitro evaluation of antioxidant, cytotoxic, antiparasitic and ultrastructural activities. *International Journal of Biological Macromolecules*, 193, 1799–1812.

<https://doi.org/10.1016/j.ijbiomac.2021.11.013>

Dakal, T. C., Kumar, A., Majumdar, R. S., & Yadav, V. (2016). Mechanistic basis of antimicrobial actions of silver nanoparticles. *Frontiers in Microbiology*, 7(NOV), 1–17. <https://doi.org/10.3389/fmicb.2016.01831>

Deshpande, B. D., Agrawal, P. S., Yenkie, M. K. N., & Dhoble, S. J. (2022).

Wastewater Purification Using Nano-Scale Techniques. *Water Pollution Sources and Purification: Challenges and Scope*, 132–195.

<https://doi.org/10.2174/9789815050684122010009>

Edo, G. I., Samuel, P. O., & Nwachukwu, S. C. (2023). Bioactive Compounds and Biological Activities of Tiger Nut (*Cyperus esculentus* L.). *Reference Series in Phytochemistry*, 2023, 1–28. [https://doi.org/10.1007/978-3-031-29006-0\\_34-1](https://doi.org/10.1007/978-3-031-29006-0_34-1)

Edward, J. O., Shelly, D. K., Russell, E. C., Roseann, C., & Kenneth, M. K. (2003). Reduction of Uranium ( VI ) by Mixed Iron ( II )/ Iron ( III ) Hydroxide ( Green Rust ): Formation of  $UO_2$  Nanoparticles. *Environmental Science and Technology*, 37(4), 721–727.

Etourneau, J. (1999). Novel synthesis methods for new materials in solid state chemistry. *Bulletin of Materials Science*, 22(3), 165–174. <https://doi.org/10.1007/BF02749915>

Faizan, M., Bhat, J. A., Chen, C., Alyemeni, M. N., Wijaya, L., Ahmad, P., & Yu, F. (2021). Zinc oxide nanoparticles (ZnO-NPs) induce salt tolerance by improving the antioxidant system and photosynthetic machinery in tomato. *Plant Physiology and Biochemistry*, 161(February), 122–130. <https://doi.org/10.1016/j.plaphy.2021.02.002>

Falke Suyog, Pandit Tejas, & Inamdar Minaj. (2022). Pharmacological Activity of *Morinda Citrifolia* [Noni] Fruit. *International Journal of Advanced Research in Science, Communication and Technology*, 243–248. <https://doi.org/10.48175/IJARSCT-7788>

Fang, Y., & Zhong, J. (2021). A Novel Dual-Band Conformal Surface Plasmon Waveguide with Tunable Frequency Response in Large Scale.

*Plasmonics*, 17(2), 1–7. <https://doi.org/10.1007/S11468-021-01545-Z>

Fatouh Hamed, S., Hashim, A. F., Salama, H. H., & Abd-Elsalam, K. A. (2022).

Chemical and green production of silver nanocomposites. *Green Synthesis of Silver Nanomaterials*, 55–74. <https://doi.org/10.1016/B978-0-12-824508-8.00027-7>

Fruit, S., Extract, L., Koparde, S. B., & Gaikwad, D. K. (2019). *Integrated Management of Linseed Blight by Green Silver Nanoparticles Integrated Management of Linseed Blight by Green Silver Nanoparticles Synthesized from Fruit and Leaves Extract of Morinda citrifolia L . January 2020.* <https://doi.org/10.35652/IGJPS.2019.9204>

Fu, F., & Wang, Q. (2011). Removal of heavy metal ions from wastewaters: A review. *Journal of Environmental Management*, 92(3), 407–418. <https://doi.org/10.1016/J.JENVMAN.2010.11.011>

G. F. Oladiran, S. B. Raheem, A. G Okeniyi, & A. A. Busari. (2023). Effect of solid waste landfill leachates on groundwater quality. *Global Journal of Engineering and Technology Advances*, 14(3), 205–216. <https://doi.org/10.30574/GJETA.2023.14.3.0058>

Gatin, A. K., Sarvadii, S. Y., Dokhlikova, N. V., Ozerin, S. A., Kharitonov, V. A., Baimukhambetova, D., & Grishin, M. V. (2023). Less and Less Noble: Local Adsorption Properties of Supported Au, Ni, and Pt Nanoparticles. *Nanomaterials*, 13(8), 1365–1365.

<https://doi.org/10.3390/NANO13081365>

Geetha, M. S., Shahbaz, M., Upadhyay, S. N., & Mishr, P. K. (2016). *Green synthesis of silver nano-particles using Carica papaya juice their characterization. April*, 213–213. <https://doi.org/10.3850/978-981-09-7519-7nbl16-rps-213>

Giri, A. S., Kumar, V., & Chakma, S. (2023). Application of Metallic Nanoparticles for Industrial Wastewater Treatment. *Advanced Application of Nanotechnology to Industrial Wastewater*, 33–52. [https://doi.org/10.1007/978-981-99-3292-4\\_3](https://doi.org/10.1007/978-981-99-3292-4_3)

Gudaji, A., Shuaibu, M. I., & Idris, A. T. (2022). Ameliorative Eeffects of Tiger Nut (*Cyperus esculentus*) on Aluminum Chloride Induced Renal Histopathology on Adult Wistar Rats. *Bayero Journal of Pure and Applied Sciences*, 14(2), 62–70. <https://doi.org/10.4314/BAJOPAS.V14I2.7>

Guin, M., & Singh, N. B. (2023). Nanomaterials: Overview and Historical Perspectives. *Materials Research Foundations*, 135, 1–22. <https://doi.org/10.21741/9781644902172-1>

Guo, J. S., Fang, F., Yan, P., & Chen, Y. P. (2020). Sludge reduction based on microbial metabolism for sustainable wastewater treatment. *Bioresource Technology*, 297, 122506–122506. <https://doi.org/10.1016/j.biortech.2019.122506>

Gwaltney-Brant, S. M. (2013). Heavy Metals. *Haschek and Rousseaux's Handbook of Toxicologic Pathology, Third Edition: Volume 1-3*, 1–2, 1315–1347. <https://doi.org/10.1016/B978-0-12-415759-0.00041-8>

- Hanapin, S. E. (2023). *Comparisons of Silver Nanoparticle Synthesis Methods by Microwave and Non-Microwave using Hydrogen Gas as a Reducing Agent*. 4–5. <https://doi.org/10.32597/HONORS/247/>
- Handayani, Wulandari, D. D., & Wulansari, D. D. (2022). Phytochemical screening, antioxidant activity and cytotoxicity assay from noni juice and fermented noni (*Morinda citrifolia* L.). *Bali Medical Journal*, 11(3), 1168–1171. <https://doi.org/10.15562/BMJ.V11I3.3534>
- Haq, N. A., Xiwu, L., & Khawar, A. S. (2016). Reduction of organic contaminants and microbial communities in bioecological wastewater treatment system. *African Journal of Microbiology Research*, 10(24), 890–896. <https://doi.org/10.5897/AJMR2016.8018>
- Hernández-Olivas, E., Asensio-Grau, A., Calvo-Lerma, J., García-Hernández, J., Heredia, A., & Andrés, A. (2022). Content and bioaccessibility of bioactive compounds with potential benefits for macular health in tiger nut products. *Food Bioscience*, 49, 101879–101879. <https://doi.org/10.1016/J.FBIO.2022.101879>
- Hussein, O. A., & Ibrahim, J. A. A. (2023). Leachates Recirculation Impact on the Stabilization of the Solid Wastes – A Review. *Journal of Ecological Engineering*, 24(4), 172–183. <https://doi.org/10.12911/22998993/159635>
- Ibrahim, I. M., Radwan, M. A., Sadek, M. A., Darwish, S. A., & Mostafa, N. Y. (2022). A Comparative Study on Heavy Metal Removal Capacity of Different Hydrogels through Electrostatic Interactions and Ion-Exchange Mechanisms. *The Open Chemical Engineering Journal*, 16(1).

<https://doi.org/10.2174/18741231-V16-E221128-2022-10>

Ipinge, L. N., Gabriel, N. N., & Iitembu, J. A. (2023). Pawpaw (*Carica papaya*) Extracts as Potential Growth Promoters and Sex Reversal Agents in Aquaculture. *Sustainability Sciences in Asia and Africa*, 197–207.

[https://doi.org/10.1007/978-981-19-7451-9\\_8](https://doi.org/10.1007/978-981-19-7451-9_8)

Islam, M. A., Jacob, M. V., & Antunes, E. (2021). A critical review on silver nanoparticles: From synthesis and applications to its mitigation through low-cost adsorption by biochar. *Journal of Environmental Management*, 281, 111918. <https://doi.org/10.1016/j.jenvman.2020.111918>

Jaswal, T., & Gupta, J. (2023). A review on the toxicity of silver nanoparticles on human health. *Materials Today: Proceedings*, 81(2), 859–863. <https://doi.org/10.1016/J.MATPR.2021.04.266>

Jean Bosco, M., Marie Elvira, A., Ngon Rene, M. A., Georges, T., & Nguete Caroline Viviane, Z. (2023). Influence of winds and rains on pawpaw cultivation (*Carica papaya*) in the locality of Meyomessala. *International Journal of Scientific and Research Publications*, 13(2), 392–398. <https://doi.org/10.29322/IJSRP.13.02.2023.P13448>

Joy, F., Devasia, J., Nizam, A., Lakshmaiah, V. V., & Krishna, S. B. N. (2023). Fungi-Templated Silver Nanoparticle Composite: Synthesis, Characterization, and Its Applications. *Applied Sciences*, 13(4), 2158–2158. <https://doi.org/10.3390/APP13042158>

Kane, S. N., Mishra, A., & Dutta, A. K. (2016). Preface: International Conference on Recent Trends in Physics (ICRTP 2016). *Journal of Physics:*

*Conference Series*, 755(1). <https://doi.org/10.1088/1742-6596/755/1/011001>

Kanmani, S., & Gandhimathi, R. (2013). Investigation of physicochemical characteristics and heavy metal distribution profile in groundwater system around the open dump site. *Applied Water Science*, 3(2), 387–399. <https://doi.org/10.1007/s13201-013-0089-y>

Katata-seru, L., Moremedi, T., Aremu, O. S., & Bahadur, I. (2017). PT SC. *Journal of Molecular Liquids*. <https://doi.org/10.1016/j.molliq.2017.11.093>

Kim, S., Kim, N., Seo, J., Park, J. E., Song, E. H., Choi, S. Y., Kim, J. E., Cha, S., Park, H. H., & Nam, J. M. (2020). Nanoparticle-based computing architecture for nanoparticle neural networks. *Science Advances*, 6(35), 1–9. <https://doi.org/10.1126/sciadv.abb3348>

Kräutler, B. (2023). Cobalt enzymes. *Comprehensive Inorganic Chemistry III, Third Edition, 1–10*, 268–301. <https://doi.org/10.1016/B978-0-12-823144-9.00146-1>

Kumar, P., Debele, S. E., Sahani, J., Rawat, N., Marti-Cardona, B., Alfieri, S. M., Basu, B., Basu, A. S., Bowyer, P., Charizopoulos, N., Gallotti, G., Jaakko, J., Leo, L. S., Loupis, M., Menenti, M., Mickovski, S. B., Mun, S. J., Gonzalez-Ollauri, A., Pfeiffer, J., ... Zieher, T. (2021). Nature-based solutions efficiency evaluation against natural hazards: Modelling methods, advantages and limitations. *Science of the Total Environment*, 784, 147058–147058. <https://doi.org/10.1016/j.scitotenv.2021.147058>

Kwame, T., Francis, B., & Akoto, O. (2019). Heavy metal contamination assessment of groundwater quality: a case study of Oti landfill site, Kumasi. *Applied Water Science*, 9(2), 1–15.

<https://doi.org/10.1007/s13201-019-0915-y>

Lazarenko, N. S., Golovakhin, V. V., Shestakov, A. A., Lapekin, N. I., & Bannov, A. G. (2022). Recent Advances on Membranes for Water Purification Based on Carbon Nanomaterials. *Membranes*, 12(10), 915–915. <https://doi.org/10.3390/MEMBRANES12100915>

Lee, S. H., & Jun, B. H. (2019). Silver nanoparticles: Synthesis and application for nanomedicine. *International Journal of Molecular Sciences*, 20(4), 1–23. <https://doi.org/10.3390/ijms20040865>

Leudjo Taka, A., Klink, M., Yangkou Mbianda, X., Mtunzi, F., & Bobby Naidoo, E. (2022). Carbon Nanotubes Reinforced Polymeric Hybrid Materials for Water Purification. *Composites Science and Technology*, 197–223. [https://doi.org/10.1007/978-981-19-2332-6\\_9](https://doi.org/10.1007/978-981-19-2332-6_9)

Li, J. F., Huang, Y. F., Ding, Y., Yang, Z. L., Li, S. B., Zhou, X. S., Fan, F. R., Zhang, W., Zhou, Z. Y., Wu, D. Y., Ren, B., Wang, Z. L., & Tian, Z. Q. (2010). Shell-isolated nanoparticle-enhanced Raman spectroscopy. *Nature*, 464(7287), 392–395. <https://doi.org/10.1038/nature08907>

Liu, X., & Wang, Y. (2022). Identification and Assessment of Groundwater and Soil Contamination from an Informal Landfill Site. *Sustainability*, 14(24), 16948–16948. <https://doi.org/10.3390/SU142416948>

Lucchini, R. G., Aschner, M., & Kim, Y. (2022). Manganese. *Handbook on the*

*Toxicology of Metals: Fifth Edition*, 2, 501–538.

<https://doi.org/10.1016/B978-0-12-822946-0.00019-2>

Maliszewska, I., Szewczyk, K., & Waszak, K. (2009). Biological synthesis of silver nanoparticles. *Journal of Physics: Conference Series*, 146.

<https://doi.org/10.1088/1742-6596/146/1/012025>

Manikandan, S., Subbaiya, R., Saravanan, M., Ponraj, M., Selvam, M., & Pugazhendhi, A. (2022). A critical review of advanced nanotechnology and hybrid membrane based water recycling, reuse, and wastewater treatment processes. *Chemosphere*, 289, 132867–132867.

<https://doi.org/10.1016/J.CHEMOSPHERE.2021.132867>

Marimuthu, S., Antonisamy, A. J., Malayandi, S., Rajendran, K., Tsai, P., Pugazhendhi, A., & Ponnusamy, V. K. (2020). na l P of. *Journal of Photochemistry & Photobiology, B: Biology*, 111823.

<https://doi.org/10.1016/j.jphotobiol.2020.111823>

Martinez-Boubeta, C., & Simeonidis, K. (2019). Magnetic Nanoparticles for Water Purification. *Nanoscale Materials in Water Purification*, 521–552.

<https://doi.org/10.1016/B978-0-12-813926-4.00026-4>

Milatovic, D., Gupta, R. C., Yin, Z., Zaja-Milatovic, S., Brockett, M. M., & Aschner, M. (2022). Manganese. *Reproductive and Developmental Toxicology*, 587–602. <https://doi.org/10.1016/B978-0-323-89773-0.00031-X>

X

Mittal, A. K., Bhaumik, J., Kumar, S., & Banerjee, U. C. (2014). Biosynthesis of silver nanoparticles: Elucidation of prospective mechanism and

therapeutic potential. *Journal of Colloid and Interface Science*, 415, 39–47. <https://doi.org/10.1016/j.jcis.2013.10.018>

Mohajerani, A., Burnett, L., Smith, J. V., Kurmus, H., Milas, J., Arulrajah, A., Horpibulsuk, S., & Kadir, A. A. (2019). Nanoparticles in construction materials and other applications, and implications of nanoparticle use. *Materials*, 12(19), 1–25. <https://doi.org/10.3390/ma12193052>

Mohammed, A., Sanusi, K., & Haruna, U. Y. (2022). Tiger nut ( *Cyperus esculentus* L.) and date palm ( *Phoenix dactylifera* L.) fruit blend mitigates hyperglycemia, insulin resistance and oxidative complications in type-2 diabetes models. *Journal of Food Biochemistry*, 46(12). <https://doi.org/10.1111/JFBC.14423>

Mora-Godínez, S., Contreras-Torres, F. F., & Pacheco, A. (2023). Characterization of Silver Nanoparticle Systems from Microalgae Acclimated to Different CO<sub>2</sub> Atmospheres. *ACS Omega*, 8(24), 21969–21982. <https://doi.org/10.1021/ACSOMEGA.3C01914>

Morones, J. R., Elechiguerra, J. L., Camacho, A., Holt, K., Kouri, J. B., Ramírez, J. T., & Yacaman, M. J. (2005). The bactericidal effect of silver nanoparticles. *Nanotechnology*, 16(10), 2346–2353. <https://doi.org/10.1088/0957-4484/16/10/059>

Morozova, Y. A., Dergachev, D. S., & Subotyalov, M. A. (2021). Silver nanoparticles: safety and efficiency for human health. *Reviews on Clinical Pharmacology and Drug Therapy*, 19(3), 247–257. <https://doi.org/10.17816/RCF193247-257>

Mumtaz, Z. M., Hussain, N., & Husnain Azam, H. M. (2023). Applications of novel nanomaterials in water treatment. *Nanomaterials for Bioreactors and Bioprocessing Applications*, 217–243. <https://doi.org/10.1016/B978-0-323-91782-7.00002-3>

Municipality, E. (2016). Groundwater quality assessment using statistical approach and water quality Groundwater quality assessment using statistical approach and water quality index in Ejisu-Juaben Municipality , Ghana. *Environmental Earth Sciences*, April. <https://doi.org/10.1007/s12665-015-5105-0>

Nahar, M. K., Zakaria, Z., Hashim, U., & Bari, M. F. (2015). Green Synthesis of Silver Nanoparticles Using Momordica Charantia Fruit Extracts. *Advanced Materials Research*, 1109, 35–39. <https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMR.1109.35>

Nguyen, N. Y. T., Grelling, N., Wetteland, C. L., Rosario, R., & Liu, H. (2018). Antimicrobial Activities and Mechanisms of Magnesium Oxide Nanoparticles (nMgO) against Pathogenic Bacteria, Yeasts, and Biofilms. *Scientific Reports*, 8(1), 1–23. <https://doi.org/10.1038/s41598-018-34567-5>

Njewa, J., Vunain, E., & Biswick, T. (2021). Wastewater Clarification and Microbial Load Reduction Using Agro-Forestry and Agricultural Wastes. *Tanzania Journal of Science*, 47(1), 19–33. <https://doi.org/10.4314/TJS.V47I1>

Nkansah, M. A., Ofosuah, J., & Boakye, S. (2010). *Quality of groundwater in the*

*Kwahu West district of Ghana Kwame Nkrumah University of Science and Technology, Kumasi - Ghana. 578–584.*

<https://doi.org/10.5251/ajsir.2010.1.3.578.584>

Nyairo, W. N., Shikuku, V. O., & Sanou, Y. (2022). Carbon Nanotubes in Water Treatment. *Innovative Nanocomposites for the Remediation and Decontamination of Wastewater*, 171–184. <https://doi.org/10.4018/978-1-6684-4553-2.CH009>

Owusu, K., Amano, A., Danso-boateng, E., Adom, E., & Nkansah, D. K. (2021). *Effect of waste landfill site on surface and ground water drinking quality.* 35, 715–729. <https://doi.org/10.1111/wej.12664>

Pandey, P., Khan, F., Agarwal, S., & Singh, M. (2022). Nano Adsorbents in Wastewater Treatment: A New Paradigm in Wastewater Management. *Letters in Applied NanoBioScience*, 12(4), 125–125. <https://doi.org/10.33263/LIANBS124.125>

Pandey, T., Islam, M. A., Paul, A. K., & Ahmed, T. (2022). Surface Plasmon Resonance Based Tunable D-Shaped Single Polarization Filter at Communication Band. *Optical Materials Express*, 12(5), 1947–1947. <https://doi.org/10.1364/OME.456600>

Parvin, F., & Tareq, S. M. (2021). Impact of landfill leachate contamination on surface and groundwater of Bangladesh: a systematic review and possible public health risks assessment. *Applied Water Science*, 11(6), 1–17. <https://doi.org/10.1007/s13201-021-01431-3>

Patanjali, P., Singh, R., Kumar, A., & Chaudhary, P. (2019). Nanotechnology for

water treatment: A green approach. In *Green Synthesis, Characterization and Applications of Nanoparticles*. Elsevier Inc.

<https://doi.org/10.1016/B978-0-08-102579-6.00021-6>

Patel, K. D., Buitrago, J. O., Parthiban, S. P., Lee, J. H., Singh, R. K., Knowles, J.

C., & Kim, H. W. (2019). Combined Effects of Nanoroughness and Ions Produced by Electrodeposition of Mesoporous Bioglass Nanoparticle for Bone Regeneration. *ACS Applied Bio Materials*, 5190–5203.

<https://doi.org/10.1021/acsabm.9b00859>

Patel, K. K., Tripathi, M., Pandey, N., Agrawal, A. K., Gade, S., Anjum, M. M.,

Tilak, R., & Singh, S. (2019). Alginate lyase immobilized chitosan nanoparticles of ciprofloxacin for the improved antimicrobial activity against the biofilm associated mucoid *P. aeruginosa* infection in cystic fibrosis. *International Journal of Pharmaceutics*, 563(December 2018), 30–42. <https://doi.org/10.1016/j.ijpharm.2019.03.051>

Pazdar, S., Eslamian, S., Gholami, H., & Ostad-Ali-Askari, K. (2019). Reduction of Microbial Contamination of Outlet Waste in Urban Wastewater Treatment Plants. *American Journal of Engineering and Applied Sciences*, 12(3), 432–439. <https://doi.org/10.3844/ajeassp.2019.432.439>

Pooja, Kumari, M., & Tomar, R. K. (2022). Nanotechnology for Remediation of Water Environment. *IRC-SET 2021*, 373–385.

[https://doi.org/10.1007/978-981-16-9869-9\\_29](https://doi.org/10.1007/978-981-16-9869-9_29)

Pradeepa prasad, Shrivastava, J., J, A., OM, A., S, S. S. S., & Swetha. (2023). *Morinda citrifolia* L.(Noni)-A Review on its health benefits,

Phytochemistry and its recent researches. *International Journal For Multidisciplinary Research*, 5(3).

<https://doi.org/10.36948/IJFMR.2023.V05I03.2886>

Przydatek, G., & Kanownik, W. (2019). Impact of small municipal solid waste landfill on groundwater quality. *Environmental Monitoring and Assessment*, 191(3), 1–14. <https://doi.org/10.1007/s10661-019-7279-5>

Qin, Y., Liu, Y., Yuan, L., Yong, H., & Liu, J. (2019). Preparation and characterization of antioxidant, antimicrobial and pH-sensitive films based on chitosan, silver nanoparticles and purple corn extract. *Food Hydrocolloids*, 96(April), 102–111. <https://doi.org/10.1016/j.foodhyd.2019.05.017>

Quadros, M. E., & Marr, L. C. (2010). Environmental and human health risks of aerosolized silver nanoparticles. *Journal of the Air and Waste Management Association*, 60(7), 770–781. <https://doi.org/10.3155/1047-3289.60.7.770>

Rafique, M., Sadaf, I., Rafique, M. S., & Tahir, M. B. (2017). A review on green synthesis of silver nanoparticles and their applications. In *Artificial Cells, Nanomedicine and Biotechnology* (Vol. 45, Issue 7, pp. 1272–1291). Taylor and Francis Ltd. <https://doi.org/10.1080/21691401.2016.1241792>

Rai, M., Yadav, A., & Gade, A. (2009). Silver nanoparticles as a new generation of antimicrobials. *Biotechnology Advances*, 27(1), 76–83. <https://doi.org/10.1016/j.biotechadv.2008.09.002>

Rajninec, M., Vidiš, M., Tomka, M., Šedivá, M., Gažiová, A., & Mucha, J.

(2023). Antimicrobial effect of silver nanoparticle-based thin films. *The Journal of Microbiology, Biotechnology and Food Sciences*, 12(6), e10037–e10037. <https://doi.org/10.55251/JMBFS.10073>

Ramakritinan, C. M., Kaarunya, E., Shankar, S., & Kumaraguru, A. K. (2013). Antibacterial effects of Ag, Au and bimetallic (Ag-Au) nanoparticles synthesized from red algae. *Advanced Materials Research*, 698(13), 211–230. <https://doi.org/10.4028/www.scientific.net/SSP.201.211>

Rossiter, H. M. A., Owusu, P. A., Awuah, E., Macdonald, A. M., & Schäfer, A. I. (2010). Science of the Total Environment Chemical drinking water quality in Ghana : Water costs and scope for advanced treatment. *Science of the Total Environment*, 408(11), 2378–2386. <https://doi.org/10.1016/j.scitotenv.2010.01.053>

Safatian, F., Doago, Z., Torabbeigi, M., Rahmani Shams, H., & Ahadi, N. (2019). Lead ion removal from water by hydroxyapatite nanostructures synthesized from egg shells with microwave irradiation. *Applied Water Science*, 9(4), 1–6. <https://doi.org/10.1007/s13201-019-0979-8>

Saleh, T. A., & Gupta, V. K. (2016). Application of Nanomaterial-Polymer Membranes for Water and Wastewater Purification. *Nanomaterial and Polymer Membranes*, 233–250. <https://doi.org/10.1016/B978-0-12-804703-3.00009-7>

Santonen, T., & Sainio, M. (2023). Manganese and Rhenium. *Patty's Toxicology*, 1–36. <https://doi.org/10.1002/0471125474.TOX039.PUB3>.

Sarkar, S., & Ahuja, S. (2022). Importance of nanomaterials in water purification. *Separation Science and Technology*, 15, 13–36.

<https://doi.org/10.1016/B978-0-323-90763-7.00002-0>

Shankar, S. S., Rai, A., Ahmad, A., & Sastry, M. (2004). Rapid synthesis of Au, Ag, and bimetallic Au core-Ag shell nanoparticles using Neem (Azadirachta indica) leaf broth. *Journal of Colloid and Interface Science*, 275(2), 496–502. <https://doi.org/10.1016/J.JCIS.2004.03.003>

Sharma, A. K., Tiwari, A. K., Dixit, A. R., & Singh, R. K. (2017). Investigation into Performance of SiO<sub>2</sub> Nanoparticle Based Cutting Fluid in Machining Process. *Materials Today: Proceedings*, 4(2), 133–141. <https://doi.org/10.1016/j.matpr.2017.01.006>

Sharma, P., & Sharma, B. (2023). Amoxicillin Degradation and Antimutagenic Potential of Phytofabricated Silver Nanoparticles Doped Polyurethane Membrane for Wastewater Treatment. *Nano LIFE*, 13(3). <https://doi.org/10.1142/S1793984423500095>

Shettima, S. A., Baffa, A. A., Uzoma, O. B., Akinlabi, A. K., & Shettima, A. A. (2023). Investigation Into The Potential Uses Of Noni (Morinda citrifolia) Leaves And Stem Bark. *Journal Of Chemical Society Of Nigeria*, 48(2), 326–332. <https://doi.org/10.46602/JCSN.V48I2.874>

Sim, W., Barnard, R. T., Blaskovich, M. A. T., & Ziora, Z. M. (2018). Antimicrobial Silver in Medicinal and Consumer Applications: A Patent Review of the Past Decade (2007–2017). *Antibiotics*, 7(4), 93.

<https://doi.org/10.3390/ANTIBIOTICS7040093>

Smith, G. N., Canning, S. L., Derry, M. J., Jones, E. R., Neal, T. J., & Smith, A. J. (2020). Ionic and Nonspherical Polymer Nanoparticles in Nonpolar Solvents. *Macromolecules*, 53(8), 3148–3156.

<https://doi.org/10.1021/acs.macromol.0c00121>

Subroto, E., Indiarto, R., & Andoyo, R. (2023). Bioavailability of iron and its potential to improve the immune system and wardoff COVID-19: a review. *Food Research*, 7(1), 76–92.

[https://doi.org/10.26656/FR.2017.7\(1\).701](https://doi.org/10.26656/FR.2017.7(1).701)

Sun, A., Huang, Z., He, L., Dong, W., Tian, Y., Huang, A., & Wang, X. (2023). Metabolomic analyses reveal the antibacterial properties of a novel antimicrobial peptide MOp3 from *Moringa oleifera* seeds against *Staphylococcus aureus* and its application in the infecting pasteurized milk. *Food Control*, 150, 109779–109779.

<https://doi.org/10.1016/J.FOODCONT.2023.109779>

Sun, H., & Costa, M. (2022). Chromium. *Handbook on the Toxicology of Metals: Fifth Edition*, 2, 197–220. <https://doi.org/10.1016/B978-0-12-822946-0.00007-6>

Suthar, J. K., Vaidya, A., & Ravindran, S. (2022). Toxic implications of silver nanoparticles on the central nervous system: A systematic literature review. *Journal of Applied Toxicology*, 43(1), 21–24.

<https://doi.org/10.1002/JAT.4317>

Tamilarasi, P., & Meena, P. (2019). Green synthesis of silver nanoparticles (Ag

NPs) using *Gomphrena globosa* (Globe amaranth) leaf extract and their characterization. *Materials Today: Proceedings*, 33, 2209–2216.

<https://doi.org/10.1016/j.matpr.2020.04.025>

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. *EXS*, 101, 133–164.

[https://doi.org/10.1007/978-3-7643-8340-4\\_6](https://doi.org/10.1007/978-3-7643-8340-4_6)

Teixeira, A. P. C., Tristão, J. C., Araujo, M. H., Oliveira, L. C. A., Moura, F. C. C., Ardisson, J. D., Amorim, C. C., & Lago, R. M. (2012). Iron: a versatile element to produce materials for environmental applications. *Journal of the Brazilian Chemical Society*, 23(9), 1579–1593.

<https://doi.org/10.1590/S0103-50532012005000039>

Tenenbein, M., & Huang, X. (2022). Iron. *Handbook on the Toxicology of Metals: Fifth Edition*, 2, 391–417. <https://doi.org/10.1016/B978-0-12-822946-0.00016-7>

Thakur, A., Verma, M., Bharti, R., & Sharma, R. (2023). Recent Advancement in the Green Synthesis of Silver Nanoparticles. *Current Chinese Science*, 03. <https://doi.org/10.2174/2210298103666230511162421>

Trinh, V. T., Nguyen, T. M. P., Van, H. T., Hoang, L. P., Nguyen, T. V., Ha, L. T., Vu, X. H., Pham, T. T., Nguyen, T. N., Quang, N. V., & Nguyen, X. C. (2020). Phosphate Adsorption by Silver Nanoparticles-Loaded Activated Carbon derived from Tea Residue. *Scientific Reports*, 10(1), 3634–3634. <https://doi.org/10.1038/S41598-020-60542-0>.

- Ty, B., Phat, C., Fidero, K., Andrews, E. M., Kurniawan, W., & Hinode, H. (2022). Heavy Metals. *Water and Life in Tonle Sap Lake*, 379–386. [https://doi.org/10.1007/978-981-16-6632-2\\_36](https://doi.org/10.1007/978-981-16-6632-2_36)
- Vankdoth, S., Velidandi, A., Sarvepalli, M., & Vangalapati, M. (2022). Role of plant (tulasi, neem and turmeric) extracts in defining the morphological, toxicity and catalytic properties of silver nanoparticles. *Inorganic Chemistry Communications*, 140, 109476–109476. <https://doi.org/10.1016/J.INOCHE.2022.109476>
- Verma, A., & Bharadvaja, N. (2021). Plant-Mediated Synthesis and Characterization of Silver and Copper Oxide Nanoparticles: Antibacterial and Heavy Metal Removal Activity. *Journal of Cluster Science*, 33(4), 1–16. <https://doi.org/10.1007/S10876-021-02091-8>
- Vincent, J. B. (2023). Chromium. *Encyclopedia of Human Nutrition: Volume 1-4, Fourth Edition*, 1–4, 181–188. <https://doi.org/10.1016/B978-0-12-821848-8.00001-9>
- Wang, Q., Li, Y., Liu, Y., Ren, J., Zhang, Y., Qu, G., & Wang, T. (2021). Effective removal of the heavy metal-organic complex Cu-EDTA from water by catalytic persulfate oxidation: Performance and mechanisms. *Journal of Cleaner Production*, 314, 128119. <https://doi.org/10.1016/j.jclepro.2021.128119>
- Wang, Z., Wang, Z., Lin, S., Jin, H., Gao, S., Zhu, Y., & Jin, J. (2018). Nanoparticle-templated nanofiltration membranes for ultrahigh performance desalination. *Nature Communications*, 9(1).

<https://doi.org/10.1038/s41467-018-04467-3>

Water, S., & Management, R. (2022). Assessment of the Quality of Water Resources in the Upper East Region , Assessment of the quality of water resources in the Upper East Region , Ghana : a review. *Sustainable Water Resources Management*, June 2020. <https://doi.org/10.1007/s40899-020-00409-4>

Wdowczyk, A., & Szymańska-Pulikowska, A. (2021). Analysis of the possibility of conducting a comprehensive assessment of landfill leachate contamination using physicochemical indicators and toxicity test. *Ecotoxicology and Environmental Safety*, 221, 112434. <https://doi.org/10.1016/j.ecoenv.2021.112434>

Wierzba, S., Makuchowska-Fryc, J., Kłos, A., Ziembik, Z., & Ochędzan-Siodłak, W. (2022). Role of calcium carbonate in the process of heavy metal biosorption from solutions: synergy of metal removal mechanisms. *Dental Science Reports*, 12(1), 17668. <https://doi.org/10.1038/S41598-022-22603-4>

Xu, R., Li, Q., Yang, Y., Jin, S., Liao, L., Wu, Z.-X., Zhe Yin, B. X., Nan, X., He, Y., Zhu, B., & Jiang, T. (2022). Removal of heavy metal(loid)s from aqueous solution by biogenic FeS-kaolin composite: Behaviors and mechanisms. *Chemosphere*, 299.

Xu, Y., Zhong, Z., Zeng, X., Zhao, Y., Deng, W., & Chen, Y. (2023). Novel Materials for Heavy Metal Removal in Capacitive Deionization. *Applied Sciences*, 13(9), 5635–5635. <https://doi.org/10.3390/APP13095635>

- Yao, Y., Zhou, Y., Liu, L., Xu, Y., Chen, Q., Wang, Y., Wu, S., Deng, Y., Zhang, J., & Shao, A. (2020). Nanoparticle-Based Drug Delivery in Cancer Therapy and Its Role in Overcoming Drug Resistance. *Frontiers in Molecular Biosciences*, 1–14. <https://doi.org/10.3389/fmolb.2020.00193>
- Yaseen, B., Gangwar, C., Kumar, I., Sarkar, J., & Naik, R. M. (2022). Detailed Kinetic and Mechanistic Study for the Preparation of Silver Nanoparticles by a Chemical Reduction Method in the Presence of a Neuroleptic Agent (Gabapentin) at an Alkaline pH and its Characterization. *ACS Omega*, 7(7), 5739–5750. <https://doi.org/10.1021/ACSOMEGA.1C05499>
- Yin, I. X., Zhang, J., Zhao, I. S., Mei, M. L., Li, Q., & Chu, C. H. (2020). The antibacterial mechanism of silver nanoparticles and its application in dentistry. *International Journal of Nanomedicine*, 15, 2555–2562. <https://doi.org/10.2147/IJN.S246764>
- Yu, Y., Lu, X., Zhang, T., Zhao, C., Guan, S., Pu, Y., & Gao, F. (2022). Tiger Nut (*Cyperus esculentus* L.): Nutrition, Processing, Function and Applications. *Foods*, 11(4), 601–601. <https://doi.org/10.3390/FOODS11040601>
- Zeng, D., Chen, G., Zhou, P., Xu, H., Qiong, A., Duo, B., Lu, X., Wang, Z., & Han, Z. (2021). Factors influencing groundwater contamination near municipal solid waste landfill sites in the Qinghai-Tibetan plateau. *Ecotoxicology and Environmental Safety*, 211, 111913. <https://doi.org/10.1016/j.ecoenv.2021.111913>
- Zhang, J., Feng, C., & Yu, C. (2019). The use of functional nanoparticles for water purification. *Revolutionizing Tropical Medicine: Point-of-Care*

*Tests, New Imaging Technologies and Digital Health*, 600–614.

<https://doi.org/10.1002/9781119282686.CH34>

Zhao, H., Li, J., Zhang, Q., Li, S., & Yin, X. (2022). Spoof Surface Plasmon Polariton Antenna With Dual-Band Endfire Gain and Flexible Small Frequency Ratio. *IEEE Transactions on Antennas and Propagation*, 70(11), 11079–11084. <https://doi.org/10.1109/TAP.2022.3184499>



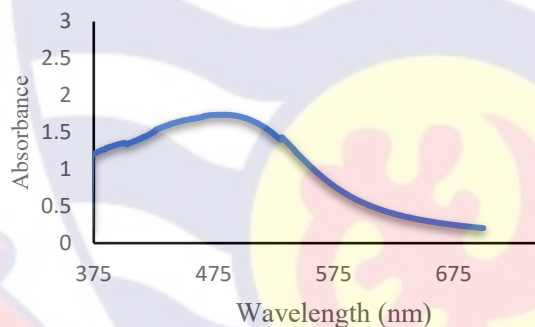
## APPENDICES

### APPENDIX A

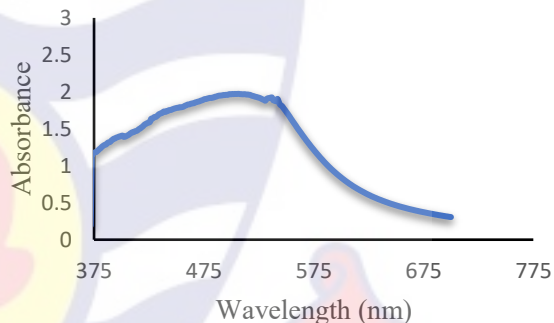
#### RATIOS OF NONI LEAVES EXTRACT TO THE PRECURSOR

Summary graphs on the mix ratios and their respective plasmonic absorbances for the synthesis of AgNPs using Noni leaves extract and 0.001 AgNO<sub>3</sub> precursor solution.

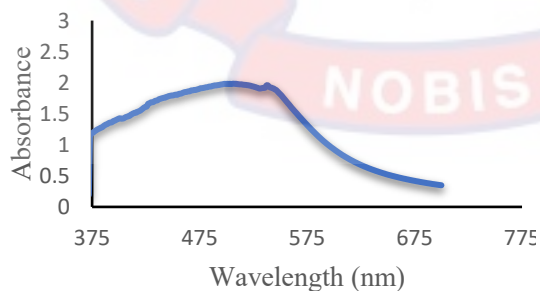
**Plasmonic absorbance spectra of the 1:1 ratio of extract to 0.001 AgNO<sub>3</sub> precursor solution**



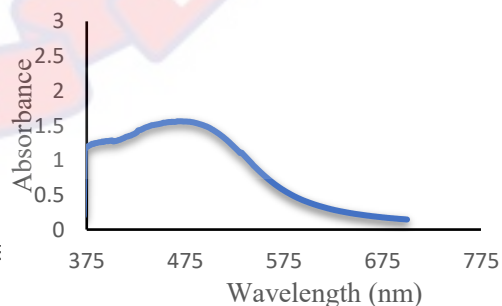
**Plasmonic absorbance spectra of the 1:4 ratio of extract to 0.001 AgNO<sub>3</sub> precursor solution**



**Plasmonic absorbance spectra of the 1:5 ratio of extract to 0.001 AgNO<sub>3</sub> precursor solution**



**Plasmonic absorbance spectra of the 2:1 ratio of extract to 0.001 AgNO<sub>3</sub> precursor solution**



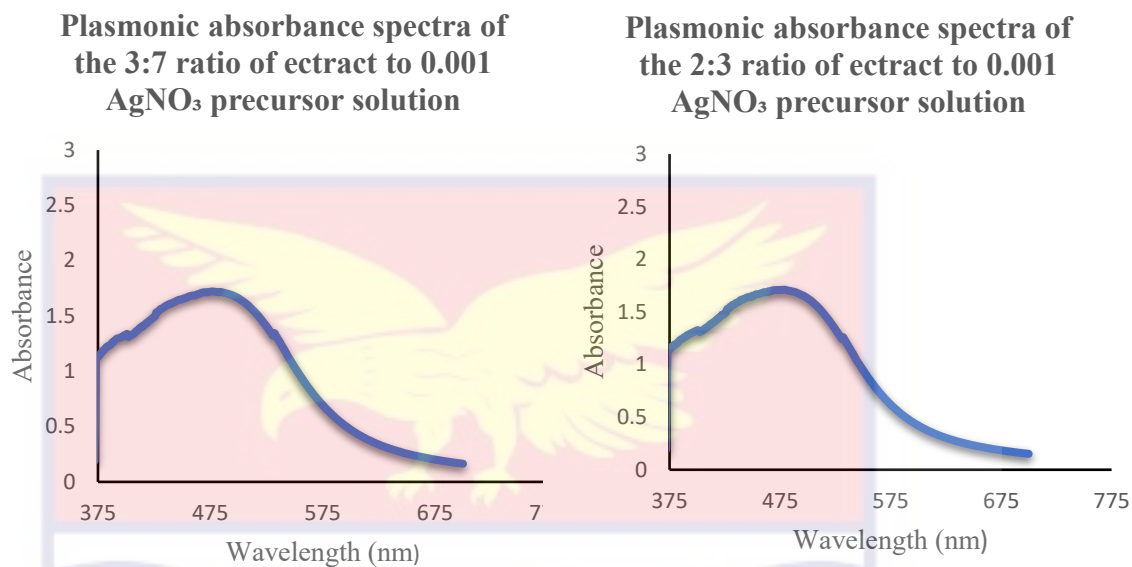


*Figure A:* Various Ratios of the Noni Leaves Extract to the Precursor

## APPENDIX B

### RATIOS OF PAWPAP PEEL EXTRACT TO THE PRECURSOR

Summary graphs on the mix ratios and their respective plasmonic absorbances for the synthesis of AgNPs using Pawpaw pel extract and 0.001 AgNO<sub>3</sub> precursor solution

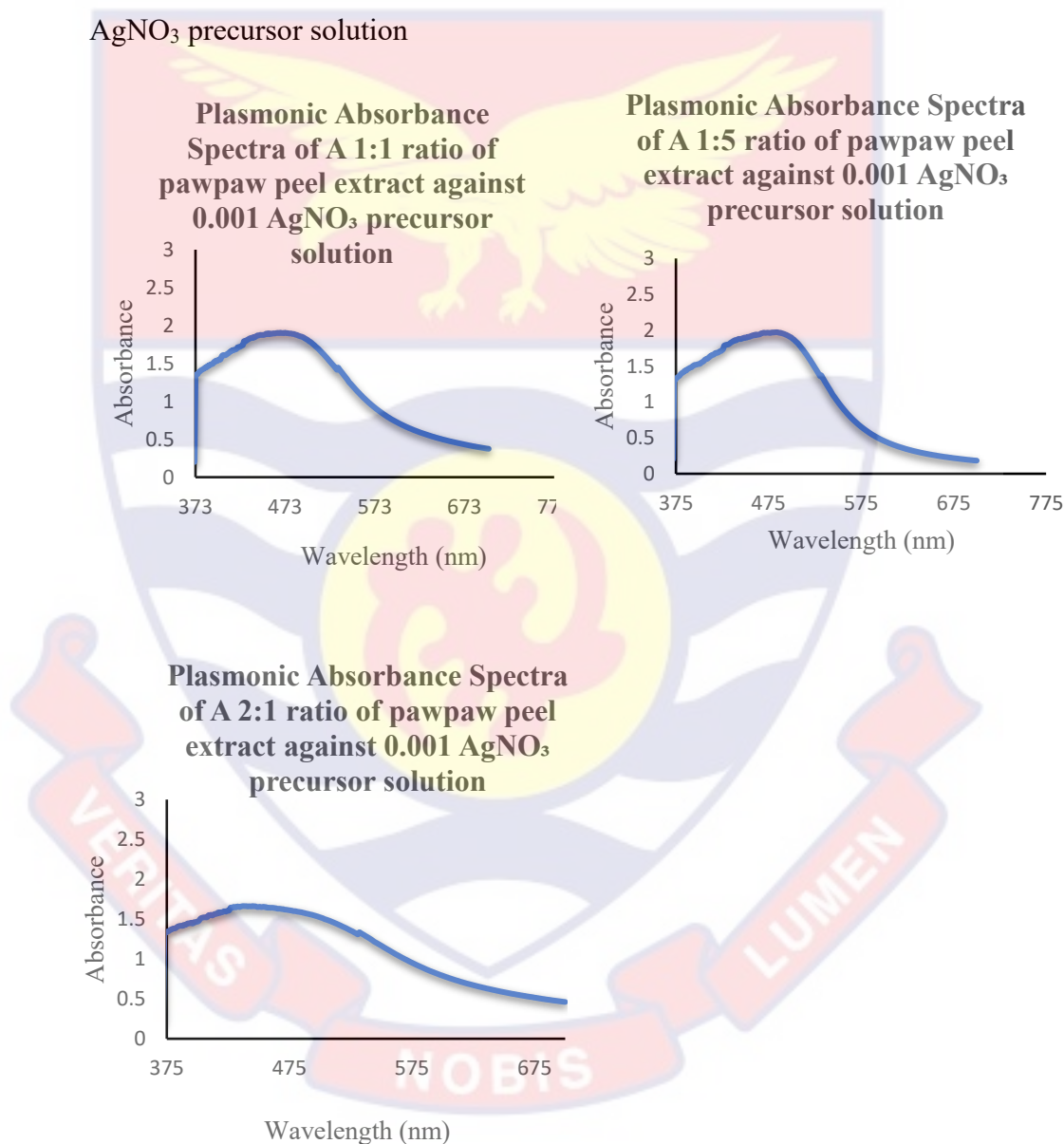


Figure B: Various Ratios of the Pawpaw Peel Extract to the Precursor

## APPENDIX C

### GRAPHS SHOWING BEFORE AND INCUBATED METAL IONS WITH AgNPs

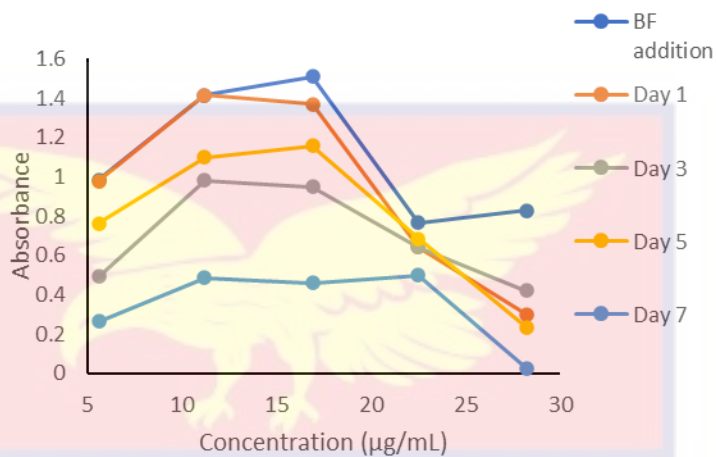


*Figure C1: A Graph of Chromium Ions Incubated with AgNPs Synthesized from Noni Extracts*

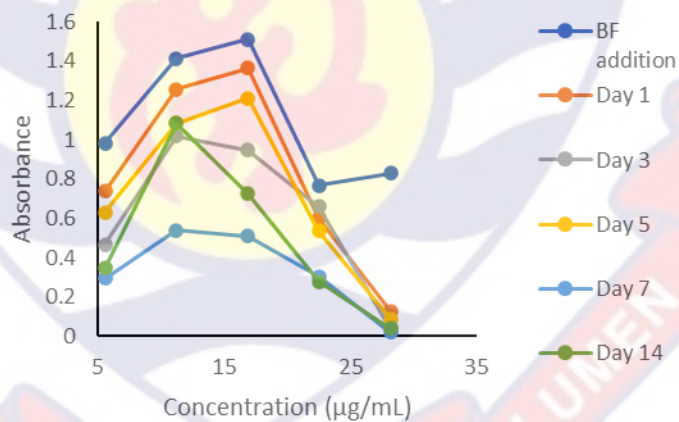


*Figure C2: A Graph of Chromium Ions Incubated with AgNPs Synthesized from Tiger Nut Extracts*

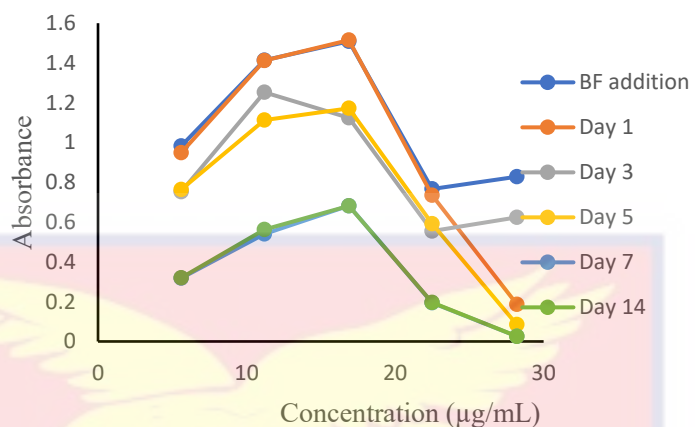


*Figure C3: A Graph of Chromium Ions Incubated with AgNPs Synthesized from Pawpaw Peel Extracts*

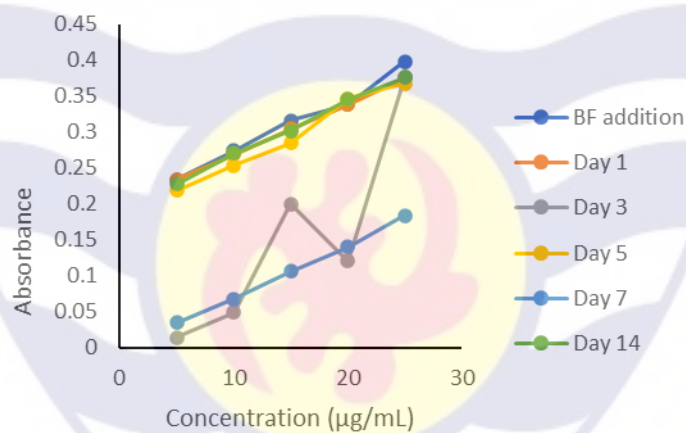


*Figure C4: A Graph of Cobalt Ions Incubated with AgNPs Synthesized from Noni leaves Extracts*

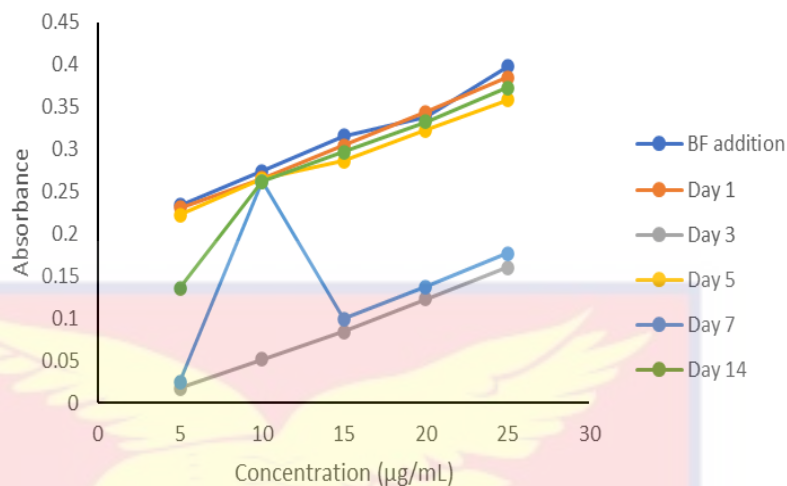


*Figure C5: A Graph of Cobalt Ions Incubated with AgNPs Synthesized from Tiger Nut Extracts*

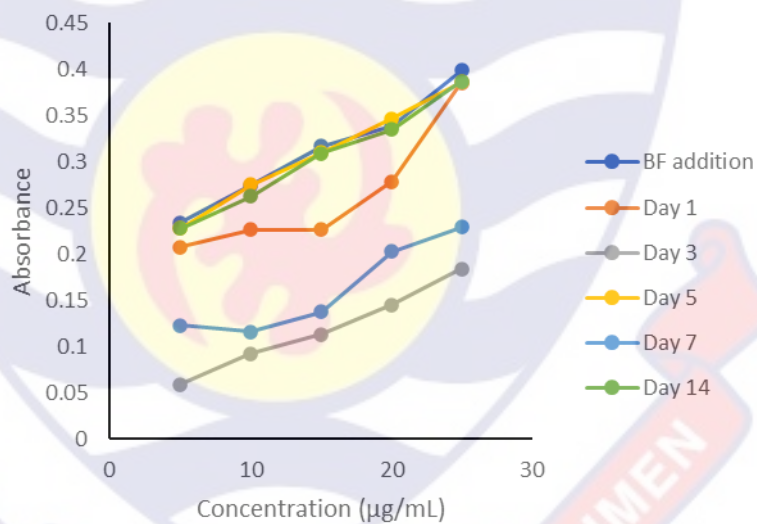


*Figure C6: A Graph of Cobalt Ions Incubated with AgNPs Synthesized from Pawpaw Peel Extracts*

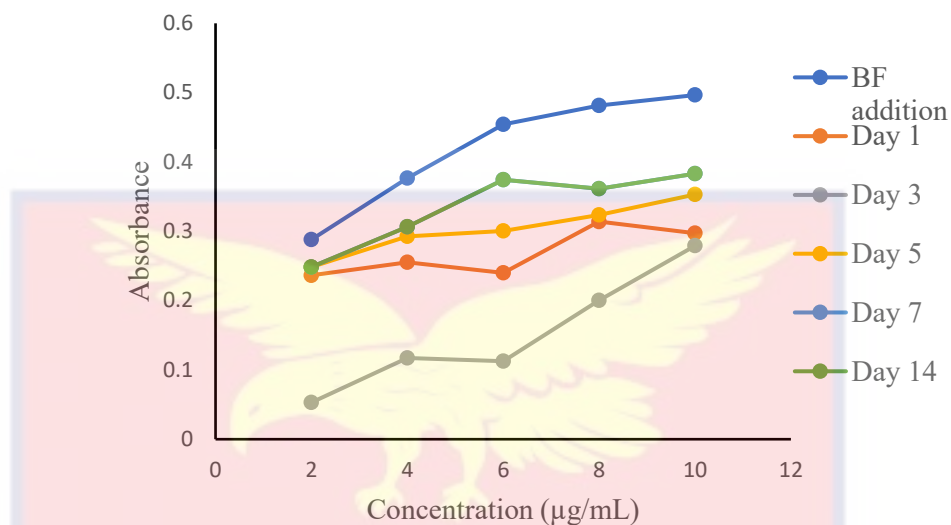


Figure C7: A Graph of Manganese Ions Incubated with AgNPs Synthesized from Noni leaves Extracts

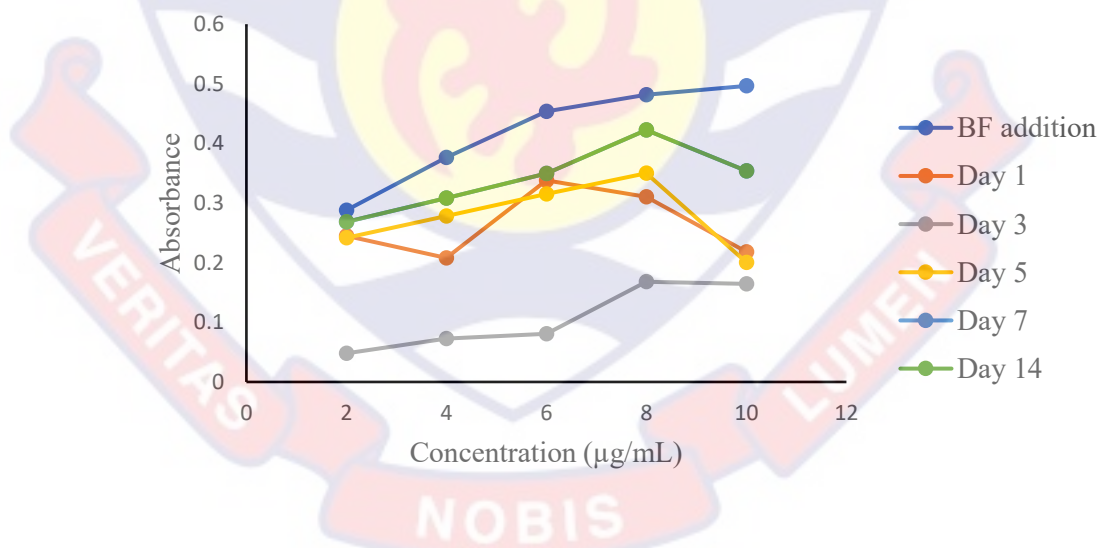


Figure C8: A Graph of Manganese Ions Incubated with AgNP Synthesized from Tiger Nut Extracts

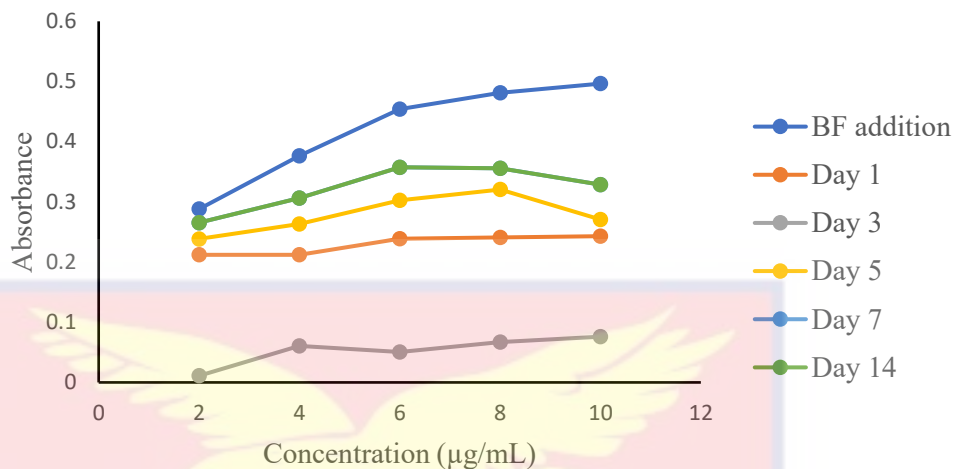


*Figure C9: A Graph of Manganese Ions Incubated with AgNPs Synthesized from Pawpaw Peel Extracts*

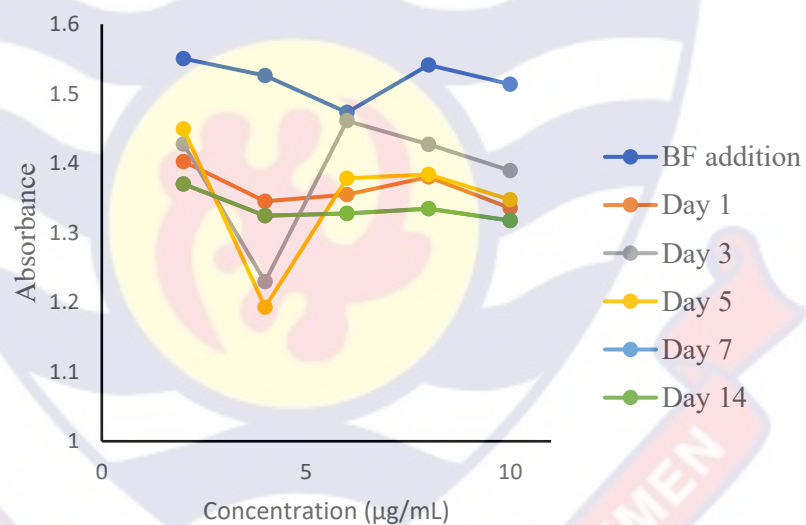


*Figure C10: A Graph of Iron ions Incubated with AgNPs Synthesized from Noni leave Extract*

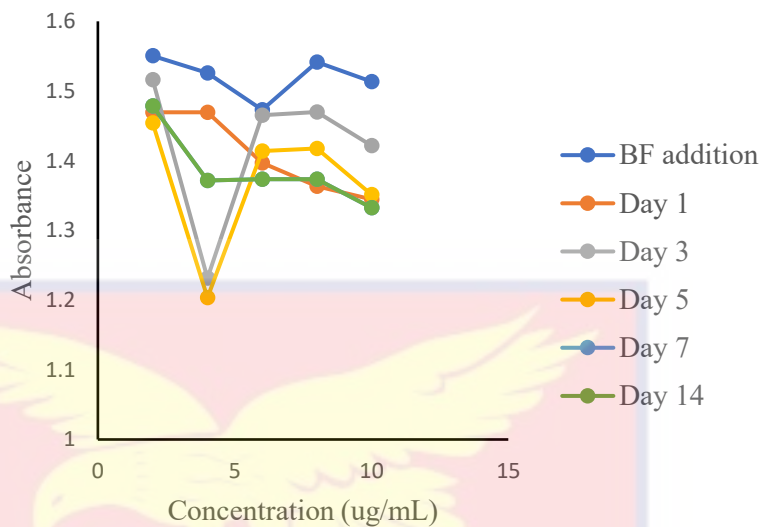


Figure C11: A Graph of Iron ions Incubated with AgNPs Synthesized from Tiger nut Extracts

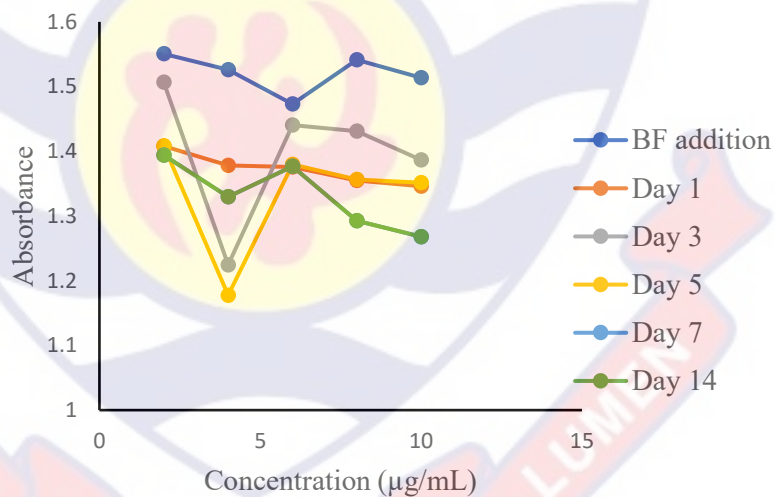


Figure C12: A Graph of Iron ions Incubated with AgNPs Synthesized from Pawpaw Peel Extracts