POTENTIALS OF *Moringa oleifera* SEEDS AND ALUMINIUM SULPHATE AS COAGULANTS FOR TREATMENT OF WATER SAMPLES FROM USUMA RIVER, ABUJA

By

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CERTIFICATION

I certify that this work *"The potentials of Moringa oleifera seeds and Aluminium Sulphate as coagulants for the treatment of water samples from Usuma River Abuja"* was carried out by Arayi Chinyere Elechi, 20054494988 in partial fulfilment of the requirements for award of the M.Sc. degree in Environmental Health Biology, Federal University of Technology Owerri.

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DEDICATION

This thesis is dedicated to the Almighty God and to my parents, Elder and Mrs Mark Elechi Onyelucheya.

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NOMENCLATURE

mg/l:	Milligrams per litre
rpm:	Rotations per minute
NTU:	Nephelometric Turbidity Units
ppm:	Parts per million
µS	MicroSiemens

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ABSTRACT

The potentials of *Moringa oleifera* seeds and Aluminium Sulphate as coagulants for the treatment of water samples from Usuma River Abuja was carried out. The physicochemical parameters investigated were the Turbidity (in NTU), Total Dissolved Solids (in mg/l), Conductivity (in µS), and Salinity (in ppm). For the water treatment with Alum, the standard municipal water treatment dosing of 360 mg/l was used. For the treatment with the natural coagulant, there was need to determine the optimum amount and conditions of application. The Box-Wilson Central Composite Rotatable Factorial Design was applied using Design Expert software for modeling the impacts of *Moringa oleifera*seed concentration (X_1 in mg/l), mixing time (X_2 in minutes), and mixing speed (X_3 in rpm) on the percentage reduction of each of the studied parameter. Data from the experimental run for each parameter were fitted sequentially with a linear model, two factor interaction model, quadratic model, and cubic model. For each model fit, the model equation was obtained and the Analysis of Variance (ANOVA) carried out to assess the statistical significance of the model and the experimental factors based on their p-values. Further statistical inferences were drawn from the determination coefficients of the model (R^2), "lack of fit" of the model and the model graphs where applicable. Results obtained showed that the effect of *Moringa oleifera*seeds on the % turbidity reduction was best represented by the quadratic model. The maximum % Turbidity reduction that could be achieved was 74.79% and would be achieved with a coagulant concentration of 10mg/l, mixing time of 43 minutes and mixing speed of 80 rpm. For the total dissolved solids, salinity and conductivity, none of the models tested gave adequate representation of the data and hence it was not possible to predict optimum conditions for the effects of *Moringa oleifera*seeds on these parameters. However from the experimental results, average reductions of 54.96%, 49.36%, and 56.19% were achieved for the total dissolved solids, conductivity and salinity respectively. For aerated water treated with 360 mg/l of Alum, a percentage decrease of 16.17%, 2.13%, 2.08% and 3.85% was achieved for turbidity, total dissolved solids, conductivity and salinity respectively. These results indicate that the natural coagulant performed better than the artificial coagulant under the treatment conditions investigated in this study.

Key words: *Moringa oleifera*, Aluminium Sulphate, Turbidity, Total dissolved solids, Conductivity, Salinity.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND INFORMATION

Water covers 70% of the Earth's surface and is vital for all known forms of life. It is an essential element in the maintenance of all forms of life and most living organisms can survive only for short periods without water (Tchobanoglous and Schroeder, 1985).Water in its liquid form is the material that makes life possible on earth. All living organisms are composed of cells that contain at least 60 percent water. Metabolic activities in living organisms take place in a water solution. Organisms can exist only where they have access to adequate supplies of water. For man, as well as for some commercial and industrial uses, the quality of water is as important as its quantity (Enger and Smith, 2006).Water is one of the important constituents of life support system. It is indeed a wonderful chemical medium which has unique properties of dissolving and carrying in suspension a huge variety of chemicals. Thus it can easily get contaminated (Santra, 2005).

Natural surface water bodies often have impurities. Water must be substantially free of dissolved salts, plant and animal wastes, and bacterial contamination to be suitable for human consumption. Unpolluted fresh water that is suitable for drinking is known as potable water (Enger and Smith, 2006). Already at least 1.1 billion people lack access to safe drinking water and twice that number do not have modern sanitation. Polluted water and lack of sanitation are estimated to contribute to the ill health of more than 1.2 billion people annually, including the death of 15 million children per year (Cunningham *et al*:, 2005). About 40 percent of world population live in countries where water demands now exceed supplies. Experts predict that by 2025, two-thirds of the world's population will live in countries suffering from serious water shortages (Cunningham *et al*:, 2005). Water, as an essential component of life, plays an indispensable role in human existence. Consequently provision and management of water for drinking and other domestic uses take the center stage in any economy of nations of the world. Sound management practices in water service delivery will contribute both quantitatively and qualitatively to sustainable development. This is because water services contribute to social cohesion and economic development within a community and the quality and efficiency of service have implications for virtually all activities of the society.

Clean drinking water is essential to man and other living things. Water suppliers use a variety of water treatment processes to make water fit for consumption and no single treatment process is expected to remove all the contaminants that can be found in water. The number of treatment processes required is influenced by the initial quality of the raw water (Bhatia, 2011).

1.2 PROBLEM STATEMENT

Generally, raw water goes through the following steps before entering the major distribution network: screening, aeration, clarification/coagulation, filtration, disinfection and stabilization. When the above steps are applied and correctly, production of high quality potable water is achieved. The major process of water treatment is during the clarification stage when coagulation takes place. The chemical coagulant, aluminium sulphate, has been used over the years for water treatment. However it is now evident that aluminium, which has been historically proved to be relatively non toxic in healthy individuals, can have adverse effects on the nervous system (Davey, 1997).This inference necessitated this research which seeks to evaluate the potentials of a natural coagulant for commercial water treatment applications.

1.3 AIM AND OBJECTIVES

The aim of this project was basically to study the physicochemical parameters of water samples from the Usuma River at the Usuma Water Works Abuja, FCT before and after treatment with natural *(Moringa oleifera* seeds) and artificial (aluminium sulphate) coagulants. The specific objectives included to analyse the turbidity, total dissolved solids, conductivity and salinity; and evaluate the impacts of *Moringa oleifera* seed concentration, mixing time and mixing speed on the percentage reduction of each of the above parameters.

1.4 JUSTIFICATION OF THE STUDY

Recently there is abundant evidence that aluminium can have adverse effects on the nervous system resulting to diseases such as Parkinson's, Alzheimer's and Lou Gehrig's. Aluminium may cause skeletal problems; and intake of large amounts of aluminium can also cause anaemia, osteomalacia (brittle or soft bones), glucose intolerance and cardiac arrest in man (Davey, 1997).

This research is therefore aimed at finding an alternative natural coagulant that will not have adverse effects on health. Such is the case with *Moringa oleifera* seeds which are used as coagulants in water treatment.

1.5 SCOPE OF STUDY

The scope of this study is as follows:

i)To determine the physicochemical qualities of water samples from Usuma River before and after treatment with an artificial coagulant-aluminium sulphate.

ii)To determine the physicochemical qualities of water samples from Usuma River before and after treatment with a natural coagulant-*Moringa oleifera* seeds.

iii)To determine the optimum conditions for the application of the *Moringa oleifera* seeds in water coagulation.

iv)To compare the effects of aluminium sulphate and *Moringa oleifera* seeds and evaluate the applicability of *Moringa oleifera* seeds in potable water treatment.

CHAPTER TWO

LITERATURE REVIEW

2.1 SOURCES AND USES OF WATER

2.1.1 SOURCES OF WATER

Sources of fresh water include surface water, under river flow, ground water, desalination, frozen water.

Surface Water: This is water in a river, lake or fresh water wetland. Surface water is naturally replenished by precipitation and naturally lost through discharge to the oceans, evaporation and sub-surface seepage.

Under river flow: This is a combination of the visible free water flow together with a substantial contribution flowing through subsurface rocks and gravel that underlie the river and its floodplain.

Groundwater: Groundwater is fresh water located in the pore space of soil and rocks. It is also water that is flowing within aquifers below the water table.

Desalination: Desalination is an artificial process by which saline water (generally sea water) is converted to fresh water. The most common desalination processes are distillation and reverse osmosis.

Frozen water: Frozen water in form of icebergs can also be used as water source. Glacier runoff is considered to be surface water.

2.1.2 USES OF FRESH WATER

Uses of freshwater can be categorized into consumptive and non-consumptive (sometimes called "renewable"). Use of water is consumptive, if that water is not available immediately for another use. Uses of water include agricultural, industrial, household, recreational, environmental, chemical, heat exchange, fire extinction and for religious purposes.

Agricultural use: The most important use of water in agriculture is for irrigation. It is estimated that 69% of worldwide water use is for irrigation

Industrial use: It is estimated that 22% of worldwide water use is industrial.Major industrial uses include power plants which use water for cooling or as a power source. Water is used in power generation. Hydroelectricity is obtained from hydropower. Industrial uses also include ore and oil refineries, which use water in chemical processing, and manufacturing plants which use water as solvent.

Household uses: It is estimated that 8% of worldwide water use is for household purposes. These include drinking, washing, bathing, cooking, sanitation and gardening.

Recreational use: Water is used by man for many recreational purposes such as exercising and sports. Some of these include swimming, water skiing, boating, surfing and diving. In addition, some sports like ice hockey and ice skating are played on ice. Lakesides, beaches and water parks are popular places for people to go to relax and enjoy recreation.

Environmental use: Environmental use of water includes artificial wetlands and artificial lakes intended to create wildlife habitat; water released from reservoirs are also timed to help fish spawn.

Chemical use: Water is used wildly in chemical reactions as a solvent or reactant. In inorganic reactions, water is a common solvent, dissolving many ionic compounds.

Heat Exchange: Water and steam are used as heat transfer fluids in diverse heat exchange systems due to its availability and high heat capacity, both as a coolant and for heating.

Fire extinction: Water has a high heat of vaporization and is relatively inert; this makes it a good fire extinguishing fluid. The evaporation of water carries heat away from the fire.

Religious purposes: Water is also considered as a purifier in some religions. Some faiths incorporate ritual washing.

2.2 TYPES OF WATER

Next to oxygen, water is the most important factor for survival of man and animals (Christopher, 2007). A person can do without food for five weeks or more but without water he can only survive a few days. From a sanitary standpoint, water may be classified as potable, contaminated or polluted (Smith, 1973). There are some other types of water, and they include hard water, boiled water, raw water, rain water, snow water, filtered water, soft water, de-ionized water, distilled water and water which has been passed through reverse osmosis.

Potable Water: Potable water is one free of injurious agents and pleasant to taste. In other words, it is a satisfactory drinking water.

Contaminated water: Contaminated water is one that contains dangerous microbial or chemical agents.

Polluted water: A polluted water is one of unpleasant appearance or odour, because of its content; it is unclear and unfit for human use (Smith,1973).

Hard water: This is water in which lime, magnesium and iron are dissolved. It is saturated with these and many other inorganic materials. Since hard water contains essential minerals, it is sometimes the preferred drinking water, not only because of health benefits, but also because of the flavour. Hard water makes clothes look dingy, leaves dishes with spots and residue and bathtubs with lots of film and soap scum. Hard water can take a toll on household appliances as well as use up more energy.

Boiled water: This is water which has been boiled. Boiling helps remove some of the germs but concentrates the inorganic minerals.

Raw water: This is water which has not been boiled. It may be hard or soft as rain water. It usually contains a lot of germs.

Rain water: This is water which has been condensed from the clouds. When it falls as rain, it picks up germs, dust, smoke, minerals and many other atmospheric chemicals from the atmosphere.

Snow water: This is frozen rain. Freezing does not eliminate any germs. All snowflakes have hardened mineral deposits. When snow is melted it is often seen to be saturated with dirt, inorganic minerals, germs and viruses.

Filtered water: This is water that has passed through a fine strainer called a filter. This filter does not prevent germs from passing through its fine meshes. The filter only picks up and retains suspended solids.

Soft water: Soft water is water in which no mineral is dissolved. This may be classified as water which is harder than distilled water. Soft water makes chores easier as tasks can actually be performed more efficiently with it. Soap lathers better and items are left cleaner with soft water. Soft water saves money as less soap and detergents are used. With soft water, appliances work less hard; soft water can also prolong the life of washing machines, dishwashers and water heaters. Energy bills are lower when using soft water.

Deionized water: This is water which has gone through a process of exchanging “hard” ions for soft. The total ions are still present.

Distilled water: This is water which has first been turned into steam so that all its impurities are left behind. Then through condensation it is turned back into water. This is the only water free from all contamination.

Distilled water may be considered as the only pure water on earth (Christopher, 2007).

Another type of water is water which has passed through reverse osmosis system of water purification, which allows pre-filtered water to be forced through a semi-permeable membrane to separate impurities from drinking water. This water can be considered to be second to distilled water.

2.3 WATER POLLUTION

Water pollution is the contamination of water bodies e.g lakes, rivers, oceans and groundwater. Any physical, biological or chemical change in water quality that adversely affects living organisms or makes water unsuitable for desired uses can be considered water pollution(Cunningham *et al*; 2005).Water pollution occurs when something enters water and changes the natural ecosystem or interferes with water use by segment of society (Enger and Smith, 2006). Pollution occurs when pollutants are discharged directly or indirectly into water bodies without adequate treatment to remove harmful compounds. Water is referred to as polluted when it is impaired by anthropogenic contaminants and is either unfit for human use like serving as drinking water and/or is unable to support aquatic life such as fish. Shortage of potable freshwater throughout the world can also be directly attributed to human abuse in form of pollution. Water pollution has negatively affected water supplies throughout the world. In many developing nations, people do not have access to safe drinking water. The World Health Organization estimates that about 25% of the world's population do not have access to safe drinking water (Enger and Smith, 2006). According to the United Nations Environment Programme, 5 to 10 million deaths occur each year from water- related diseases (Enger and Smith, 2006), particularly in the developing countries.

2.3.1 SOURCES OF WATER POLLUTION

There are two sources of water pollution namely point source and non-point source. When a source of pollution can be readily identified because it has a definite source and place where it enters the water, it is said to come from a point source (Enger and Smith, 2006). Municipal and industrial discharge pipes are good examples of point sources. Factories, power plants, sewage treatment plants, underground coal mines and oil wells are classified as point sources because they discharge pollutants from specific locations such as drain pipes, ditches or sewer outfalls. These sources are discrete and identifiable so they are relatively easy to monitor and regulate. Diffuse pollutants, such as from agricultural land and urban paved surfaces, acid rain and runoff, are said to come from non-point sources, and are more difficult to identify and control. Non-point sources of water pollution are scattered and diffuse having no specific location where they discharge into a particular body of water. Non-point sources include runoff from farm fields and feedlots, golf courses, lawns and gardens, construction sites, logging areas, roads, streets and parking lots. Indirect sources of pollution also include contaminants that enter the water supply from soils, groundwater systems and from the atmosphere via rain water. Contaminants can be broadly classified into organic, inorganic, radioactive and acid/base (Rubin, 2011).

2.3.2 SOME EFFECTS OF WATER POLLUTION

Some pollutants seriously affect the quality and possible uses of water. Toxic chemicals or acids may kill aquatic organisms and make the water unfit for human use. If these chemicals are persistent, they bioaccumulate in aquatic organisms and biomagnify in food chains. Dissolved organic matter is a significant water pollution problem because soluble organic matter decays in water. As the micro-organisms naturally present in water breakdown the organic matter, they use up available dissolved oxygen in the water. If too much dissolved oxygen is removed, aquatic organisms die. Nutrients are also a pollution problem. Additional nutrients, in form of nitrogen and phosphorous compounds from fertilizers, sewage, detergents and animal wastes increase the rate of growth of aquatic plants and algae. Physical properties can also negatively affect water quality. Particles alter the clarity of water; they can cover spawning sites, act as abrasives that injure organisms and carry toxic materials.

2.3.3 CATEGORIES OF WATER POLLUTANTS

Aquatic pollutants can be grouped into two (i) Those that cause health problems and (ii) Those that cause ecosystem disruption.

(i) Those that cause health problems include

(a) Infectious agents such as bacteria, viruses and parasites whose source is human and animal excreta.

(b) Organic chemicals such as pesticides, plastics, detergents, oil and gasoline from industrial and farm use.

(c) Inorganic chemicals such as acids, caustics, salts, metals from industrial effluents, household cleansers, surface runoff.

(d) Radioactive materials such as uranium, thorium, cesium, iodine, radon from mining and processing of ores, power plants, weapons production and natural sources

(ii) Those that cause ecosystem disruption include

(a) Sediments such as soil, silt, from land erosion.

(b) Plant nutrients such as nitrates, phosphates, ammonium from agricultural and urban fertilizers, sewage and manure.

(c) Oxygen demanding wastes such as animal manure and plant residues from sewage, agricultural runoffs, paper mills, food processing.

(d) Thermal such as heat from power plants and industrial cooling.

2.3.4 TYPES OF WATER POLLUTION

Types of water pollution include Municipal water pollution, Agricultural water pollution, Industrial water pollution, Thermal water pollution, Marine oil pollution and Groundwater pollution (Enger and Smith, 2006).

MUNICIPAL WATER POLLUTION

Municipalities are faced with the double-edged problem of providing suitable drinking water and disposing of wastes. These consist of stormwater runoff, wastes from industries and wastes from homes and commercial establishments. Wastes from home consist primarily of organic matter from garbage, food preparation, cleaning of clothes and dishes and human wastes.

Human wastes are mostly undigested food material and a concentrated population of bacteria such as *Escherichia coli* and *Streptococcus faecalis.* These bacteria normally grow in large intestines (colon) of man and are thus present in high numbers in the faeces of man. The population of these bacteria present in water is directly related to the amount of faecal wastes entering the water. Wastewater from cleaning dishes and clothing contains some organic materials along with the soap or detergent, which help to separate the contaminant from dishes or clothes. Many detergents contain phosphates as part of their chemical make-up and these contribute to eutrophication i.e. the excessive growth of algae and aquatic plants due to added nutrients. (Enger and Smith, 2006).

AGRICULTURAL WATER POLLUTION

Agricultural activities are the primary cause of water pollution. Excessive use of fertilizer results in eutrophication in aquatic ecosystems because precipitation causes dissolved nutrients (nitrogen and phosphorus compounds) to enter streams and lakes. In addition, groundwater may become contaminated with fertilizer and pesticides. Erosion discharges silts into water courses. Runoffs from animal feedlots carry nutrients, organic matter and bacteria. One of the water pollution problems is agricultural runoff from large expanses of open fields (Enger and Smith, 2006).

INDUSTRIAL WATER POLLUTION

Factories and Industries dispose some or all of their wastes into municipal sewage systems. Depending on the type of industry involved, these wastes contain organic materials, petroleum products, metals, acid, toxic materials, organisms, nutrients or particulates. A special source of industrial water pollution is mining. Mining disturbs the surface of the earth and increases the chances that sediments and other materials will pollute surface water. Hydraulic mining is practiced in some countries and involves spraying hillsides with high pressure water jets to dislodge valuable ores. Often chemicals are used to separate valuable metals from ores and wastes from these processes are released into streams as well (Enger and Smith, 2006)

THERMAL POLLUTION

Thermal pollution occurs when an industry removes water from a source, uses the water for cooling purposes and then returns the heated water to its source. Power plants heat water to convert it into steam which drives the turbine that generates electricity. For steam turbines to function efficiently, the steam must be condensed into water after it has left the turbine. This condensation is usually accomplished by taking water from a lake, stream or ocean to absorb the heat. Then the heated water is discharged. The least sexpensive and easiest method of discharging heated water is to return the water to the aquatic environment (Enger and Smith, 2006).

MARINE OIL POLLUTION

Marine oil pollution has many sources. One source is accidents such as oil drilling blow outs or oil tanker accidents. The potential for increased oil pollution has grown due to increase in the number of offshore oil wells and in the numbers and size of oil tankers (Enger and Smith, 2006).

GROUNDWATER POLLUTION

Major sources of groundwater contamination include:-

(i) Agricultural products:-Pesticides contribute to high levels of organic contaminants in groundwater. Other sources of groundwater pollution include animal feeding operations, fertilizer application and irrigation practices.

(ii) Underground Storage tanks:-Underground storage tanks containing gasoline and other hazardous substances leak at times, and contaminate water supplies.

(iii) Landfills:-Some landfills have special liners and water collection systems, but some do not have liners to stop leakage to underlying groundwater, while some have no systems to collect the leachate that seeps from the landfill. These leakages and leachate cause contamination.

(iv) Septic Tanks:- Poorly designed and inadequately maintained septic systems have contaminated groundwater with nitrate bacteria and toxic cleaning agents, particularly in developing countries.

(v) Surface impoundments:- Pits, ponds and lagoons are usually used to store or treat wastes. Some of these impoundments do not have leak detection systems, while some have no restriction on the wastes placed in the impoundment. Many of these ponds are located near groundwater supplies.

(vi) Other sources of groundwater pollution include mining wastes "salting for controlling road ice", land application of treated wastewater, open dumps, cemeteries, radioactive disposal sites, urban runoff, construction excavation, fallout from the atmosphere and animal feedlots (Enger and Smith, 2006).

2.4 DISEASES TRANSMITTED BY WATER

Diseases transmitted by water include water-borne diseases and water-related diseases. Waterborne diseases are caused by pathogenic micro-organisms which are directly transmitted when contaminated freshwater is consumed (WHO Burden of disease and cost effectiveness, 2011).Waterborne disease is a disease with water as the sole or principal means of infection. It is got through ingestion of the water. Waterborne diseases can be caused by protozoa, viruses or bacteria many of which are intestinal parasites. Waterborne diseases of man include Typhoid fever, Cholera, Amoebic dysentery, Guineaworm, Poliomyelitis and infectious hepatitis. There is a difference between water-borne disease and water-related disease. In water-related disease, water aids the vector in its lifecycle. The disease is not contacted through the consumption of the infected water. Water-related diseases include malaria (plasmodiasis), schistosomiasis and onchocerciasis.

2.5 WATER TREATMENT PROCESSES

The treatment of a metropolitan water supply is designed to provide a safe water supply by eliminating pathogenic microbes as well as harmful chemicals. The number of treatment processes required is influenced by the quality of the sourcewater (Bhatia, 2011). In general the raw water goes through the following steps prior to entering the main distribution network.

(i) Screening:-This step removes any large debris floating down the river and prevents it from entering the pumping station and causing equipment damage; after this the partially treated water enters the water treatment plant through a flow meter, then the major treatment process begins.

(ii) Aeration:- At this stage water is mixed with air to release any trapped gases and to absorb oxygen.

(iii) Coagulation:- This process can be accomplished through the addition of inorganic salts of aluminium or iron. These inorganic salts neutralize the charged particles causing turbidity and also hydrolyze to form insoluble precipitates which entrap particles (BonoArtes, 2011).The water is mixed rapidly at first, then slowly as the water continues through this step. The reaction of the chemically treated water to the mixing, causes the small light-weight particles to clump together (coagulate) into much larger particles. The chemical aluminium sulphate ($Al_2(SO_4)_3.14H_2O$) is also called "alum". Coagulation can successfully remove a large amount of organic compounds including dissolved organic material referred to as Natural Organic Matter (NOM). Coagulation can also remove suspended particles, including inorganic precipitates such as iron (SDWF, 2009). While coagulation can remove particles and some dissolved matter, the water may still contain pathogens. It is however an important step in water treatment process, because it removes many of the particles that make water difficult to disinfect.

(iv) Flocculation: - Flocculation refers to water treatment process where the larger particles continue to combine (flocculate) into much larger and heavier particles called flocs. These particles become too heavy to float and begin to sink (settle).

(v) Sedimentation: - At this stage the water flows slowly through a basin or tank where the floc settles to the bottom.

(vi) Filtration: - This process is used to remove all particles. The particles include clays, silts and natural organic matter (Excel Water Technologies, 2007). At this stage, the clear water is filtered through coal, sand and gravel to remove small, light particles. Particles not removed in the previous step will be removed here.

(vii) Disinfection: - Small amount of chlorine is added to kill remaining germs to keep the water pure as it travels through the pipelines.

(viii) Stabilization: - This step aids in the reduction of pipe corrosion and scale build up problems in the water service piping system. The pH of water is adjusted upwards to just above neutral by the addition of lime.

2.6 HEALTH EFFECTS OF ALUMINIUM IN DRINKING WATER

Aluminium makes up around 8% of the Earth's surface making it the most common element in the Earth crust (Peterson, 2011). Aluminium is present in soil, water and air (Davey, 1997). Aluminium's physical and chemical properties make it ideal for a variety of uses in food, drugs, consumer products and water treatment processes.

2.6.1 EXPOSURE TO ALUMINIUM

Exposure to Aluminium can come from food, air and water. Most of our daily aluminium intake is from food and water (Peterson, 2011). Although most of our daily aluminium intake comes from food; aluminium in food appears to be bound to other food substances and thus is in a form that cannot be absorbed into the bloodstream (Davey, 1997). In contrast, aluminium in water can be absorbed by man because after water treatment, the aluminium is largely in an unbound form. Aluminium in water is in a form that is more readily absorbed by the body and very high levels in water can be of concern.

2.6.2 TREATMENT OF DRINKING WATER WITH ALUMINIUM SULPHATE

Micro-organisms present in drinking water include viruses, bacteria (eg *E.coli*) and protozoa (e.g *Cryptosporidium*) and the beaver-fever causing organism, *Giardia*. At low levels, these microorganisms pose a very serious health risk and can cause sicknesses and diseases (for example, severe diarhoea). They are difficult to remove from water, especially the parasites *Giardia* and *Cryptosporidium* which are resistant to most types of disinfection including chlorination (Peterson, 2011). Water treatment with aluminium sulphate, called coagulant, is however effective at removing these particles when used in a chemical treatment process. Coagulation is a process in which small particles bunch together to form large particles which can then be removed by settling or filtration. In natural water, most particles including micro-organisms have a negative electric charge, and rather than clump together to form larger particles, the particles repel each other. To get the particles in solution to form larger clumps, this negative charge must be neutralized by adding positive ions such as aluminium ions. These react with the negative particles to form clusters called microflocs. The microfloc grows and is then removed by sedimentation and filtration. Aluminium sulphate is the most common chemical used for the coagulation of particles because it is effective, readily available and relatively inexpensive. During coagulation, other undesirable impurities in water, including naturally occurring organic matter which reacts with chlorine to form disinfection by-products that may be carcinogenic are also removed (Peterson, 2011).

2.6.3 HEALTH RISKS ASSOCIATED WITH ALUMINIUM IN DRINKING WATER

Aluminium has historically been considered to be relatively non-toxic in healthy individuals, but there is now abundant evidence that Aluminium may have adverse effects on the nervous system (Davey, 1997) and is possibly connected to several diseases such as Parkinson's, Alzheimers and Lou Gehrig's. It is speculated that aluminium may cause skeletal problems (Peterson, 2011). Intake of large amounts of aluminium can also cause anaemia, osteomalacia (brittle or soft bones), glucose intolerance and cardiac arrest in man (Davey, 1997).

2.7 *MORINGA OLEIFERA* IN WATER CLARIFICATION

Moringa oleifera has its origin in Arabia and India. The tree *Moringa oleifera Lam* is native to the Sub-Himalayan region of India (Grabow *et al*., 1985). The tree is common to landscapes all over the tropics from South Asia to West Africa (Von Maydell, 1986). It is widely cultivated in Africa, Central and South America, Sri Lanka, India, Mexico, Malaysia, Indonesia and the Philippines (Dian, 1985). Other names for *Moringa* in English include :- "Drumstick tree" from the appearance of the slender, triangular pods, "Horse radish tree", from the taste of the roots, which can serve as a rough substitute for horse radish, "Ben oil tree" from the oil derived from the seeds (Schwarz, 2000). The tree can be found both in the Northern and Southern parts of Nigeria. The plant is known as Zogale in Hausa, Gawara in Fulani, Okwe Oyibo in Igbo and Ewe Igbale in Yoruba. *Moringa oleifera* is cultivated by cutting or by planting the seeds. Seeds can be sown either directly or in containers and no seed treatment is required. In a favourable environment, an individual tree can yield 50 to 70 kg of pods in one year (Sherkar, 1993).

2.7.1 COAGULATION WITH *MORINGA OLEIFERA* SEEDS

A few traditional plant flocculants such as *Moringa oleifera* seeds acting as primary coagulants have been recommended for domestic water treatment in rural areas of Africa and Asia (Jahn, 1988). Generally, coagulants are used for purification of turbid raw waters. At a very high turbidity, the water can no longer be adequately treated by using filters. Coagulants have to be applied to transform water constituents into forms that can be separated out physically in large scale treatment plants. Aluminium sulphate is used as a conventional chemical coagulant. As an alternative to conventional coagulants, *Moringa oleifera* seeds can be used as a natural coagulant in household water treatment as well as in the community water treatment (Schwarz, 2000). The coagulant properties of the seeds are due to a series of low molecular weight cationic proteins (Tauscher, 1994).

The seed is often used to purify dirty or cloudy drinking water. It is pounded into small fragments, wrapped in some sort of cloth and then placed into water jars or containers. This pounded seed acts as flocculent, taking impurities out of the water solution.

The seed kernels of *Moringa oleifera* contain significant quantities of low molecular weight, water-soluble proteins which carry a positive charge. When the crushed seeds are added to raw water, the proteins produce positive charges acting like magnets and attracting the predominantly negatively charged particles such as clay, silk, bacteria and other toxic particles in water. The flocculation process occurs when the proteins bind the negative charges and form flocs through the aggregation of particles which are present in the water. These flocs are easy to remove by settling or filtration. *Moringa oleifera* seeds can clarify highly turbid muddy water, and also water of medium and low turbidity. Due to the fact that bacteria adhere to the solids, this seedcake also effectively removes bacteria (Donovan, 2007). Britain's University of Leicester is studying the coagulating properties in those tasty *Moringa* pods, which researchers believe, work better than the common water purifier aluminium sulphate which can be toxic (Fritz, 2000). Studies have been carried out to consider the potential toxicity associated with the use of *Moringa oleifera* seeds (Berger *et al*., 1984 and Grabow *et al*., 1985). The conclusions of both were that the doses typically used for water treatment posed no threat to human health. Pritchard *et al*., (2010) studied the parameters affecting the effectiveness of *Moringa oleifera* seeds in drinking water purification with a view to establishing the most appropriate dosing method, optimum dosage for turbidity removal, influence of pH , temperature and shelf life. They reported that the most suitable dosing method was to mix the powder into a concentrated paste hence forming a stock solution. They also stated that alkaline conditions were generally more favourable than acidic conditions though the coagulant performance was not too sensitive to pH fluctuations and that cold waters ($<15^0$C) were found to hinder the effectiveness of the coagulation process. Also seeds aged 24 months showed a significant decline in coagulation efficiency. Jafari *et al*., (2014) worked on process optimization for fluoride removal from water by *Moringa oleifera* seed extract using Response Surface technique. From the results of their investigations, they concluded that an increase in *Moringa oleifera* seed dosage resulted in an increase in flouride removal and that pH had no significant effect in the process.

2.7.2 ADDITIONAL USES OF *MORINGA OLEIFERA*

Pods, leaves and seeds of *Moringa oleifera* are eaten as vegetables and are highly nutritious; the leaves are high in protein, Vitamin A and Vitamin C. The flowers produce good honey. The root is a popular food in East Africa. Oil from the seeds is used for cooking, soap making, cosmetics, as fuels and used in oil lamps. The leaves can also be used as fertilizer. Powdered seeds are used to heal bacterial skin infections (Schwarz, 2000). Various parts of the plant are used in medicine as diuretics and treatments for bladder ailments (DallaRosa, 1993).

2.8 WATER ANALYSES

Three broad aspects of investigations are usually carried out on a water sample to ascertain its potability. These examinations include:-

(i) Physical examination

(ii) Chemical examinations

(iii) Microbiological examination.

Physical examination

The physical properties of water include Taste, Temperature, Odour, Turbidity, Colour/appearance, pH units, Conductivity, Salinity and Total Dissolved Solids (Zuane, 1997). For water to be acceptable for drinking it must maintain good aesthetic qualities otherwise the users will give it a low rating or it can attract outright rejection.

Chemical examination

Quite a number of chemicals are dissolved in water as it passes various terrains because water is a universal solvent. Some of these dissolved substances are corrosive and toxic. Therefore the main purposes of chemical analysis include:-

(a) To classify the water sample with respect to the level of mineral constituents.

(b) To determine the absence or excess of any particular constituents as it affects the potability and general use of the water.

(c) To assess potability of water.

The uses of these chemical analyses are very wide and valid because of health implications of such substances. Some of the chemicals usually analysed in water include analysis for Hardness, Iron, Nitrate, Manganese, Phosphate, Sulphate, Alkalinity and Chloride ion.

Microbiological examination

Ideally drinking water should not contain any micro-organisms known to be pathogenic (Guidelines for drinking water quality, Vol 2*)*. Poor microbiological quality of water is likely to lead to serious outbreaks of epidemics of waterborne or water related diseases. Microbiological standards therefore seek to ensure that drinking water is not contaminated with human or animal faeces and is free from micro-organisms which can cause diseases.

2.8.1 PHYSICO-CHEMICAL PARAMETERS IN WATER ANALYSIS AND THEIR HEALTH IMPLICATIONS

2.8.1.1 PHYSICAL PARAMETERS

These include:-

COLOUR :- Colour in drinking water may be due to the presence of coloured organic matter e.g humic substances, metals such as iron and manganese or highly coloured industrial wastes(Guidelines for drinking water quality. Vol 2). Brown, red, orange or yellow colour is usually caused by rust (MassDep, 2011). A red, brown or rusty colour is therefore generally indicative of iron or manganese in water (Keyser, 1997). Colour is an aesthetic value in drinking water. Drinking water should be colourless or else consumers may turn to alternative and perhaps unsafe sources of drinking water. Colour when noticed in drinking water by the consumer is an objectionable characteristic that would make the water psychologically unacceptable.

TASTE AND ODOUR :- Taste and odour go together, as such it is often difficult to distinguish the two (Keyser, 1997). Taste and odour can enter water in a variety of ways. Surface water sources can become contaminated through algal blooms or through industrial wastes or domestic sewage introducing taste-and odour-causing chemicals into the water (Cooke, 2000).

Odours associated with water are usually from the presence of decaying organic matter (Tchobanoglous and Schroeder, 1985). Decaying organic matter may accumulate in the bottom deposits layer enough to provide suitable conditions for the anaerobic bacteria that produce noxious gases. Change in the normal taste of a public water supply may indicate changes in the quality of the raw water source or deficiencies in the treatment process. Taste is used to determine the acceptability of drinking water (Zuane, 1997).

TEMPERATURE

Temperature affects a number of important water quality parameters (Tcholobangus and Shroeder, 1985). An ideal water supply should have at all times an almost constant temperature, or one with minimum variations. This small variation of temperature would indicate a physically protected water supply. Temperature has insignificant health effects. In general temperature has an influence on the treatment of water supplies; biochemical reactions may double the rate for a 10 degree Celsius increase in temperature. It also has effect on the taste of the drinking water, on the dissolved oxygen content, on solubility of solids in water and on the rate of corrosion in the distribution systems.

TURBIDITY

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates (Lenntech, 2009). Turbidity can also be described as the cloudiness or haziness of a fluid caused by individual particles(suspended solids) that are generally invisible to the naked eye. Turbidity is also a measure of light transmission, and indicates the presence of suspended materials such as clay, silt, finely divided organic material, plankton and other inorganic materials (Adams, 2001). High levels of turbidity can protect micro-organisms from the effects of disinfection, stimulate the growth of bacteria and exert a significant chlorine demand. Turbidity has no health effects; the main impact is merely aesthetic.

pH

The term pH is a measure of the concentration of hydrogen ions in a solution (Rogers, 2010). The pH scale of value extends from 0(very acidic) to 14(very alkaline). pH is an indicator of the acid or alkaline condition of water. Water with a pH value less than 7 indicates acidity and tends to be corrosive, while water with a value greater than 7 indicates alkalinity and tends to affect the taste of the water (Excel Water Technologies, 2007). The pH of drinking water is not a health concern; health concerns are most pronounced in pH extremes. Water with an elevated pH above 11 can cause skin, eye and mucous membrane irritation. On the opposite end of the scale, pH values below 4 also cause irritation due to the corrosive effects of low pH levels. The WHO warns that extreme pH level can worsen existing skin conditions. High pH levels can lead to nausea, vomiting or diarrhea (Rogers, 2010). The acidity of some drinking water has the potential to cause acidosis in the body. Acidosis can cause irreversible cell damage, lower bone density and immune body response (Woolhether, 2011).

CONDUCTIVITY

Conductivity is a measure of the ability of water to carry an electric current (Government of Saskatchenwan, 2012). This ability depends on the presence of ions, which are expressed as dissolved solids in water. Conductivity is commonly reported as μohms/cm (micro ohms per centimeter) or dS/cm (deciSiemens per centimeter). It is also measured in microSiemens. This is a useful test in raw and treated water for quick determination of minerals.

TOTAL DISSOLVED SOLIDS

Total Dissolved Solids (often abbreviated TDS) is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionized or micro-granula suspended form. High concentrations of total dissolved solids may cause unpleasant taste. Mineral deposition and corrosion may also occur (Environmental and Workplace Health, 2009). Total dissolved solids in water supplies originate from natural sources, sewage, urban and agricultural runoff and industrial wastewater. Total Dissolved Solids (TDS) comprise inorganic salts and small amounts of organic matter that are dissolved in water. Water can be classified by the amount of TDS per litre. Fresh water has TDS value of less than 1500 mg/l, brackish water has TDS values between 1500 to 5000 mg/l, while saline water has TDS value greater than 5000 mg/l. (Ela, 2007).

SALINITY

Salinity is a measure of the amount of salt in water. The major problem with drinking salt water is the dehydration effect, which can lead to seizures, brain damage, unconsciousness, coma and even death.

2.8.1.2 CHEMICAL PARAMETERS

HARDNESS: - The term 'hard water' is an indication of the presence of usually calcium and magnesium carbonates that reduce the lathering of soaps or precipitate soap residues onto sinks and bathtubs and reduce washing efficiency (WHO/Chemical Hazards in drinking-water-hardness, 2011). Waters that are hard have no known adverse health effects (Adams, 2001). Hardness may be considered a physical or chemical parameter of water. It is the property which makes water form an insoluble curd with soap. Hard water is primarily of concern because it requires more soap for effective cleaning, forms scum and curd, causes yellowing of fabrics, forms scales in boilers, water heaters, pipes and cooking utensils. A positive aspect of hard water is less danger of corrosivity and within certain limits a better taste (Zuane, 1997). Hard water also contributes a small amount towards Calcium and Magnesium human dietary needs. Originally water hardness was understood to be a measure of the capacity of water to precipitate soap (APHA, 1989).

ALKALINITY

Alkalinity is defined as the capacity of water to accept protons; this concept is used in water chemistry only (Zuane, 1997). Alkalinity is also a measure of the capacity of water to resist a change in pH that would tend to make the water more acidic. Highly mineralized alkaline waters also cause excessive drying of the skin because of their tendency to remove normal skin oils. Alkalinity of a water is its acid-neutralizing capacity (APHA, 1989).

CHLORIDES

Chlorides are leached from various rocks into soil and water by weathering. The chloride ion is highly mobile and is transported to closed basins or oceans. High chloride waters may also produce a laxative effect (Adams, 2001). In large concentrations, chlorides cause a brackish taste that definitely is undesirable.

IRON

Iron is a white malleable, ductile metallic element vital to animal and plant life. Iron is the fourth most abundant element by weight in the earth's crust. Iron may be present in water supply or be introduced by corroding pipes (Herman,1996). In surface water supplies, the presence of iron is almost exclusively due to corrosion of pipes (the most commonly used material for water piping) and storage tanks. In groundwater supplies, in addition to corrosion problems of the distribution system, high iron content can be encountered due to the frequency of the elevated iron level in the earth strata to the feeding aquifers. Large amounts of iron in drinking water can give it an unpleasant metallic taste (Garvin, 2011),while still being safe to drink (Herman,1996). Iron is an essential element in human nutrition and the health effects of iron in drinking water may include warding off fatigue and anaemia. Iron is not considered hazardous to health. In fact iron is essential for good health because it transports oxygen in the blood. Iron may cause reddish brown stains on clothes or household fixtures.

MANGANESE

This is a very brittle grayish-white metallic chemical element resembling iron but harder (Zuane, 1997). Manganese has the undesirable effects of taste, staining of laundry and discoloration of water. Manganese is one out of three toxic essential trace elements, which means that it is not only necessary for humans to survive, but is also toxic when too high concentrations are present in human body(Lentech, 2009). Significant deficits in the intelligence quotient (IQ) of children exposed to higher concentrations of manganese in drinking water have been reported (Bouchard *et al*., 2010). Several studies have linked excessive manganese exposure and neurological disorders in children, particularly infants. Effects of manganese are felt mainly in the respiratory tract and in the brains. Symptoms of manganese poisoning are hallucinations, forgetfulness and nerve damage. Manganese can also cause Parkinson disease, lung embolism and bronchitis. When men are exposed to manganese for a longer time they may become impotent. A syndrome that is caused by manganese has symptoms such as schizophrenia, dullness, weak muscles, headaches, insomnia (Lenntech, 2009). Shortage of manganese can cause the following health problems; glucose intolerance, blood clotting, skin problems, lowered cholesterol levels, skeleton disorders, birth defects and changes of hair colour (Lenntech, 2009).

NITRATE

Nitrate is a water soluble molecule made up of nitrogen and oxygen. It is formed when nitrogen from ammonia or other sources combines with oxygenated water (Daamgard, 2003). Nitrate is a salt or ester of nitric acid or an end product of the aerobic stabilization of organic nitrogen (Zuane, 1997). When nitrate is detected in potable water in considerable amounts, it is indication of sewage bacterial contamination and inadequate disinfection. Common sources of nitrate include fertilizers and manure, animal feedlots, municipal wastewater and sludge, septic systems and N-fixation from atmosphere by legumes, bacteria and lightning (Self and Waskom, 2008). Nitrate is toxic when present in excessive amounts in drinking water and in some cases causes methaemoglobinaemia or 'blue baby' syndrome found especially in bottle-fed infants less than six months (Guidelines for drinking water quality, Vol 1). The condition is called 'blue baby' syndrome because the skin appears blue-gray in colour. This colour change is caused by lack of oxygen in the blood. The stomach acid of an infant is not as strong as in older children and adults. This causes an increase in bacteria that can readily convert nitrate to nitrite. Nitrite is absorbed in the blood and the haemoglobin is converted to methaemoglobin. Methaemoglobin does not carry oxygen efficiently. This results in reduced oxygen supply to vital tissues such as the brain. Severe methaemoglobinemia can result in brain damage and death (Self and Waskom, 2008).

PHOSPHATE

Phosphorous occurs in natural waters and in waste waters almost solely as phosphates (APHA, 1989). Water supplies may contain phosphate from natural contact with minerals or through pollution from application of fertilizers, sewage and industrial waste. (Zuane, 1997). High levels of phosphate can make water unpleasant. Presence of phosphate emits bad odour, makes swimming difficult and makes filtering of water for drinking more complicated and expensive. Phosphate in water has insignificant health problems, but may interfere with digestion.

SULPHATE

Sulphate can be found in almost all natural waters. The origin of most sulphate compounds is the oxidation of sulfite ores, the presence of shale or industrial wastes (Lenntech, 2009). Drinking water high in sulphates can cause diarrhoea, intestinal pain (especially in babies), dehydration as a result of diarrhea and a slight decrease in normal stomach acidity (WDHS, 2000). At high levels, sulphate can give water a bitter or astringent taste. Sulphate minerals can cause scale buildup in water pipes (Oram, 2011). High sulphate levels may also corrode plumbing, particularly copper plumbing.

2.8.2 BACTERIOLOGICAL ANALYSIS OF WATER

Pathogens which cause water pollution are vast. As a result it is not practical to test for all pathogens in every water sample collected. The presence of pathogens is determined by testing for an "indicator" organism such as coliform bacteria (NYSDH, 2011). These are microbes that are routinely found in faeces; they survive longer than other intestinal pathogens and are relatively easy to detect and enumerate (Nester *et al*., 2004). They are usually present in larger numbers than more dangerous pathogens and respond to the environment, wastewater treatment and water treatment similarly to many pathogens. As a result testing for coliform bacteria can be a reasonable indication of presence of other pathogenic bacteria.

The most common group of bacteria used as indicator organisms are total coliforms. These are lactose-fermenting members of the family *Enterobacteriaceae* including *Escherichia coli*. The group is functionally defined as facultatively anaerobic Gram-negative, rod-shaped, non-spore forming bacteria that ferment lactose forming acid and gas within 24-48 hours at 35ºC. These organisms are routinely present in the intestinal contents of warm blooded animals. Some species can also thrive in soil and in plant material. Thus the presence of coliform does not necessarily imply faecal pollution. To compensate for this shortcoming, faecal coliform, a subset of total coliforms more likely to be of intestinal origin, are also used as indicator organisms. The most common faecal coliform is *Escherichia coli*. The detection of faecal coliform organisms, particularly *Escherichia coli* provides definite evidence of faecal pollution.

2.8.3 FACTORIAL DESIGN OF EXPERIMENTS

Design of Experiment (DOE) is a means of determining the optimal experimental design or sequence to be used for simultaneous varying of all the factors to be analysed. The purpose of statistically designing an experiment is to collect the maximum amount of relevant information with a minimum expenditure of time and resources. The traditional approach demands considerable material expense and is more time consuming because for the effect of each factor experiment may be designed to investigate one factor at a time with all the other independent variables (factors) held constant. When properly utilized, DOE yields more precise data and more complete information on the studied phenomenon with minimal number of experiments and the lowest possible material cost.

Choice of a DOE has to do with determination of the number of experimental point-trials and such a distribution of those points in a factorial space that facilitates obtaining the necessary information with a minimal number of design point trials. When selecting the design of experiments, a design matrix or standard type table is constructed where all the conditions of doing the design points that are part of the chosen design are defined. Mostly in a design matrix, rows correspond to different design point trials and columns to individual factors. Obtaining a model has to do with performing a Full Factorial Experiment or a Fractional Factorial Experiment, which is a definite part of the full Full Factorial Design. Full Factorial Experiment is the experiment where all possible combinations of levels of factors are realized and the experiments processed by applying statistical analysis. Full factorial experiments are called the the design experiment of type 2^k and in cases where we have a large number of factors, it requires a large number of trials ($N=2^k$). When composing the factorial experiment matrices, coded factor values are used. Coding factors require linear transformation of the factor space coordinates with the coordinate beginning in the null point or experimental centre and defining the coordinate axis ratio in units of the factor variation interval.

It is characteristic for design of experiments that it uses polynomial models since the quality of the approximation may be improved by increasing the polynomial degree. Such models are especially suitable for solving optimization problems as it is possible to take into account the effects of interaction and a large number of factors. Besides, it is easy to estimate the degree of lack of fit of polynomial models of different orders. Based on the magnitude of the regression coefficients, one may speak about the strength of influence of the associated factors on the response. The higher the coefficient of an associated factor the more intensely it affects the response (optimization parameter), either positively or negatively depending on its sign.

CHAPTER THREE

MATERIALS AND METHOD

3.1 DESCRIPTION OF THE STUDY AREA

The Usuma dam is located at latitude 9° 0’ 12” N and longitude 7° 25’ 16 E and situated within the higher altitude areas of the Federal Capital Territory. It is sited on a virgin location where human activity is minimal, thereby ensuring non pollution of the environment and free from industrial pollution. The treatment plant is fed by gravity from the reservoir to raw water chamber into a cascade of aerators, clarifiers, filters and clean water tank.

3.2 SAMPLE COLLECTION AND PREPARATION OF *MORINGA* SEEDS

Water samples for physicochemical analyses were collected in clean plastic containers and analyses were carried out at different stages of treatment at the Usuma water works namely;

- at the aeration chamber of the treatment plant, to assess the quality of the water before any type of coagulant was added.
- at the clarification chamber of the treatment plant, to assess the quality of the water after aluminium sulphate, an artificial coagulant had been added.

- from the aeration chamber with ground *Moringa oleifera* seeds powder added, to assess the quality of water after crushed *Moringa oleifera* seeds, a natural coagulant was added to the water.

The *Moringa oleifera* seeds were purchased at the Dutse-alhaji market along Bwari road, Abuja; the seeds were deshelled, pounded in a mortar and sieved with fine muslin cloth.

3.3 FACTORIAL DESIGN FOR THE COAGULANT EFFECT OF *MORINGA OLEIFERA* SEEDS ON RESULTANT WATER QUALITY

To determine the coagulant effect of *Moringa oleifera* seeds on the resultant water quality, the impact of the following independent variables were investigated; the coagulant concentration (mg/l), mixing time (min), and mixing speed (rpm). The water quality parameters (responses) studied were the Total Dissolved Solids (mg/l), Turbidity (NTU), Conductivity (µS) and Salinity (ppm). In order to examine the combined effect of these 3 factors on the % change in the responses and derive a model, a Central Composite Factorial Design of $2^3 = 8$, plus 6 centre points and (2 x 3 = 6) star points leading to a total of 20 experiments were performed on the water sample. The factor levels with the corresponding real values are shown in Table 3.1, while the experimental design matrix is shown in Table 3.2. The matrix for the three variables was varied at five levels (-α, -1, 0, +1, and +α). As usual, the experiments were performed in random order to avoid systematic error.

Table 3.1: Experimental Range of the Independent variables at their different levels for the Coagulant Effect of *Moringa oleifera* seeds on Water Quality

INDEPENDENT VARIABLE	SYMBOLS	CODED LEVELS				
		-1.68	-1	0	+1	+1.68
		ACTUAL LEVELS				
Coagulant Concentration,(mg/l)	X_1	3.2	10	20	30	36.8
Mixing Time (min)	X_2	23.2	30	40	50	56.8
Mixing Speed (rpm)	X_3	26.4	40	60	80	93.6

Table 3.2: Experimental Design Matrix for the Central Composite Design

Exptl Run	FACTORS						RESPONSES			
	CODED VALUES			ACTUAL VALUES			*Y_1 (Turbidity)*	*Y_2 (TDS)*	*Y_3 (Conductivity)*	*Y_4 (Salinity)*
	X_1	X_2	X_3	X_1	X_2	X_3				
1	+	+	+	30	50	80				
2	+	+	-	30	50	40				
3	+	-	+	30	30	80				
4	+	-	-	30	30	40				
5	-	+	+	10	50	80				
6	-	+	-	10	50	40				
7	-	-	+	10	30	80				
8	-	-	-	10	30	40				
9	-1.68	0	0	3.2	40	60				
10	+1.68	0	0	36.8	40	60				
11	0	-1.68	0	20	23.2	60				
12	0	+1.68	0	20	56.8	60				
13	0	0	-1.68	20	40	26.4				
14	0	0	+1.68	20	40	93.6				
15	0	0	0	20	40	60				
16	0	0	0	20	40	60				
17	0	0	0	20	40	60				
18	0	0	0	20	40	60				
19	0	0	0	20	40	60				
20	0	0	0	20	40	60				

3.3.1 EXPERIMENTAL PROCEDURE

The initial values of the water quality parameters (Total Dissolved Solids, turbidity, conductivity and salinity) were obtained prior to the coagulation experiments. The experiments were run for all the samples under the conditions indicated for X_1, X_2 and X_3 as shown in Table 3.2and allowed to settle for 1 hour. The samples were then analysed to obtain final values for the Total Dissolved Solids, turbidity, conductivity and salinity. The percentage reduction in the values of these parameters was chosen as the system response (Y_1,Y_2, Y_3 & Y_4) and used as the optimization parameter.

The analysis for the percentage reduction in Total Dissolved Solids, turbidity, conductivity and salinity were also repeated using the standard alum dosing of 360 mg/l.

3.4 METHODS FOR ANALYSIS OF PHYSICOCHEMICAL PARAMETERS

Standard methods and procedures according to Standards Methods for the Examination of Water and Wastewater,17th edition by American Public Health Association, (1989) were adopted.

3.4.1 DETERMINATION OF TURBIDITY

This was determined by the use of a turbidimeter (HACH 2100P). 10 mls of distilled water was added to a cuvette and the zero button was pressed to zero the sample. After zeroing, 10 mls of the water sample was added to a cuvette and placed in a turbidimeter, then the read button was pressed to read the turbidity of the water sample.

3.4.2 DETERMINATION OF CONDUCTIVITY

The Conductivity meter (HACH CO150) was used. The Conductivity meter was used to determine conductivity, Salinity and Total Dissolved Solids. The sensing probe of the Conductivity meter was dipped into the water sample and the conductivity button was pressed and the reading for conductivity was taken when ‘Ready’ was indicated on the screen.

3.4.3 DETERMINATION OF TOTAL DISSOLVED SOLIDS

The Conductivity meter (HACH CO150) was also used. The sensing probe was dipped into the water sample, the Total dissolved solids button was pressed and the reading for Total dissolved solids was taken when ‘Ready’ was indicated on the screen.

3.4.4 DETERMINATION OF SALINITY

The Conductivity meter (HACH CO150) was used. The sensing probe was dipped into the water sample and the salinity button was pressed, the reading for salinity was taken when ‘Ready’ was indicated on the screen.

3.5 DETERMINATION OF COAGULANT CONCENTRATION, MIXING TIME AND MIXING SPEED

3.5.1 DETERMINATION OF COAGULANT CONCENTRATION

The weighing scale was used to determine the coagulant concentration.

3.5.2 DETERMINATION OF MIXING TIME

A flocculator was used to determine the mixing time. The flocculator consists of six one litre jars/beakers of length 17.5cm and width 9cm, with paddles for stirring (see appendix 17). The button for setting the time was used to set the mixing time.

3.5.3 DETERMINATION OF MIXING SPEED

A flocculator was used to get the mixing speed. The button for setting the speed was used to adjust the speed at different rotations per minute.

3.6 DETERMINATION OF STATISTICAL ANALYSIS OF THE PHYSICOCHEMICAL RESULTS OF THE WATER TREATED WITH *MORINGA OLEIFERA* SEEDS

It was necessary to carry out a statistical analysis of the results obtained from the physicochemical tests of the water samples treated with *Moringa oleifera* seeds. This was important because large scale water treatment with *Moringa oleifera* seeds has not yet attained commercial competitiveness and hence the need to understand its optimum application conditions and the impact of the various factors on its performance.

The statistical analyses were done using Design Expert software version 9.0.3.1 (Stat-Ease Inc. USA). Each physicochemical parameter was analysed with a linear model, a Two Factor Interaction model, a Quadratic model and a Cubic model. For each of these models, the model equation was obtained and the Analysis of Variance (ANOVA) carried out to assess the statistical significance of the model and the experimental factors based on their p-values, the Determination Coefficients of the model, and lack of fit of the model. The model graphs were also plotted to enable further statistical inference to be drawn.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 PHYSICOCHEMICAL PARAMETERS OF WATER TREATED WITH ALUM

The initial values from the physicochemical analyses of the untreated water are shown in Table 4.1. For water treated with the standard Alum dosing of 360 mg/l, the percentage decrease in the values of turbidity, total dissolved solids, conductivity and salinity are as given in Table 4.2.

Table 4.1: Initial Physicochemical Parameter values for the untreated water.

Parameter	**Initial Value**
Turbidity	3.03 NTU
TDS	46.9 mg/l
Conductivity	67.2 µS
Salinity	31.2 ppm

Table 4.2: Percentage Decrease in Physicochemical Parameter values for Aerated water treated with Alum.

Parameter	Percentage Decrease
Turbidity	16.17
TDS	2.13
Conductivity	2.08
Salinity	3.85

4. 1.2 PHYSICOCHEMICAL PARAMETERS OF WATER TREATED WITH *MORINGA OLEIFERA* SEEDS

Table 4.3 shows the percentage decrease in the values of the Turbidity, Total dissolved solids, Conductivity and Salinity when the water sample was treated with *Moringa oleifera* seeds.

Table 4.3: Percentage Decrease in Physicochemical Parameter values for Aerated water treated with *Moringa oleifera* seeds.

Exptl Run	FACTORS						RESPONSES (Percent Reductions)			
	CODED VALUES			ACTUAL VALUES			Y_1	Y_2	Y_3	Y_4
	X_1	X_2	X_3	$X_{1(mg/l)}$	$X_{2(min)}$	$X_{3(rpm)}$	*%Turbidity*	*%TDS*	*%Conductivity*	*%Salinity*
1	+	+	+	30	50	80	36.06	55.87	49.61	57.18
2	+	+	-	30	50	40	21.19	55.28	48.43	54.69
3	+	-	+	30	30	80	12.52	55.09	48.27	55.87
4	+	-	-	30	30	40	32.34	55.28	48.43	55.13
5	-	+	+	10	50	80	69.52	55.97	49.13	56.16
6	-	+	-	10	50	40	58.36	55.48	49.29	56.16
7	-	-	+	10	30	80	79.43	56.16	50.08	55.72
8	-	-	-	10	30	40	78.19	56.26	49.37	57.64
9	-1.68	0	0	3.2	40	60	80.42	37.18	49.06	57.18
10	+1.68	0	0	36.8	40	60	37.30	56.56	49.21	56.60
11	0	-1.68	0	20	23.2	60	33.58	55.48	48.58	55.28
12	0	+1.68	0	20	56.8	60	54.65	56.56	48.98	56.01
13	0	0	-1.68	20	40	26.4	39.78	54.40	47.87	54.69
14	0	0	+1.68	20	40	93.6	52.17	57.24	50.94	56.60
15	0	0	0	20	40	60	49.78	55.68	48.74	56.01
16	0	0	0	20	40	60	45.97	55.77	49.06	58.36
17	0	0	0	20	40	60	58.36	56.56	50.08	56.45
18	0	0	0	20	40	60	52.43	56.65	49.53	57.33
19	0	0	0	20	40	60	44.73	55.68	53.23	54.99
20	0	0	0	20	40	60	64.56	55.97	49.29	55.72

Key

X_1= Coagulant Concentration

X_2= Mixing Time

X_3= Mixing Speed

4.1.3 STATISTICAL ANALYSIS OF THE PHYSICOCHEMICAL PARAMETERS OF THE WATER TREATED WITH *MORINGA OLEIFERA* SEEDS

4. 1.3.1 EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TURBIDITY OF TREATED WATER

The effects of *Moringa oleifera* on the turbidity of treated water was obtained by fitting the data with a Linear model, a Two Factor Interaction model, a Quadratic model and a Cubic model respectively. The key statistical values of each model were then sequentially assessed and relevant inferences drawn.

4.1.3.2 LINEAR MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TURBIDITY OF TREATED WATER

A linear model fit of the experimental results for the effects of *Moringa oleifera* on the percentage Turbidity Reduction (TR) of the treated water gave the following final equation in terms of coded factors:

$$\% TR = 49.57 - 18.74X_1 + 1.32X_2 + 2.07X_3 \qquad 4.1$$

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default the high levels of the factors are coded as +1 and the low levels of the factors are coded as

-1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. The model coefficient of determination (R^2) and adjusted R^2 values are 0.7532 and 0.7069 respectively.

The ANOVA Table, externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Turbidity reduction using *Moringa oleifera* seeds are given in Appendix 1 and Figures 4.1 to 4.3 for the Linear model fit.

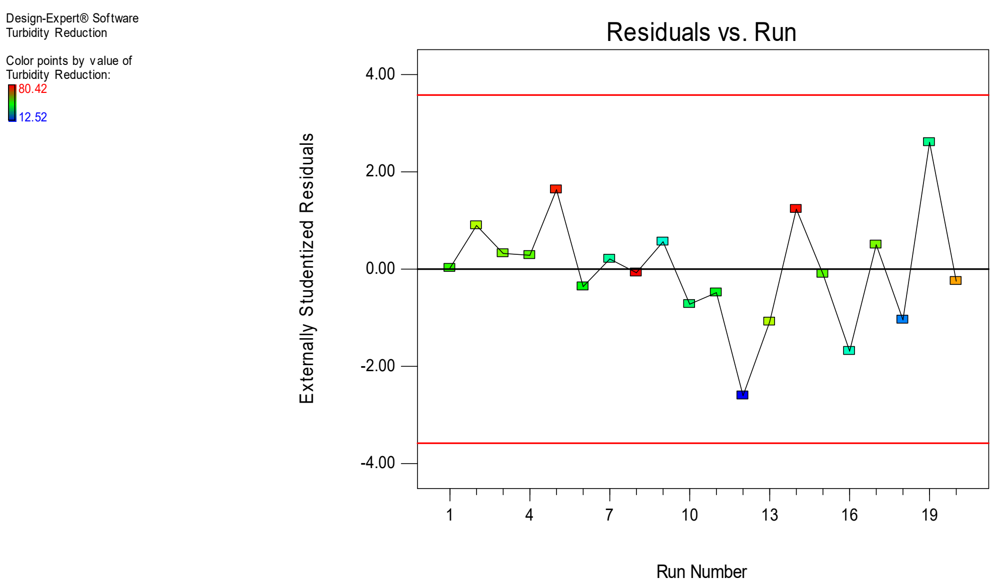

Figure 4.1. Residuals versus run number of experiments for % TR using *Moringa oleifera* seeds (Linear model fit)

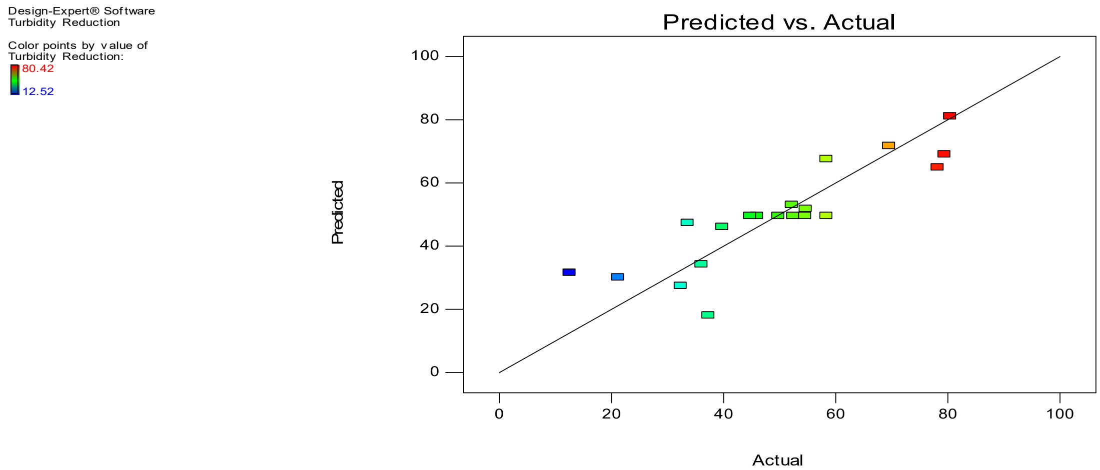

Figure 4.2. Normal probability plot of predicted value by model versus actual values from the experimental runs response for % TR using *Moringa oleifera* seeds (Linear model fit)

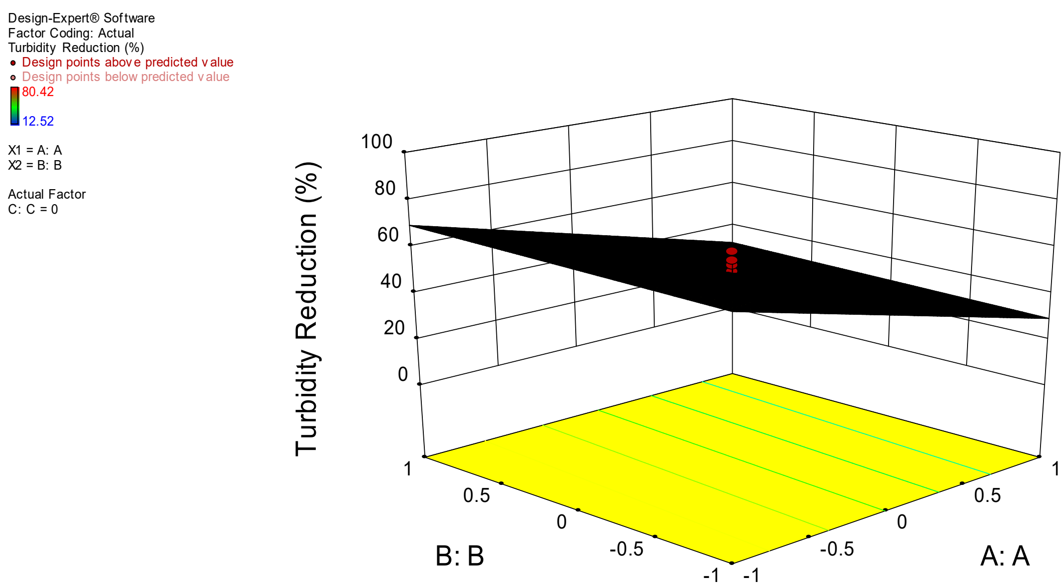

Figure 4.3. Response surface and contour plots for % Turbidity Reduction showing interaction of *Moringa oleifera* seeds dose and mixing time at mixing speed of 60 rpm (Linear model fit)

4.1.3.3 TWO FACTOR INTERACTION MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TURBIDITY OF TREATED WATER

A Two Factor Interaction (2FI) model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Turbidity Reduction (TR) of the treated water gave the following final equation in terms of coded factors:

$$\%\boldsymbol{TR} = \mathbf{49.57 - 18.74}\boldsymbol{X_1} + \mathbf{1.32}\boldsymbol{X_2} + \mathbf{2.07}\boldsymbol{X_3} + \mathbf{5.27}\boldsymbol{X_1X_2} - \mathbf{2.17}\boldsymbol{X_1X_3} + \mathbf{5.58}\boldsymbol{X_2X_3} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \mathbf{4.2}$$

The model Coefficient of Determination (R^2) and Adjusted R^2 values are 0.8316 and 0.7539 respectively

The ANOVA Table, externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Turbidity reduction using *Moringa oleifera* are given in Appendix 2 and Figures 4.4, 4.5, 4.6, 4.7 and 4.8 for the Two Factor Interaction model fit.

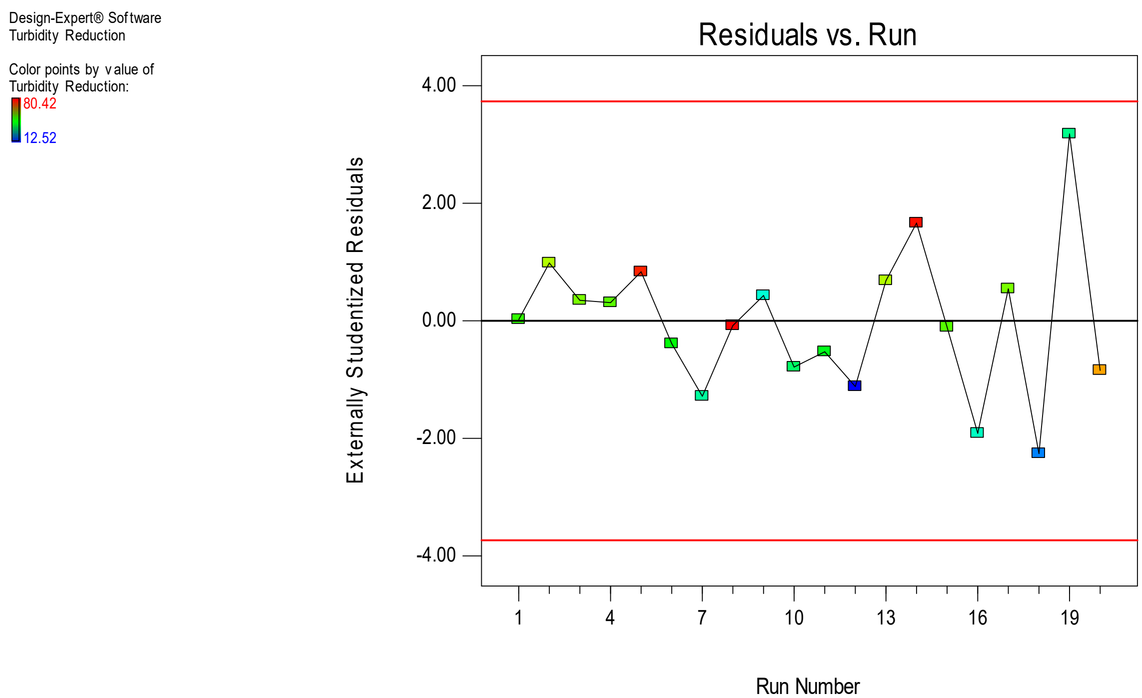

Figure 4.4. Residuals versus run number for % TR using *Moringa oleifera* seeds (Two Factor Interaction Model fit)

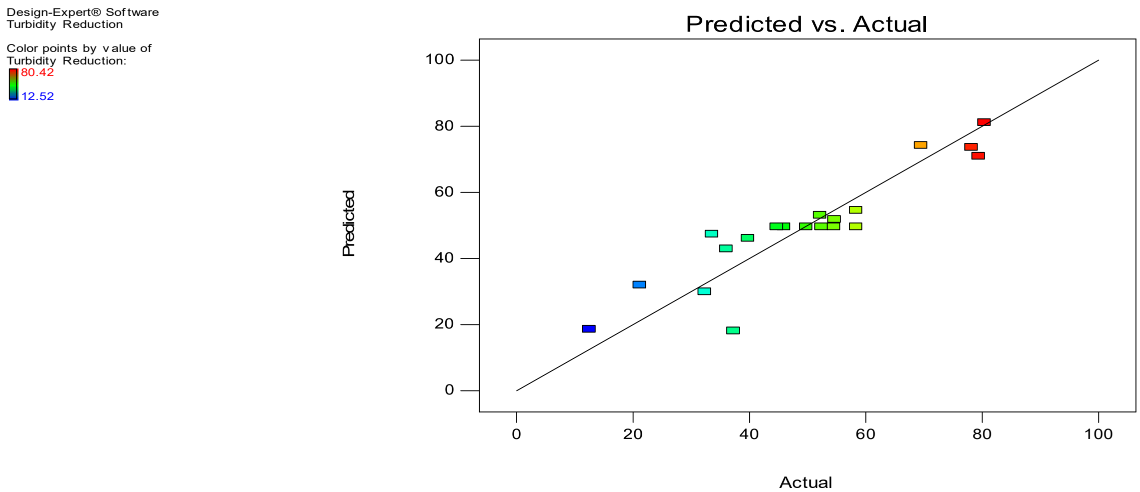

Figure 4.5. Normal probability plot of predicted values versus actual values response for % TR using *Moringa oleifera* seeds (Two Factor Interaction model fit)

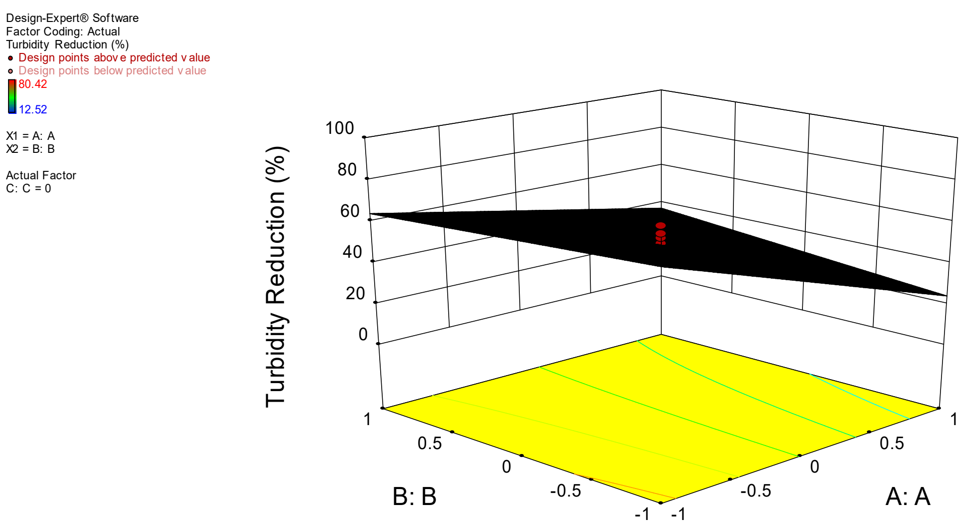

Figure 4.6. Response surface and contour plots for % Turbidity Reduction showing interaction of *Moringa oleifera* seeds dose and mixing time at mixing speed of 60 rpm (Two Factor Interaction model fit)

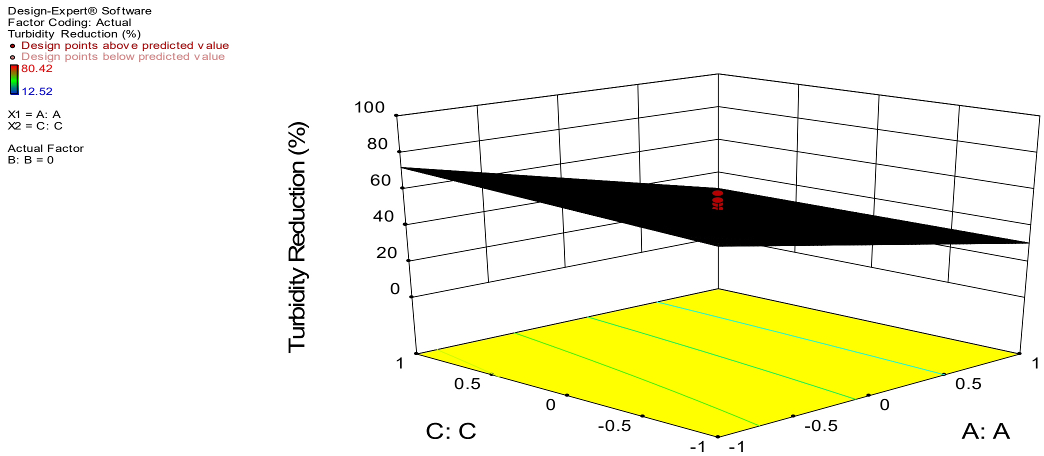

Figure 4.7. Response surface and contour plots for % Turbidity Reduction showing interaction of *Moringa oleifera* seeds dose and mixing speed at mixing time of 40 minutes (Two Factor Interaction model fit)

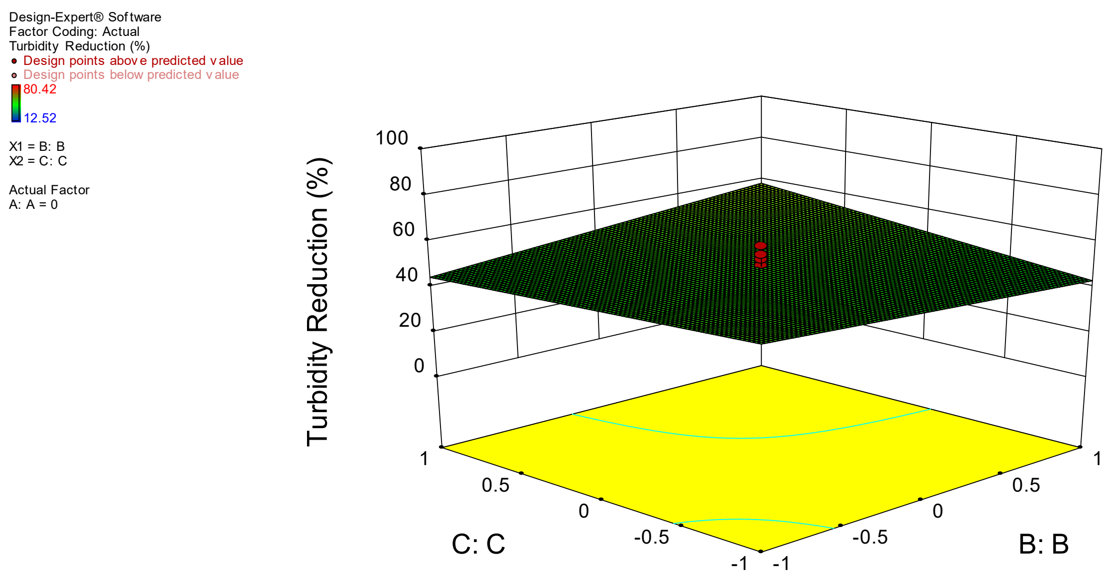

Figure 4.8. Response surface and contour plots for % Turbidity Reduction showing interaction of mixing time and mixing speed at *Moringa oleifera* seeds dosing of 20 mg/L (Two Factor Interaction model fit)

4.1.3.4 QUADRATIC MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TURBIDITY OF TREATED WATER

A Quadratic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Turbidity Reduction (TR) of the treated water gave the following final equation in terms of coded factors:

$$\begin{aligned}\% \boldsymbol{TR} = {} & 51.01 - 18.74X_1 + 1.32X_2 + 2.07X_3 + 5.27X_1X_2 \\ & - 2.17X_1X_3 + 5.58X_2X_3 + 2.55{X_1}^2 - 2.66{X_2}^2 \\ & - 2.00{X_3}^2 \qquad \dots\dots\dots \; 4.3\end{aligned}$$

The model Coefficient of Determination (R^2) and Adjusted R^2 values are 0.8742 and 0.7610 respectively.

The ANOVA Table, externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Turbidity reduction using *Moringa oleifera* seeds are given in the Appendix 3 and Figures 4.9, 4.10, 4.11, 4.12 and 4.13 for the Quadratic model fit.

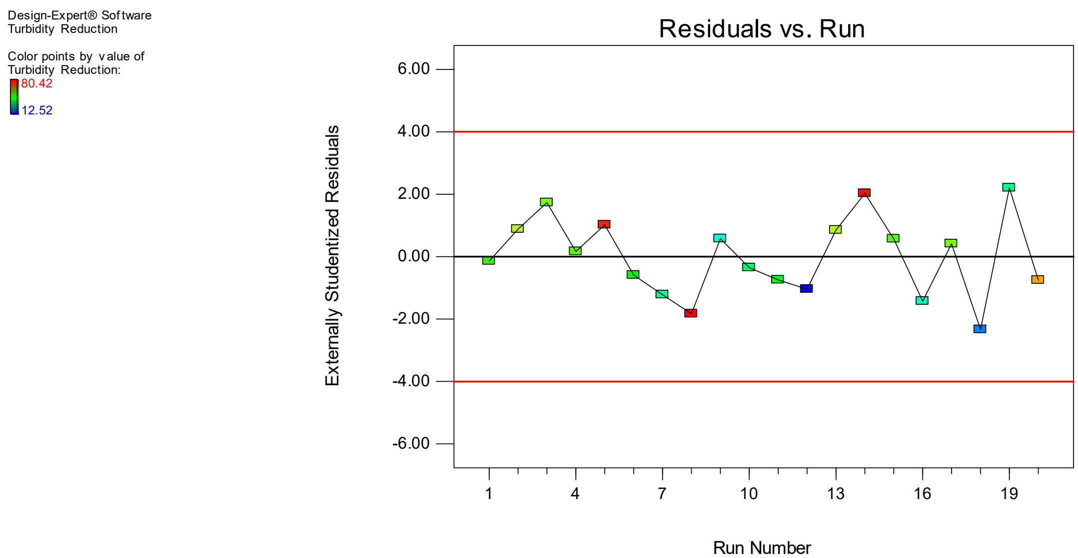

Figure 4.9. Residuals versus run number for % TR using *Moringa oleifera* seeds (Quadratic Model fit)

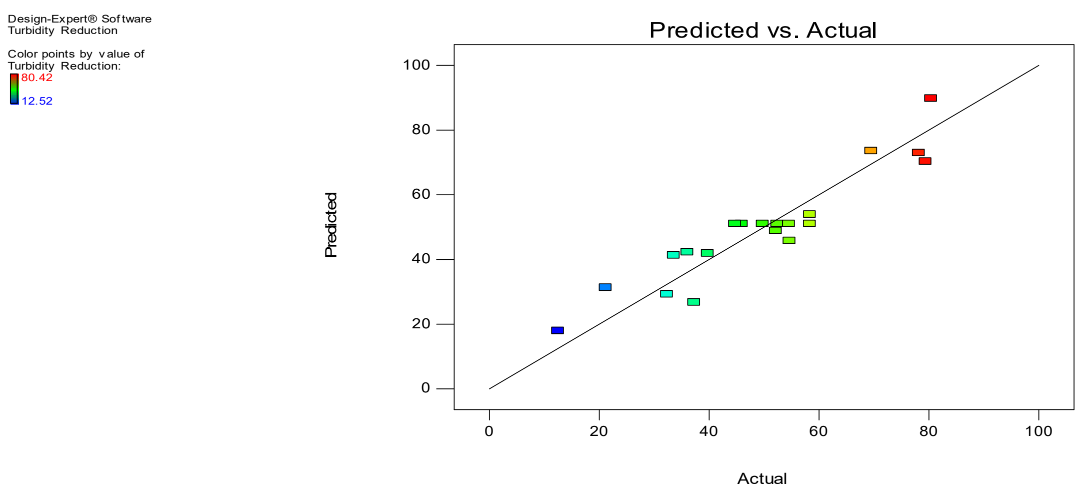

Figure 4.10. Normal probability plot of predicted versus actual values of experimental runs response for % TR using *Moringa oleifera* seeds(Quadratic model fit)

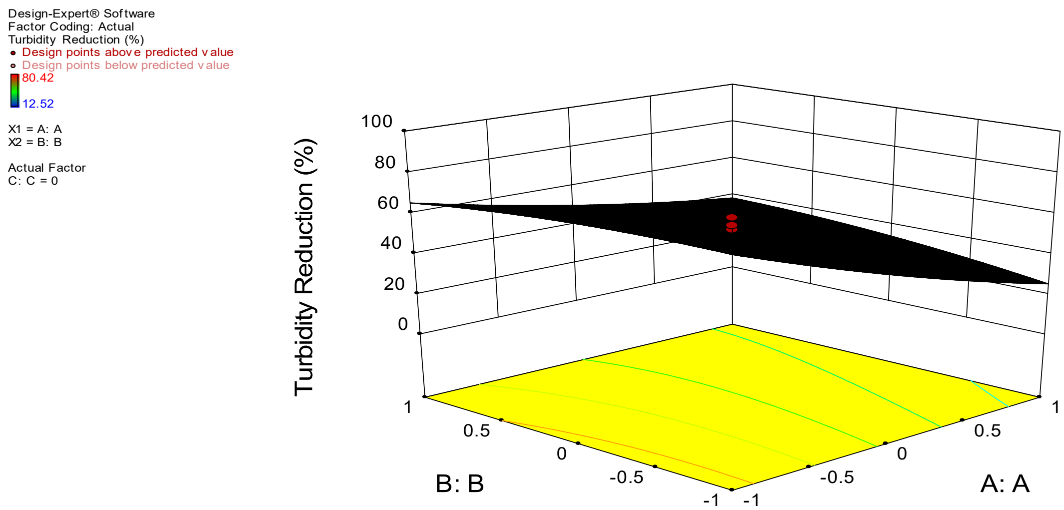

Figure 4.11. Response surface and contour plots for % Turbidity Reduction showing interaction of *Moringa oleifera* seeds dose and mixing time at mixing speed of 60 rpm (Quadratic model fit)

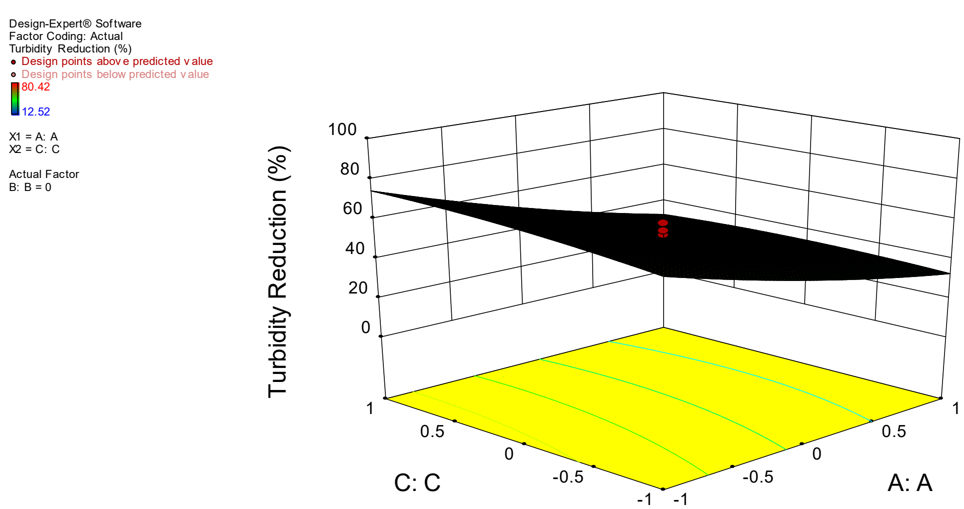

Figure 4.12. Response surface and contour plots for % Turbidity Reduction showing interaction of *Moringa oleifera* seeds dose and mixing speed at mixing time of 40 minutes (Quadratic model fit)

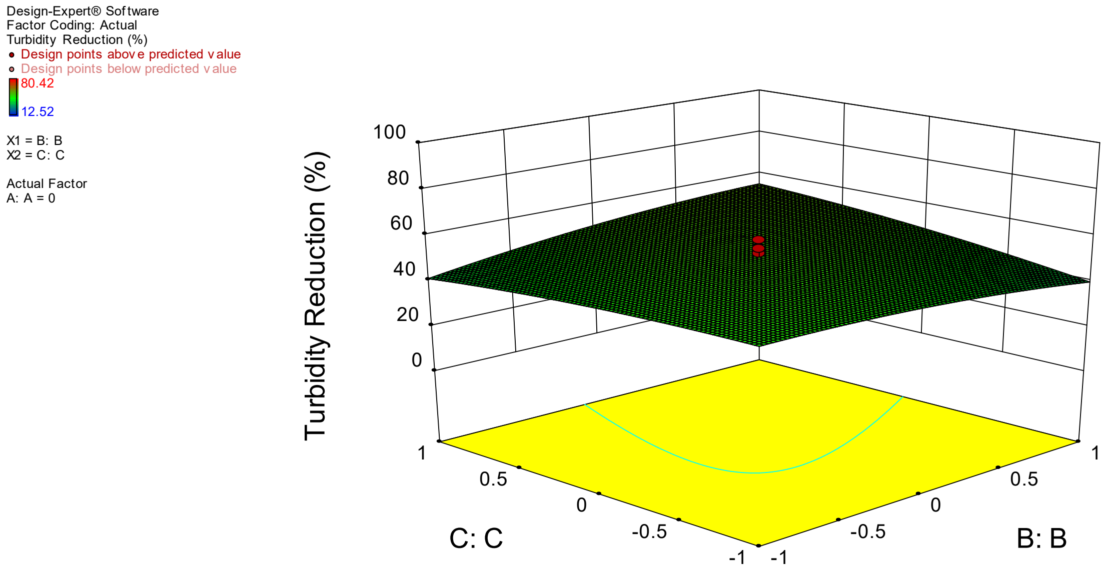

Figure 4.13. Response surface and contour plots for % Turbidity Reduction showing interaction of mixing time and mixing speed at *Moringa oleifera* seeds dosing of 20 mg/L (Quadratic model fit)

4.1.3.5 CUBIC MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TURBIDITY OF TREATED WATER

A Cubic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Turbidity Reduction (TR) of the treated water gave the following final equation in terms of coded factors:

$$\begin{aligned}\% \boldsymbol{TR} = 51.01 &- 12.82X_1 + 6.26X_2 + 3.68X_3 + 5.27X_1X_2 \\ &- 2.17X_1X_3 + 5.58X_2X_3 + 2.55{X_1}^2 - 2.66{X_2}^2 \\ &- 2.00{X_3}^2 + 3.10X_1X_2X_3 - 8.43{X_1}^2X_2 - 2.75{X_1}^2X_3 \\ &- 10.10X_1{X_2}^2 + 0.00[X_1{X_3}^2 + {X_2}^2X_3 + X_2{X_3}^2 + {X_1}^3 \\ &+ {X_2}^3 + {X_3}^3] \quad \ldots\ldots\ldots \quad 4.4\end{aligned}$$

This Cubic model is however aliased and will not be analysed further because the least squares parameter estimates for aliased models will not be unique and the resulting contour plots will be misleading. A model is said to be aliased when the estimate due to an effect also includes the influence of one or more other effects (usually higher order interactions). If for example the effect of X_1^3 in our model actually estimates $X_1^3 + 2.83X_1 - 1.83X_1X_2^2$,then the effects of X_1^3 is aliased with the other factors and hence not unique especially when those other factors are significant. A summary of the key statistical parameter values obtained from the percentage Turbidity Reduction data for each model is given in Appendix 4. This presentation is to enable easy comparison of the various models.

4.1.4 EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TOTAL DISSOLVED SOLIDS (TDS) OF TREATED WATER

The effects of *Moringa oleifera* seeds on the total dissolved solids of treated water was obtained by fitting the data with a Linear model, a Two Factor Interaction model, a Quadratic model and a Cubic model respectively. The key statistical values of each model were then sequentially assessed and relevant inferences drawn.

4.1.4.1 LINEAR MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TDS OF TREATED WATER

A linear model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage total dissolved solids Reduction (% TDSR) of the treated water gave the following final equation in terms of coded factors:

$$\%\,TDSR = 54.96 + 2.21X_1 + 0.12X_2 + 0.41X_3 \qquad 4.5$$

The model coefficient of determination (R^2) and adjusted R^2 values are 0.2038 and 0.0546 respectively

The ANOVA analysis is given in Appendix 5 for the Linear model fit.

The Linear model does not provide a good fit of the % Total Dissolved Solids reduction data as the ANOVA has shown that the model is not significant and it also has significant "lack of fit". This inference is further collaborated by the low R^2 and adjusted R^2 values. Hence the analysis will not be continued further to obtain the externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Total Dissolved Solids reduction using *Moringa oleifera* seeds.

4.1.4.2 TWO FACTOR INTERACTION MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TOTAL DISSOLVED SOLIDS OF TREATED WATER

A Two Factor Interaction model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Total Dissolved Solids Reduction (% TDSR) of the treated water gave the following final equation in terms of coded factors:

$$\begin{aligned}\% \boldsymbol{TDSR} = {} & \mathbf{54.96 + 2.21}\boldsymbol{X_1} + \mathbf{0.12}\boldsymbol{X_2} + \mathbf{0.41}\boldsymbol{X_3} + \mathbf{0.22}\boldsymbol{X_1X_2} \\ & + \mathbf{0.0013}\boldsymbol{X_1X_3} \\ & + \mathbf{0.17}\boldsymbol{X_2X_3} \qquad \ldots\ldots\ \ldots\ldots\ldots \quad \mathbf{4.6}\end{aligned}$$

The model Coefficient of Determination (R^2) and Adjusted R^2 values are 0.2057 and -0.1610 respectively.

The ANOVA analysis is given in Appendix 6 for the Two Factor Interaction model fit.

As with the Linear model, the Two Factor Interaction model does not provide a good fit of the % TDS reduction data since the ANOVA has shown that the model is not significant and it also has significant "lack of fit". This inference is further collaborated by the low R^2 and adjusted R^2 values. Hence the analysis will not be continued further to obtain the externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % TDS reduction using *Moringa oleifera* seeds.

4.1.4.3 QUADRATIC MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TOTAL DISSOLVED SOLIDS OF TREATED WATER

A Quadratic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Total Dissolved Solids Reduction (TDSR) of the treated water gave the following final equation in terms of coded factors:

$$\%\,TDSR = 55.96 + 2.21X_1 + 0.12X_2 + 0.41X_3 + 0.22X_1X_2 - 0.001X_1X_3 + 0.17X_2X_3 - 2.62X_1^2 + 0.61X_2^2 + 0.54X_3^2 \quad \ldots\ldots\ldots\ldots\ldots \quad 4.7$$

The model Coefficient of Determination (R^2) and Adjusted R^2 values are 0.5516 and 0.1480 respectively.

The ANOVA analysis is given in Appendix 7 for the Quadratic model fit.

As with the Linear and the Two Factor Interaction models, the Quadratic model does not provide a good fit of the % Total Dissolved Solids reduction data since the ANOVA has shown that the model is not significant and it also has significant "lack of fit". This inference is further collaborated by the low R^2 and adjusted R^2 values. Hence the analysis will not be continued further to obtain the externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Total Dissolved Solids reduction using *Moringa oleifera* seeds.

4.1.4.4 CUBIC MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TDS OF TREATED WATER

A Cubic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Total Dissolved Solids Reduction (TDSR) of the treated water gave the following final equation in terms of coded factors:

$$\% \boldsymbol{TDSR} = 55.96 + 5.76X_1 + 0.32X_2 + 0.84X_3 + 0.22X_1X_2 + 0.001X_1X_3 + 0.17X_2X_3 - 2.62X_1^2 + 0.61X_2^2 + 0.54X_3^2 + 0.024X_1X_2X_3 - 0.34X_1^2X_2 - 0.75X_1^2X_3 - 6.06X_1X_2^2 + 0.00[X_1X_3^2 + X_2^2X_3 + X_2X_3^2 + X_1^3 + X_2^3 + X_3^3] \quad \ldots\ldots\ldots \quad 4.8$$

This Cubic model is also aliased and will not be analysed further because of the reasons previously stated.

4.1.5 EFFECTS OF *MORINGA OLEIFERA* SEEDS ON THE CONDUCTIVITY OF TREATED WATER

The effects of *Moringa oleifera* seeds on the conductivity of treated water was obtained by fitting the data with a Linear model, a Two Factor Interaction model, a Quadratic model and a Cubic model respectively. The key statistical values of each model were then sequentially assessed and relevant inferences drawn.

4.1.5.1 LINEAR MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON CONDUCTIVITY OF TREATED WATER

A linear model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Conductivity Reduction (% CR) of the treated water gave the following final equation in terms of coded factors:

$$\% \boldsymbol{CR} = 49.36 - 0.21X_1 + 0.072X_2 + 0.49X_3 \qquad 4.9$$

The model coefficient of determination (R^2)and adjusted R^2 values are 0.1590 and 0.0013 respectively

The ANOVA analysis is given Appendix 9 for the Linear model fit.

The Linear model does not provide a good fit of the % Conductivity reduction data as the ANOVA has shown that the model is not significant. This inference is further collaborated by the low R^2 and adjusted R^2 values. Hence the analysis will not be continued further to obtain the externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Conductivity reduction using *Moringa oleifera* seeds.

4.1.5.2 TWO FACTOR INTERACTION MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON CONDUCTIVITY OF TREATED WATER

A Two Factor Interaction model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Conductivity Reduction (% CR) of the treated water gave the following final equation in terms of coded factors:

$$\boldsymbol{\%\,CR = 49.36 - 0.21X_1 + 0.072X_2 + 0.49X_3 + 0.30X_1X_2 + 0.059X_1X_3 + 0.059X_2X_3 \quad \ldots\ldots\ \ldots\ldots\ldots\ 4.10}$$

The model Coefficient of Determination (R^2) and Adjusted R^2 values are 0.1891 and -0.1852 respectively.

The ANOVA analysis is given in Appendix 10 for the Two Factor Interaction model fit.

As with the Linear model, the Two Factor Interaction model does not provide a good fit of the % Conductivity reduction data since the ANOVA has shown that the model is not significant. This inference is further collaborated by the low R^2 and adjusted R^2 values. Hence the analysis will not be continued further to obtain the externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Conductivity reduction using *Moringa oleifera* seeds.

4.1.5.3 QUADRATIC MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON THE CONDUCTIVITY OF TREATED WATER

A Quadratic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Conductivity Reduction (CR) of the treated water gave the following final equation in terms of coded factors:

$$\begin{aligned}\%\,CR = {} & 49.36 - 0.21X_1 + 0.072X_2 + 0.49X_3 + 0.30X_1X_2 + 0.059X_1X_3 \\ & + 0.059X_2X_3 - 0.30X_1{}^2 - 0.42X_2{}^2 - 0.20X_3{}^2 \quad \ldots\ldots\ldots\ldots\ldots \quad 4.11\end{aligned}$$

The model Coefficient of Determination (R^2) and Adjusted R^2 values are 0.3398 and -0.2544 respectively

The ANOVA analysis is given in Appendix 11 for the Quadratic model fit.

As with the Linear and the Two Factor Interaction models, the Quadratic model does not provide a good fit of the % Conductivity reduction data since the ANOVA has shown that the model is not significant. This inference is further collaborated by the low R^2 and adjusted R^2 values. Hence the analysis will not be continued further to obtain the externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Conductivity reduction using *Moringa oleifera* seeds.

4.1.5.4 CUBIC MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON CONDUCTIVITY OF TREATED WATER

A Cubic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Conductivity Reduction (CR) of the treated water gave the following final equation in terms of coded factors:

$$
\begin{aligned}
\%\, CR = 49.36 &- 0.21X_1 + 0.072X_2 + 0.49X_3 + 0.30X_1X_2 \\
&+ 0.059X_1X_3 + 0.059X_2X_3 - 0.30{X_1}^2 - 0.42{X_2}^2 \\
&- 0.20{X_3}^2 + 0.28X_1X_2X_3 - 0.08{X_1}^2X_2 - 0.72{X_1}^2X_3 \\
&- 0.44X_1{X_2}^2 + 0.00[X_1{X_3}^2 + {X_2}^2X_3 + X_2{X_3}^2 + {X_1}^3 \\
&+ {X_2}^3 + {X_3}^3] \quad \ldots\ldots\ldots \; 4.12
\end{aligned}
$$

This Cubic model is also aliased and will not be analysed further because of the reasons previously stated.

4.1.6 EFFECTS OF *MORINGA OLEIFERA* SEEDS ON THE SALINITY OF TREATED WATER

The effects of *Moringa oleifera* seeds on the salinity of treated water was obtained by fitting the data with a Linear model, a Two Factor Interaction model, a Quadratic model and a Cubic model respectively. The key statistical values of each model were then sequentially assessed and relevant inferences drawn.

4.1.6.1 LINEAR MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON SALINITY OF TREATED WATER

A linear model fit of the experimental results for the effects of *Mo* on the percentage Salinity Reduction (% SR) of the treated water gave the following final equation in terms of coded factors:

$$\% SR = 56.19 - 0.28X_1 + 0.077X_2 + 0.33X_3 \qquad 4.13$$

The model coefficient of determination (R^2) and adjusted R^2 values are 0.1385 and -0.0230 respectively

The ANOVA analysis is given in Appendix 13 for the Linear model fit.

The Linear model does not provide a good fit of the % Salinity reduction data as the ANOVA has shown that the model is not significant. This inference is further collaborated by the low R^2 and adjusted R^2 values. Hence the analysis will not be continued further to obtain the externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Salinity reduction using *Moringa oleifera* seeds.

4.1.6.2 TWO FACTOR INTERACTION MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON SALINITY OF TREATED WATER

A Two Factor Interaction model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Salinity Reduction (% SR) of the treated water gave the following final equation in terms of coded factors:

$$\% \boldsymbol{SR} = 56.19 - 0.28X_1 + 0.077X_2 + 0.33X_3 + 0.24X_1X_2 + 0.64X_1X_3 + 0.46X_2X_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 4.14$$

The model Coefficient of Determination (R^2) and Adjusted R^2 values are 0.4260 and 0.1610 respectively. The ANOVA analysis is given in Appendix 14 for the Two Factor Interaction model fit.

As with the Linear model, the Two Factor Interaction model does not provide a good fit of the % Salinity reduction data since the ANOVA has shown that the model is not significant. This inference is further collaborated by the low R^2 and adjusted R^2 values. Hence the analysis will not be continued further to obtain the externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % Conductivity reduction using *Moringa oleifera* seeds.

4.1.6.3 QUADRATIC MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* ON THE SALINITY OF TREATED WATER

A Quadratic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Salinity Reduction (SR) of the treated water gave the following final equation in terms of coded factors:

$$\begin{aligned}\%\,SR = {} & 56.19 - 0.28X_1 + 0.077X_2 + 0.33X_3 + 0.24X_1X_2 + 0.64X_1X_3 \\ & + 0.46X_2X_3 + 0.15{X_1}^2 - 0.29{X_2}^2 \\ & - 0.29{X_3}^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .4.15\end{aligned}$$

The model Coefficient of Determination (R^2) and Adjusted R^2 values are 0.5722 and 0.1872 respectively

The ANOVA analysis is given in Appendix 15 for the Quadratic model fit.

As with the Linear and the Two Factor Interaction models, the Quadratic model does not provide a good fit of the % Salinity reduction data since the ANOVA has shown that the model is not significant. This inference is further collaborated by the low R^2 and adjusted R^2 values. Hence the analysis will not be continued further to obtain the externally studentised residuals versus run number, normal probability plot of predicted versus actual response, and Response surface with contour plots for the % salinity reduction using *Moringa oleifera* seeds.

4.1.6.4 CUBIC MODEL FIT OF THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON SALINITY OF TREATED WATER

A Cubic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Salinity Reduction (SR) of the treated water gave the following final equation in terms of coded factors:

$$\begin{aligned}\% SR = 56.19 &- 0.17X_1 + 0.22X_2 + 0.57X_3 + 0.24X_1X_2 + 0.64X_1X_3 \\ &+ 0.46X_2X_3 + 0.15X_1{}^2 - 0.29X_2{}^2 - 0.29X_3{}^2 - 0.021X_1X_2X_3 \\ &- 0.24X_1{}^2X_2 - 0.40X_1{}^2X_3 - 0.18X_2{}^2 + 0.00[X_1X_3{}^2 + X_2{}^2X_3 \\ &+ X_2X_3{}^2 + X_1{}^3 + X_2{}^3 + X_3{}^3] \quad \ldots\ldots\ldots \; 4.16\end{aligned}$$

This Cubic model is also aliased and will not be analysed further because of the reasons previously stated.

4.2 DISCUSSION

4.2.1 THE EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TURBIDITY OF TREATED WATER

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. From the linear model fit equation, it can be inferred that X_1 (the coagulant concentration) had greater impact on the percentage turbidity reduction, than the X_2 (the mixing time) and X_3 (the mixing speed). The inference is further supported by the ANOVA result for Response Surface Linear Model of percentage Turbidity reduction. From the p-value analysis of the ANOVA result, values of "Prob >F" less than 0.0500 indicated that the model is significant while the model terms were not significant otherwise. The model was significant with a p-value <0.0001. The Coagulant concentration (X_1) was also a significant model term, while mixing time (X_2) and mixing speed (X_3) were not significant. Coagulant dosage is one of the most important factors that have been considered to determine the optimum condition for the performance of coagulants in coagulation and flocculation. Essentially insufficient dosage or overdosing would result in poor performance in flocculation. Therefore it is significant to determine the optimum dosage to minimize the dosing cost and also to obtain the optimum performance in treatment (Patel and Vashi, 2013). The model however was not the best for the data as it had significant "Lack-of-fit" while an insignificant "Lack-of-fit" was desirable. The model coefficient of determination (R^2) and adjusted R^2 values were 0.7532 and 0.7069 respectively. The closer these values are to 1 the better the model represents the experimental data. The random distribution of the residual values through the experimental runs indicated that there were no systematic errors due to personnel or equipment during the study. The normality plot of the predicted versus actual response indicated that a better fit than the linear model was desirable. The response surface plot indicated that the percentage Turbidity reduction was virtually unaffected by mixing time as the value remained constant from the high (+1) to low (-1) value range while a change was recorded for the X_1 (coagulant concentration) factor between the high (+1) to low (-1) values. From the Two Factor Interaction model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Turbidity reduction of the treated water in terms of coded factors, it can also be inferred that X_1 (the coagulant concentration) had greater impact on the percentage Turbidity reduction, than the X_2 (the mixing time) and X_3 (the mixing speed) based on the magnitude of their coefficients. The inference is further supported by the ANOVA result for Response Surface Two Factor Interaction Model of percentage Turbidity reduction. The model was significant. The Coagulant concentration (X_1) was significant while X_2 and X_3 were not significant. The model also has an insignificant "Lack-of-fit" which was desirable. The model coefficient of determination (R^2) and adjusted R^2 values were 0.8316 and 0.7539 respectively. The random distribution of the residual values through the experimental runs indicated that there were no systematic errors due to personnel or equipment during the study. The normality plot of the predicted versus actual response indicated that the model gave a better fit than the linear model as there was better agreement between the predicted and actual responses. The response surface plots indicated that the percentage Turbidity reduction was virtually unaffected by mixing time (X_2) and mixing speed (X_3) as the values remained constant from the high (+1) to low (-1) value range while a change was observed for the X_1 factor between the high (+1) to low (-1) values.

From the quadratic model fit equation of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Turbidity reduction of the treated water in terms of coded factors, it can also be inferred that X_1 (the coagulant concentration) had greater impact on the percentage Turbidity reduction, than X_2 (the mixing time) and X_3 (the mixing speed), based on the magnitude of their coefficients. Walsh *et al.,* (2009) in their study found out that coagulant dose was the most important variable for treatment performance. The inference is further supported by the ANOVA result for Response Quadratic Model of percentage Turbidity reduction. The model was significant. The coagulant concentration (X_1) was also significant, while mixing time (X_2) and mixing speed (X_3) were not significant. The model also had an insignificant "Lack-of-fit" which was desirable. The model coefficient of determination (R^2) and adjusted R^2 values are 0.8742 and 0.7610 respectively. The closer these values are to 1 the better the model represents the experimental data. The random distribution of the residual values through the experimental runs indicated that there were no systematic errors due to personnel or equipment during the study. The normality plot of the predicted versus actual response indicated that the model gave a better fit than the Two Factor Interaction model as there was better agreement between the predicted and actual responses. The response surface plots shown in Figures 4.11 and 4.12 indicated that the percentage Turbidity reduction is virtually unaffected by X_2 and X_3 as the values remained constant from the high (+1) to low (-1) value range while a change was recorded for the X_1 factor between the high (+1) to low (-1) values.

The Cubic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the Percentage Turbidity reduction of the treated water is aliased. The quadratic model therefore was the model that gave the best estimate of the data. Using this model, the maximum percentage Turbidity Reduction that could be achieved was 74.79% and would be attained when $X_1 = -1$, $X_2 = 0.305$, *and* $X_3 = 1$. In actual factor terms; this maximum percentage Turbidity reduction would be achieved with a coagulant concentration of 10mg/l, mixing time of 43 minutes, and mixing speed of 80 rpm. The percentage reduction in turbidity achieved through the use of *Moringa oleifera* seeds is attributed to the fact that the seed kernels of *Moringa oleifera* contain significant quantities of low molecular weight water soluble proteins which carry a positive charge. The coagulant properties of the seeds are due to a series of low molecular weight proteins (Tauscher, 1994). When the crushed seeds are added to raw water, the proteins produce positive charges which act like magnets and attract the predominantly negatively charged particles in water. The turbidity reduction agreed with Nkurunziza *et al.,* (2009) on their study on the effect of turbidity levels and *Moringa oleifera* seed concentration on the effectiveness of coagulation in water treatment, their study found out that turbidity removal was influenced by initial turbidity, the turbidity removal ranged from 83.2%

to 99.8% based on initial turbidity levels of 50NTU and 450NTU. Also according to Sarpong and Richardson (2010), efficiency of turbidity removal was high at initial 94% for initial turbidity of source water at turbidity range of 88 to 195NTU.

4.2.2 EFFECTS OF *MORINGA OLEIFERA* SEEDS ON TOTAL DISSOLVED SOLIDS OF TREATED WATER

From the linear model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Total Dissolved Solids reduction of the treated water, in terms of coded factors, it can be inferred that X_1 (the coagulant concentration) had a slightly greater impact on the percentage Total Dissolved Solids reduction than X_2 (the mixing time) and X_3 (the mixing speed) based on the magnitude of their coefficients. The model was not significant. The Coagulant concentration (X_1), mixing time (X_2) and mixing speed (X_3) were also not significant. The model also had a significant "Lack-of-fit" which was not desirable for a good model. The linear fit model was therefore not a good representation of the data for the effects of *Moringa oleifera* seeds on the Total Dissolved Solids of the treated water.

From the Two Factor Interaction model fit equation of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Total Dissolved Solids reduction of the treated water in terms of coded factors, it can also be inferred that X_1 (the coagulant concentration) had a slightly greater impact on the percentage Total Dissolved Solids reduction than X_2 (the mixing time) and X_3 (the mixing speed) based on the magnitude of their coefficients. The model was not significant. The Coagulant concentration (X_1), mixing time (X_2) and mixing speed (X_3) were also not significant. The model also had a significant "Lack-of-fit" which was not desirable for a good model. The model coefficient of determination (R^2) and adjusted R^2 values were 0.2057 and -0.1610 respectively. The Two Factor Interaction model was therefore not also a good representation of the data for the effects of *Moringa oleifera* seeds on the Total Dissolved Solids of the treated water.

From the quadratic model fit equation of the experimental results for the effects of *Moringa oleifera* seeds on the percentage Total Dissolved Solids reduction of the treated water in terms of coded factors, it can also be inferred that X_1 (the coagulant concentration) had a slightly greater impact on the percentage Total Dissolved Solids reduction than X_2 (the mixing time) and X_3 (the mixing speed) based on the magnitude of their coefficients. From the ANOVA result for Response Surface Quadratic Model of percentage Total Dissolved Solids reduction, the model was not significant. The Coagulant concentration (X_1), mixing time (X_2) and mixing speed (X_3) were also not significant. The model also had a significant "Lack-of-fit" which was not desirable for a good model. The model coefficient of determination (R^2) and adjusted R^2 values were low. The quadratic model was therefore not also a good representation of the data for the effects of *Moringa oleifera* seeds on the Total Dissolved Solids of the treated water.

The Cubic model fit of the experimental results for the effects of *Moringa oleifera* on the Percentage Total Dissolved Solids Reduction of the treated water given is aliased.

Since none of the models tested gave adequate representation of the data, it was not possible to predict optimum conditions for the effects of *Moringa oleifera* seeds on the Total Dissolved Solids of the treated water. However, from the experimental results, an average of 54.96% Total Dissolved Solids reduction was achieved for all the experimental runs. This study contrasted that of Khallaf *et al* (2014), which observed that Total Dissolved Solids was not affected by *Moringa* seed powder at different concentrations.

4.2.3 EFFECTS OF *MORINGA OLEIFERA* SEEDS ON CONDUCTIVITY OF TREATED WATER

From the linear model fit equation of the experimental results for the effects of *Moringa oleifera* seeds on the percentage conductivity reduction of the treated water in terms of coded factors, it can be inferred that X_3 (the mixing speed) has a slightly greater impact on the percentage reduction in conductivity values than X_1 (the coagulant concentration) and X_2 (the mixing time) based on the magnitude of their coefficients. The model was not significant. The coagulant concentration (X_1), mixing time (X_2) and mixing speed (X_3) were also not significant. The model did not have a significant "Lack-of-fit" and the model coefficient of determination (R^2) and adjusted R^2 values were low. The linear fit model was therefore not a good representation of the data for the effects of *Moringa oleifera* seeds on the conductivity of the treated water because the model was not significant and the R^2 values were very low.

From the Two Factor Interaction model fit equation of the experimental results for the effects of *Moringa oleifera* seeds on the percentage conductivity reduction of the treated water in terms of coded factors, it can be inferred that X_3 (the mixing speed) has a slightly greater impact on the percentage conductivity reduction than X_1 (the coagulant concentration) and

X_2 (the mixing time) based on the magnitude of their coefficients. The model was not significant. The coagulant concentration (X_1), mixing time (X_2) and mixing speed (X_3) were also not significant. The model did not have a significant "Lack-of-fit" and the model coefficient of determination (R^2) and adjusted R^2 values were very low. The Two Factor Interaction model was therefore not also a good representation of the data for the effects of *Moringa oleifera* seeds on the conductivity of the treated water because the model was not significant and the R^2 values were very low.

From the quadratic model fit equation of the experimental results for the effects of *Moringa oleifera* seeds on the percentage conductivity value reduction of the treated water in terms of coded factors, it can be inferred that X_3 (the mixing speed) had a slightly greater impact on the percentage conductivity reduction than X_1 (the coagulant concentration) and X_2 (the mixing time) based on the magnitude of their coefficients. The model was not significant. The coagulant concentration (X_1), mixing time (X_2) and mixing speed (X_3) were also not significant. The model did not have a significant "Lack-of-fit" and the model coefficient of determination (R^2) and adjusted R^2 values were low. The quadratic model was therefore not also a good representation of the data for the effects of *Moringa oleifera* seeds on the conductivity of the treated water because the model was not significant and the R^2 values are very low.

The Cubic model fit equation of the experimental results for the effects of *Moringa oleifera* seeds on the Percentage conductivity value reduction of the treated water is aliased.

Since none of the models tested gave adequate representation of the data, it was not possible to predict optimum conditions for the effects of *Moringa oleifera* seeds on the conductivity values of the treated water. However, from the experimental results shown in Table 4.3, an average of 49.36% conductivity reduction was achieved for all the experimental runs. The result from this work contrasted that of Sarpong and Richardson (2010), which did not observe any change in the conductivity value, upon treatment of water with *Moringa oleifera* seed extract. Also in contrast was the study by Khallaf *et al*.,2014), which observed that the conductivity was not affected by *Moringa* seed powder at different concentrations.

4.2.4 EFFECTS OF *MORINGA OLEIFERA* SEEDS ON SALINITY OF TREATED WATER

From the linear model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage salinity reduction of the treated water in terms of coded factors, it can be inferred that X_3 (the mixing speed) and X_1 (the coagulant concentration) had a greater impact on the percentage salinity reduction than X_2 (the mixing time) based on the magnitude of their coefficients. The model was not significant. The coagulant concentration (X_1), X_2 and X_3 were also not significant. The model did not have a significant "Lack-of-fit" and the model coefficient of determination (R^2) and adjusted R^2 values were low. The linear fit model was therefore not a good representation of the data for the effects of *Moringa oleifera* seeds on the salinity of the treated water because the model was not significant and the R^2 values were very low.

From the Two Factor Interaction model fit equation of the experimental results for the effects of *Moringa oleifera* seeds on the percentage salinity reduction of the treated water in terms of coded factors, it can be inferred that X_3 (the mixing speed) and X_1 (the coagulant concentration) have a greater impact on the percentage salinity reduction than X_2 (the mixing time) based on the magnitude of their coefficients. The model was not significant.

The coagulant concentration X_1, the mixing time X_2 and the mixing speed X_3 were also not significant. The model did not have a significant "Lack-of-fit" and the model coefficient of determination (R^2) and adjusted R^2 values were low. The Two Factor Interaction model was therefore not also a good representation of the data for the effects of *Moringa oleifera* seeds on the salinity of the treated water because the model was not significant and the R^2 values were very low.

From the quadratic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage salinity reduction of the treated water in terms of coded factors, it can be inferred that X_3 (the mixing speed) and X_1 (the coagulant concentration) had greater impact on the percentage salinity reduction than X_2 (the mixing time) based on the magnitude of their coefficients. The model was not significant. The coagulant concentration (X_1), mixing time (X_2) and mixing speed (X_3) were also not significant. The model did not have a significant "Lack-of-fit" and the model coefficient of determination (R^2) and adjusted R^2 values were low. The quadratic model was therefore not also a good representation of the data for the effects of *Moringa oleifera* seeds on the salinity of the treated water because the model was not significant and the R^2 values were very low.

The Cubic model fit of the experimental results for the effects of *Moringa oleifera* seeds on the percentage salinity reduction of the treated water given in equation is aliased.

Since none of the models tested gave adequate representation of the data, it was not possible to predict optimum conditions for the effects of *Moringa oleifera* seeds on the salinity of the treated water. However, from the experimental results shown in Table 4.3, an average of 56.19% salinity reduction was achieved for all the experimental runs. This contrasted with the study by Kalikawe *et a*l.,(2015), which indicated that *Moringa oleifera* seed extract had no substantial effects on salinity, although during the study, turbidity and pH were varied.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study has shown that use of plant flocculants such as *Moringa oleifera* seeds is beneficial for water purification and can serve as alternative to aluminium sulphate which could be toxic. *Moringa oleifera* seeds reduced the number of suspended particles drastically, thereby reducing the quantity of microorganisms in raw water automatically. An advantage of *Moringa oleifera* seeds over aluminium sulphate is that it is not pH dependent and hence no need for pH control unlike aluminium sulphate where optimum coagulation efficiency occurs at pH 6.0 to 7.0. Another advantage is that because *Moringa* can be produced locally, using it as alternative to aluminium sulphate would generate farm and employment income.

Most of the other studies previously done with *Moringa* on water were more on the ability of *Moringa* to act as a coagulant and to remove bacteria from water while this study focused on the effects of addition of *Moringa oleifera* seeds on the physicochemical parameters of the water namely, the Turbidity, Total Dissolved Solids, Salinity and Conductivity. Response Surface modeling was applied to determine the impact of the *Moringa oleifera* seeds concentration, mixing time and mixing speed on these physicochemical parameters to evaluate their significance. The *Moringa oleifera* seeds concentration was noted to be the key factor that showed a significant effect on the physicochemical parameters while the effects of mixing time and mixing speed were not significant. This study has strengthened earlier postulations that *Moringa oleifera* seeds can be used as a good alternative for aluminium sulphate in large scale/municipal water treatment. Developing this process to attain technical and commercial competitiveness will improve the health and safety of man and the environment.

5.2 RECOMMENDATIONS

I recommend that further studies on the preparation, preservation and shelf life analysis of *Moringa oleifera* seeds be carried out to determine how to maintain the seeds in prime condition for use in water treatment. It is also needful to consider the modifications that can be made to water treatment plants to accommodate the use of *Moringa oleifera* seeds on large scale.

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LIST OF APPENDIX

Appendix 1: ANOVA for Response Surface Linear Model of % Turbidity Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	4877.89	3	1625.96	16.27	<0.0001	Significant
X_1	4795.35	1	4795.35	47.99	<0.0001	Significant
X_2	23.95	1	23.95	0.24	0.6311	
X_3	58.59	1	58.59	0.59	0.4550	
Residual	1598.76	16	99.92			
Lack of Fit	1463.77	11	133.07	4.93	0.0455	Significant
Pure Error	134.99	5	27.00			
Cor Total	6476.65	19				

Appendix 2: ANOVA for Response Surface Two Factor Interaction Model of % Turbidity Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	5386.14	6	897.69	10.70	0.0002	significant
X_1	4795.35	1	4795.35	57.17	<0.0001	significant
X_2	23.95	1	23.95	0.29	0.6021	
X_3	58.59	1	58.59	0.70	0.4184	
$X_1 X_2$	221.87	1	221.87	2.64	0.1279	
$X_1 X_3$	37.63	1	37.63	0.45	0.5147	
$X_2 X_3$	248.76	1	248.76	2.97	0.1088	
Residual	1090.51	13	83.89			
Lack of Fit	955.52	8	119.44	4.42	0.0591	not significant
Pure Error	134.99	5	27.00			
Cor Total	6476.65	19				

Appendix 3: ANOVA for Response Surface Quadratic Model of % Turbidity Reduction for water treated with *Moringa oleifera* seeds

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	5661.92	9	629.10	7.72	0.0018	significant
X_1	4795.35	1	4795.35	58.86	<0.0001	significant
X_2	23.95	1	23.95	0.29	0.5996	
X_3	58.59	1	58.59	0.72	0.4163	
$X_1 X_2$	221.87	1	221.87	2.72	0.1299	
$X_1 X_3$	37.63	1	37.63	0.46	0.5122	
$X_2 X_3$	248.76	1	248.76	3.05	0.1112	
X_1^2	93.92	1	93.92	1.15	0.3082	
X_2^2	101.99	1	101.99	1.25	0.2894	
X_3^2	57.80	1	57.80	0.71	0.4193	
Residual	814.73	10	81.47			
Lack of Fit	679.75	5	135.95	5.04	0.0503	not significant
Pure Error	134.99	5	27.00			
Cor Total	6376.65	19				

Appendix 4: Summary of key statistical parameters obtained from each model for the effects of *Moringa oleifera* seeds on the % Turbidity Reduction

	Linear Model	**Two Factor Interaction Model**	**Quadratic Model**	**Cubic Model**
p-value of model	<0.0001	0.0002	0.0018	aliased
p-value of X_1	<0.0001	<0.0001	<0.0001	aliased
p-value of X_2	0.6311	0.6021	0.5996	aliased
p-value of X_3	0.4550	0.4184	0.4163	aliased
'lack of fit' p-value	0.0455	0.0591	0.0503	aliased
R^2	0.7532	0.8316	0.8742	aliased
Adjusted R^2	0.7069	0.7539	0.7610	aliased

The percentage reduction in turbidity that could be achieved was 74.79% using the quadratic model.

Appendix 5: ANOVA for Response Surface Linear Model of % TDS Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	69.44	3	23.15	1.37	0.2890	not significant
X_1	66.97	1	66.97	3.95	0.0642	
X_2	0.19	1	0.19	0.011	0.9162	
X_3	2.27	1	2.27	0.13	0.7193	
Residual	271.19	16	16.95			
Lack of Fit	270.22	11	24.57	125.50	<0.0001	significant
Pure Error	0.98	5	0.20			
Cor Total	340.63	19				

Appendix 6: ANOVA for Response Surface Two Factor Interaction Model of % TDS Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	70.05	6	11.68	0.56	0.7540	not significant
X_1	66.97	1	66.97	3.22	0.0961	
X_2	0.19	1	0.19	0.0093	0.9246	
X_3	2.27	1	2.27	0.11	0.7465	
$X_1 X_2$	0.38	1	0.38	0.18	0.8942	
$X_1 X_3$	0.0001	1	0.0001	0.0000006	0.9994	
$X_2 X_3$	0.23	1	0.23	0.011	0.9171	
Residual	270.58	13	20.81			
Lack of Fit	269.60	8	33.70	172.17	<0.0001	significant
Pure Error	0.98	5	0.20			
Cor Total	340.63	19				

Appendix 7: ANOVA for Response Surface Quadratic Model of % TDS Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	187.89	9	20.88	1.37	0.3155	not significant
X_1	66.97	1	66.97	4.38	0.0627	
X_2	0.19	1	0.19	0.013	0.9126	
X_3	2.27	1	2.27	0.15	0.7080	
$X_1 X_2$	0.38	1	0.38	0.025	0.8774	
$X_1 X_3$	0.00001	1	0.00001	0.0000008	0.9993	
$X_2 X_3$	0.23	1	0.23	0.15	0.9038	
X_1^2	99.02	1	99.02	6.48	0.0291	
X_2^2	5.43	1	5.43	0.36	0.5643	
X_3^2	4.25	1	4.25	0.28	0.6094	
Residual	152.74	10	15.27			
Lack of Fit	151.76	5	30.35	155.06	<0.0001	Significant
Pure Error	0.98	5	0.20			
Cor Total	340.63	19				

Appendix 8: Summary of key statistical parameters obtained from each model for the effects of *Moringa oleifera* seeds on the % Total Dissolved Solids Reduction

	Linear Model	**Two Factor Interaction Model**	**Quadratic Model**	**Cubic Model**
p-value of model	0.2890	0.7540	0.3155	aliased
p-value of X_1	0.0642	0.0961	0.0627	aliased
p-value of X_2	0.9162	0.9246	0.9126	aliased
p-value of X_3	0.7193	0.7465	0.7080	aliased
'lack of fit' p-value	<0.0001	<0.0001	<0.0001	aliased
R^2	0.2038	0.2057	0.5516	aliased
Adjusted R^2	0.0546	-0.1610	0.1480	aliased

From the experimental runs, an average of 54.96% TDS reduction was achieved.

Appendix 9: ANOVA for Response Surface Linear Model of % Conductivity Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	4.00	3	1.33	1.01	0.4148	not significant
X_1	0.61	1	0.61	0.46	0.5078	
X_2	0.071	1	0.071	0.054	0.8200	
X_3	3.32	1	3.32	2.51	0.1326	
Residual	21.15	16	1.32			
Lack of Fit	7.51	11	0.68	0.25	0.9740	not significant
Pure Error	13.63	5	2.73			
Cor Total	25.14	19				

Appendix 10: ANOVA for Response Surface Two Factor Interaction Model of % Conductivity Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	4.75	6	0.79	0.51	0.7939	not significant
X_1	0.61	1	0.61	0.39	0.5448	
X_2	0.071	1	0.071	0.045	0.8351	
X_3	3.32	1	3.32	2.12	0.1694	
$X_1 X_2$	0.70	1	0.70	0.45	0.5151	
$X_1 X_3$	0.028	1	0.028	0.018	0.8965	
$X_2 X_3$	0.028	1	0.028	0.018	0.8965	
Residual	20.39	13	1.57			
Lack of Fit	6.75	8	0.84	0.31	0.9314	not significant
Pure Error	13.63	5	2.73			
Cor Total	25.14	19				

Appendix 11: ANOVA for Response Surface Quadratic Model of % Conductivity Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	8.54	9	0.95	0.57	0.7930	not significant
X_1	0.61	1	0.61	0.37	0.5590	
X_2	0.071	1	0.071	0.043	0.8406	
X_3	3.32	1	3.32	2.00	0.1877	
$X_1 X_2$	0.70	1	0.70	0.42	0.5301	
$X_1 X_3$	0.028	1	0.028	0.017	0.8999	
$X_2 X_3$	0.028	1	0.028	0.017	0.8999	
X_1^2	1.27	1	1.27	0.76	0.4023	
X_2^2	2.57	1	2.57	1.55	0.2417	
X_3^2	0.58	1	0.58	0.35	0.5661	
Residual	16.60	10	1.66			
Lack of Fit	2.96	5	0.59	0.22	0.9403	not significant
Pure Error	13.63	5	2.73			
Cor Total	25.14	19				

Appendix 12: Summary of key statistical parameters obtained from each model for the effects of *Moringa oleifera* seeds on the % Conductivity Reduction

	Linear Model	**Two Factor Interaction Model**	**Quadratic Model**	**Cubic Model**
p-value of model	0.4148	0.7939	0.7930	aliased
p-value of X_1	0.5078	0.5448	0.5590	aliased
p-value of X_2	0.8200	0.8351	08406	aliased
p-value of X_3	0.1326	0.1694	0.1877	aliased
'lack of fit' p-value	0.9740	0.9314	0.9403	aliased
R^2	0.1590	0.1891	0.3398	aliased
Adjusted R^2	0.0013	-0.1852	-0.2544	aliased

From experimental results, an average of 49.36% conductivity values reduction was achieved.

Appendix 13: ANOVA for Response Surface Linear Model of % Salinity Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	2.63	3	0.88	0.86	0.4831	not significant
X_1	1.05	1	1.05	1.03	0.3260	
X_2	0.082	1	0.082	0.080	0.7807	
X_3	1.50	1	1.50	1.47	0.2436	
Residual	16.35	16	1.02			
Lack of Fit	9.07	11	0.82	0.57	0.7992	not significant
Pure Error	7.28	1	1.46			
Cor Total	18.98	19				

Appendix 14: ANOVA for Response Surface Two Factor Interaction Model of % Salinity Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	8.08	6	1.35	1.61	0.2221	not significant
X_1	1.05	1	1.05	1.25	0.2834	
X_2	0.082	1	0.082	0.098	0.7595	
X_3	1.50	1	1.50	1.79	0.2042	
$X_1 X_2$	0.46	1	0.46	0.54	0.4738	
$X_1 X_3$	3.32	1	3.32	3.96	0.0682	
$X_2 X_3$	1.68	1	1.68	2.01	0.1799	
Residual	10.89	13	0.84			
Lack of Fit	3.62	8	0.45	0.31	0.9308	not significant
Pure Error	7.28	5	1.46			
Cor Total	18.98	19				

Appendix 15: ANOVA for Response Surface Quadratic Model of % Salinity Reduction for water treated with *Moringa oleifera* seeds.

Source	*Sum of Squares*	*Df*	*Mean Square*	*F-Value*	*P-Value Prob > F*	*Inference*
Model	10.86	9	1.21	1.49	0.2724	not significant
X_1	1.05	1	1.05	1.29	0.2821	
X_2	0.082	1	0.082	0.10	0.7573	
X_3	1.50	1	1.50	1.84	0.2043	
$X_1 X_2$	0.46	1	0.46	0.56	0.4709	
$X_1 X_3$	3.32	1	3.32	4.08	0.0709	
$X_2 X_3$	1.68	1	1.68	2.07	0.1804	
X_1^2	0.34	1	0.34	0.42	0.5329	
X_2^2	1.19	1	1.19	1.46	0.2546	
X_3^2	1.19	1	1.19	1.46	0.2546	
Residual	8.12	10	0.81			
Lack of Fit	0.84	5	0.17	0.12	0.9832	not significant
Pure Error	7.28	5	1.46			
Cor Total	18.98	19				

Appendix 16: Summary of key statistical parameters obtained from each model for the effects of *Moringa oleifera* seeds on the % Salinity Reduction

	Linear Model	**Two Factor Interaction Model**	**Quadratic Model**	**Cubic Model**
p-value of model	0.4831	0.2221	0.2724	aliased
p-value of X_1	0.3260	0.2834	0.2821	aliased
p-value of X_2	0.7807	0.7595	0.7573	aliased
p-value of X_3	0.2436	0.2042	0.2043	aliased
'lack of fit' p-value	0.7992	0.9308	0.9832	aliased
R^2	0.1385	0.4260	0.5722	aliased
Adjusted R^2	-0.0230	0.1610	0.1872	aliased

From the experimental results, an average of 56.19% salinity reduction was achieved.

Appendix 17: A flocculator