THE OPTIMIZATION OF THE PERFORMANCE OF GRANULATED GROUNDNUT AS A COAGULANT FOR WATER TREATMENT

BY

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PLAGIARISM

This work THE OPTIMIZATION OF GRANULATED GROUNDNUT AS A COAGULANT FOR WATER TREATMENT by OKOH Destiny with Matriculation No ENG2006201 of the Department of Civil Engineering, Faculty of Engineering, University of Benin, Edo State, Nigeria, has PASSSED the PLAGIARISM TEST

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DEDICATION

To my ever concerned mum, for her constant support in words of encouragement and in deeds and to my Family at large.

To the Source and Sustainer of all Potentials, the Keeper of life, and my personal Savior, the Lord Jesus Christ.

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ABSTRACTS

This study investigates the optimization of the performance of granulated groundnuts (Arachis hypogaea) as a natural coagulant for water treatment in comparison with the Conventional chemical coagulant, alum. The increasing need for eco-friendly and sustainable water treatment methods motivated this research, as chemical coagulants such as alum have been associated with high residual ion concentration and potential health concerns. The study aimed to determine the optimum operational conditions—coagulant dosage, stirring speed, and flocculation time—that yield the best water quality in terms of turbidity, pH, conductivity, and total dissolved solids (TDS). Response Surface Methodology (RSM) using Design-Expertsoftware was employed to model and optimize the coagulation process based on experimentaldata obtained from jar tests.

For the granulated groundnut coagulant, the optimal conditions were achieved at a stirringspeed of 400 rpm, stirring time of 2.37 minutes, and dosage of 1.00 mg/L. Under theseconditions, the predicted responses were pH 6.61, conductivity 221.98 µS/cm, TDS 121.30mg/L, and turbidity 7.86 NTU. Conversely, the alum coagulant exhibited its best performance at a stirring speed of 400 rpm, stirring time of 7.06 minutes, and dosage of 2.96 mg/L, yielding a pH of 6.50, conductivity of 1392.24 µS/cm, TDS of 825.65 mg/L, and turbidity of 4.93 NTU.Although alum produced slightly lower turbidity, it significantly increased conductivity and TDS levels, indicating higher residual salt content and poorer overall water quality compared to granulated groundnut.

The findings demonstrate that granulated groundnut is an effective, biodegradable, and low-cost alternative to alum for water treatment. It provides satisfactory turbidity reduction and excellent ionic quality while maintaining near-neutral pH at lower dosages and shorter flocculation times.The study concludes that groundnut-based coagulant can serve as a sustainable option for small-scale and rural water purification systems. It recommends further studies on microbial removal efficiency and large-scale application to enhance its practical adoption in eco-friendly water treatment processes.

TABLE OF CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Water is a fundamental resource essential for human survival, economic development, and ecosystem Sustainability. However increasing urbanization, industrialization, agricultural runoff, and climate change have significantly impacted the availability and quality of freshwater worldwide. Contaminated water is a major contributor to disease outbreaks and environmental degradation, particularly in low, and middle income, countries where access to treated water is limited. Access to clean drinking water is fundamental to human health. Contaminated water can lead to waterborne diseases such as cholera, typhoid fever, and gastrointestinal infections (WHO, 2020). According to the world health organization, approximately two million people die each year due to diseases caused by unsafe water (WHO, 2019). Health risks such as cholera, typhoid, hepatitis, and long-term exposure to toxic elements like arsenic or Lead. To ensure water is safe for consumption and use, water treatment processes have evolved over time. Traditional methods such as boiling, sedimentation, and sand filtration have been used for centuries. Safe drinking water is critical to human health and development. Unfortunately, many surface water sources are contaminated by pathogens, chemicals and sediments (Naylor et al., 2023; World Health Organization [WHO], 2007). In developing regions, contaminated water is a major cause of illness: for example, the Organization for Economic Co-operation and Development (OECD) has estimated that roughly 80% of all diseases in developing countries are related to unsafe water and poor sanitation (OECD, 2006). To address this multi-stage treatment processes are typically employed. Coagulation–flocculation is a key step, it destabilizes fine colloidal particles so they can aggregate into flocs and be removed by sedimentation or filtration (Koul et al., 2022). Conventional treatment plants use coagulation (followed by flocculation, sedimentation, filtration and disinfection) to remove over 99% of bacteria and viruses from water (Abood et al., 2017).Chemical coagulants especially metal salts are the most widely used coagulants. Typical chemical coagulants include aluminum-based salts (e.g., aluminum sulfate, polyaluminum chloride) and iron-based salts (e.g., ferric sulfate, ferrous sulfate) (Koul et al., 2022; Abood et al., 2017). These salts neutralize the negative surface charge of colloids, causing the particles to clump and settle (Koul et al., 2022). However, chemical coagulants have drawbacks. They often require high dosages and careful pH adjustment, and they generate large volumes of metal-rich sludge that can be costly to dispose of (Koul et al., 2022; Bahrodin et al., 2021). Moreover, residual aluminum in treated water has raised health concerns; studies have linked long-term alum use to neurological issues such as dementia and Alzheimer’s (Abood et al., 2017; Koul et al., 2022). In practice, many regions face shortages or high costs of imported coagulant chemicals, motivating the search for cheaper, safer alternatives (Abood et al., 2017). Researchers have therefore investigated natural, plant-based coagulants as eco-friendly substitutes. Natural coagulants (e.g. seed extracts, plant gums, agricultural by-products) are biodegradable and non-toxic, and typically produce less harmful sludge (Koul et al., 2022; Bahrodin et al., 2021). These materials often work by polymeric bridging or charge neutralization of colloids. A large body of work has focused on certain well-known species: for example, Moringa oleifera seed powder, Strychnos potatorum (Nirmali seed), and cactus (Opuntia spp.) have demonstrated strong flocculant properties. In many cases, coagulating agents are proteins (or polysaccharides) extracted from seeds or plant materials, which bind impurities (Koul et al., 2022; Birima et al., 2013). Natural coagulants are generally cost-effective and safe,they are abundant in agricultural communities, work over a range of conditions, and do not significantly alter the treated water's pH. However, most studies have emphasized a few plant sources (Moringa, Jatropha, Opuntia, etc.), and recent reviews call for exploring other local plants (Bahrodin et al., 2021; Koul et al., 2022).One promising alternative is groundnut (peanut) seed extract. Peanuts (Arachis hypogaea) are widely cultivated and contain globulin proteins (arachin, conarachin) that can act as coagulants when extracted (Birima et al., 2013; Ndongo et al., 2023). Several recent studies have demonstrated the effectiveness of peanut based coagulants. For instance, Birima et al. (2013) found that a salt-extracted peanut seed coagulant removed about 92% of turbidity (200 NTU kaolin suspension) using only 20 mg/L dose. Similarly, Abood et al. (2017) reported 88.3% removal of a 340 NTU kaolin suspension at 20 mg/L dosage of peanut extract, outperforming sesame seed under the same conditions. More recently, Kingue et al. (2023) showed that groundnut extract removed 89% of turbidity in 150 NTU synthetic water with a 500 mg/L dose, and that the coagulation/flocculation process was rapid and did not significantly change water pH. Al-Wasify et al. (2023) likewise demonstrated that de-oiled peanut seed material effectively coagulated high-turbidity surface water, suggesting it as a sustainable coagulant alternative. These findings suggest that granulated groundnut could be a low-cost, locally available coagulant suitable for household or small-scale water treatment (Abood et al., 2017; Ndongo et al., 2023). The present study builds on this background by evaluating the performance of groundnut coagulant (in granulated form) under varying jar-test conditions, to quantify its efficiency in reducing turbidity and suspended solids in water. Modern treatment techniques now include coagulation and flocculation, filtration, disinfection (Chlorination, UV, ozonation), and advanced technologies like membrane filtration and activated carbon adsorption, reverse osmosis and as well as higher oxidation processes, are employed to remove dissolved contaminants and emerging pollutants such as pharmaceuticals and endocrine disrupting chemicals (Rexing et al., 2021).The global recognition of water-related health challenges led to the development of guidelines and regulations. The World Health Organization (WHO) has published comprehensive standards for drinking water quality since the 1950s, while the United States Environmental Protection Agency (EPA) established the Safe Drinking Water Act in 1974. These frameworks provide a benchmark for assessing and maintaining water safety. Despite these advancements, many communities still lack access to treated water. The United Nations Sustainable Development Goal 6 (SDG 6), launched in 2015, aims to "ensure availability and sustainable Management of water and sanitation for all" by 2030. Achieving this goal requires innovative, low-cost, and sustainable water treatment methods tailored to local condition.

1.2 Statement of the Problem

Access to clean and safe drinking water remains a significant challenge, particularly in rural and low-income Communities where conventional water treatment methods are often unaffordable or unavailable. Chemical coagulants such as aluminum sulfate, while effective, pose several concerns including high costs, limited availability, and potential health risks due to residual aluminum in treated water (Exley, 2005). These issues highlight the need for sustainable, low-cost, and locally available alternatives. Natural coagulants derived from plants, such as Moringa oleifera and Arachis hypogeal (peanut), have emerged as promising substitutes due to their biodegradability, low toxicity, and ease of use. These materials are biodegradable, renewable, locally accessible and generally non –toxic (Yin, 2010). Moringa oleifera and Arachis hypogeal has been widely studied and recognized for its coagulating properties, offering a good alternative in low income and rural communities.

1.3 Aim and Objectives of the Study

This project is aimed at examining the performance of Arachis hypogea (granulated groundnut) as a natural Coagulants for water treatment, and comparing its coagulation efficiency with alum.

Objective

1. To prepare granulated groundnuts into a coagulant fit for laboratory usage
2. To compare coagulation efficiency of granulated groundnuts and alum in the Removal of turbidity particles from water.
3. To ascertain the optimal dosage levels for both granulated groundnuts and alum in Water treatment.
4. To examine the effects of major parameters such as pH, and initial turbidity, on the Performance of each coagulant in the coagulation process.
5. To analyze and compare the treated water quality in terms of the pH, turbidity, and total dissolved solids (TDS).

1.4 Scope of the Study.

The study on the performance of granulated groundnuts as a coagulant for water treatment involved a systematic approach, beginning with the collection and preparation of the granulated groundnut coagulant. Mature, undamaged groundnuts will be selected, dehulled, washed, dried, and granulated into fine particles suitable for application. This will be followed by a comprehensive analysis of the chemical composition of the prepared groundnut coagulant to determine the active components responsible for coagulating properties. The experimental phase of the study involved the coagulation process itself, where the effects of critical parameters such as coagulant dosage, stirring speed, and stirring time were examined to optimize performance. Standard coagulation-flocculation tests (jar tests) were conducted to evaluate the turbidity removal efficiency and settling characteristics of the granulated groundnut. A comparative analysis will also be carried out using alum, a conventional chemical coagulant, to assess the relative effectiveness and suitability of the groundnut-based alternative. Finally, the study addressed its limitations, including challenges in standardization of the natural coagulant, variability in groundnut composition, and potential constraints in scaling up the application for large-scale water treatment systems.

1.5 Justification of the Study

Access to safe and affordable drinking water remains a critical challenge in rural Nigeria. Many villages lack piped water and rely on untreated surface sources (rivers, ponds, rainwater) that are often contaminated by agricultural runoff and waste. Studies report that reliance on unimproved sources is associated with high rates of diarrheal disease; Nigeria bears one of the world’s highest burdens of waterborne illness, accounting for roughly 88% of the country’s disease burden and over 150,000 under-5 deaths from diarrhea annually. Such data underscore the urgent need for low-cost, locally feasible water treatment methods. Inexpensive, point-of-use treatments could dramatically reduce morbidity and mortality in rural communities where centralized treatment is unavailable (Adamu et al., 2022). Conventional chemical coagulants (e.g. aluminum sulfate, ferric chloride) are widely used in municipal plants but have significant drawbacks. They generate large volumes of chemical sludge and can alter treated water pH. Moreover, the residual aluminum or iron in treated water has raised health concerns (Alzheimer’s disease links and other toxic effects). Chemical coagulants are also expensive and often imported, making them cost-prohibitive for rural systems (Birima et al., 2013; Diver et al., 2023). For example, Birima et al. note that “the cost of any imported chemicals can be a serious problem for developing countries,” and aluminum salts pose potential carcinogenic risks. Finally, synthetic coagulants are not environmentally sustainable: they can leave harmful residues and require extensive sludge management.Natural plant-based coagulants offer an attractive alternative. They are generally biodegradable, non-toxic, and renewable. For example, a recent review concludes that natural coagulants are “economical, easy to use, biodegradable, non-toxic, eco-friendly, [and] effective”. Plant coagulants also produce much less sludge and do not pose the pH-stability issues of alum (Diver et al., 2023). In practical terms, natural coagulants can be prepared from locally available seeds and plant wastes, reducing dependence on imported chemicals. Specifically for Arachis hypogaea (groundnut), the following benefits are noted:

Local abundance: Nigeria is one of the world’s largest peanut (groundnut) producers, ensuring raw material is cheap and locally available.

Biodegradability and safety: Groundnut proteins are biodegradable and pose no known health hazards, unlike synthetic polymers.

Proven efficacy: Research shows peanut extracts can achieve high turbidity removal. Birima et al. (2013) demonstrated that a 20 mg/L dose of peanut-seed extract removed 92% of a 200 NTU turbidity in synthetic water. Likewise, Ilaboya et al. (2025) found that granulated groundnut removed 80–98% of suspended solids under optimized conditions. These results indicate performance comparable to alum but with a natural, low-cost material. Collectively these advantages suggest groundnut is a sustainable and effective coagulant.

Comparison of Coagulant Types: Chemical coagulants (e.g. alum) effective but expensive, toxic, non-biodegradable; Natural coagulants (groundnut, moringa, etc.) are renewable, low-cost, biodegradable, and proven to remove turbidity efficiently. Meanwhile groundnut coagulants aligns with public health and global development goals by potentially providing a low-cost means to purify drinking water. This study supports Sustainable Development Goals (SDG) Clean Water and Sanitation. SDG 6.1 explicitly targets universal access to safe, affordable drinking water by 2030, and SDG 6.3 calls for reducing water pollution and hazardous chemicals. A natural coagulant derived from groundnut would directly contribute to these objectives by reducing reliance on hazardous chemicals and improving water quality in underserved areas. In public health terms, safer water would reduce waterborne diseases (e.g. cholera, typhoid, diarrhea) that currently claim many lives in Nigeria. Thus, the study’s goals resonate with national and international priorities for health and development.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water Treatment

Water treatment is a critical process that ensures the removal of contaminants and makes water safe for human consumption and other purposes such as industrial processes, agriculture, and recreation. As raw water from natural sources contains various pollutants, ranging from suspended solids and pathogens to dissolved organic and inorganic substances, treatment is essential for safeguarding public health and maintaining environmental standards (WHO, 2017).

2.1.1 Water Pollution

Water pollution refers to the contamination of water bodies (lakes, rivers, oceans, aquifers, and groundwater) by harmful substances that degrade water quality and make it unsuitable for use. The major sources of water pollution include: Domestic waste water, sewage and household waste Industrial discharges. Effluents containing chemicals, heavy metals, and oils. Agricultural runoff, fertilizers, pesticides, animal waste Oil spills and gas flaring common in the Niger Delta region. Urban stormwater: runoff from roads and urban surfaces. These pollutants contribute to the degradation of water quality parameters such as: turbidity which is the cloudiness caused by suspended particles like silt and organic matter, Color and odor often resulting from decaying vegetation and industrial waste Pathogens: including bacteria, viruses, and protozoa. Heavy metals: such as lead, arsenic, cadmium, and mercury. Nutrients such as nitrates and phosphates leading to eutrophication. Among these, turbidity is one of the most critical because it directly affects the aesthetic and microbiological quality of water. Suspended particles not only make water appear dirty but also shelter pathogenic microorganisms from disinfection, reducing the effectiveness of chlorination and other treatment steps (EPA, 2019).

2.1.2 Regulatory Standards

To safeguard public health, national and international agencies have established standards for potable water. For example, the WHO (2017) recommends that:

1. Turbidity should be less than 5 NTU (Nephelometric Turbidity Units).
2. pH should be between 6.5 and 8.5.
3. Coliforms and E. coli should be absent in 100 mL samples of treated water. Similarly, the Standards Organisation of Nigeria (SON, 2015) has developed guidelines for drinking water quality that align with WHO benchmarks. These standards serve as a framework for evaluating the performance of water treatment methods and coagulants.

2.1.3 Importance of Water Treatment

The goal of water treatment is to make water safe and suitable for specific uses by removing contaminants and adjusting undesirable properties. In the context of potable water treatment is necessary for removing harmful microorganisms, suspended solids, chemicals, and unpleasant tastes or odors. The need for water treatment becomes even more pressing in areas where source water is significantly polluted due to human and natural activities.

2.1.4 Water Treatment Processes

Water treatment typically involves a series of physical, chemical, and biological processes, each aimed at targeting specific contaminants. The major steps include:

1. Preliminary Treatment: This step removes large objects and debris that may damage equipment. It includes Screening; which is to remove floating materials like sticks and leaves.

2. Coagulation and Flocculation: This is a key chemical process where coagulants (such as alum or natural agents like Moringa oleifera or Arachis hypogaea) are added to destabilize suspended particles. It is followed by flocculation, where slow mixing helps the formation of larger aggregates (flocs) (Ndabigengesere et al., 1995).

3. Sedimentation: The flocs formed during coagulation and flocculation are allowed to settle under gravity in Sedimentation tanks.

4. Filtration: Water is passed through media like sand or activated carbon to remove remaining suspended particles and some pathogens (Montgomery, 1985).

5. Disinfection: Chemical or physical methods such as chlorination, ozonation, or UV radiation are used to kill or inactivate pathogenic microorganisms.
6. Advanced Treatment (Optional) Processes like ion exchange, reverse osmosis (RO), and activated carbon filtration may be added for specific needs like hardness removal or taste and odor control.

2.1.5 Coagulation and Flocculation in Water Treatment

Coagulation involves the addition of substances (coagulants) that destabilize colloidal particles, leading to agglomeration into larger flocs that can be removed through sedimentation or filtration. This process is affected by several factors, including coagulant type, pH, dosage, mixing conditions, and the nature of the impurities present (Ogunlela et al., 2020). Chemical coagulants such as aluminum sulfate (alum), ferric chloride, and polyaluminum chloride have been Chiefly used so far in several industries due to their proven efficacy. However, they are associated with drawbacks such as increased residual metal concentrations, changes in water pH, and the generation of non-biodegradable sludge (Yin, 2010).

Flocculation is a process by which colloidal particles come out of suspension to sediment in the form of floc or flake, either spontaneously or due to the addition of a clarifying agent.The action differs from precipitation in that, prior to flocculation, colloids are merely suspended, under the form of a stable dispersion (where the internal phase (solid) is dispersed throughout the external phase (fluid) through mechanical agitation) and are not truly dissolved in solution.Coagulation and flocculation are important processes in fermentation and water treatment with coagulation aimed to destabilize and aggregate particles through chemical interactions between the coagulant and colloids, and flocculation to sediment the destabilized particles by causing their aggregation into floc.

2.2 Mechanism of Coagulation and Flocculation

2.2.1 Coagulation Mechanism

Coagulation is the process by which colloidal particles (which are typically stable and negatively charged) are destabilized, allowing them to aggregate and form microflocs. This destabilization occurs through several mechanisms:

1. Charge Neutralization: Most colloids in water carry a negative surface charge, creating electrostatic repulsion that prevents aggregation. When a coagulant (e.g., alum, ferric chloride, or a protein-based natural coagulant) is added, it dissociates in water, releasing positively charged ions. These ions neutralize the negative charges on the colloid surfaces, reducing repulsion and allowing particles to come closer together (Gregory, 2006).
2. Sweep Flocculation (Enmeshment):At higher dosages, especially with alum or ferric salts, metal hydroxide precipitates form a "sweep" floc that physically traps or enmeshes fine particles during settling. This mechanism is predominant when coagulation occurs at optimal pH conditions that promote rapid hydrolysis (Letterman et al., 1999).
3. Adsorption and Bridging: This mechanism is more common with polymeric or natural organic coagulants like Moringa oleifera or Arachis hypogaea. The long-chain

molecules of these coagulants adsorb onto the particle surfaces and form bridges between them, creating larger flocs. This process is particularly effective in low turbidity water and is a key mechanism for natural coagulants (Ndabigengesere & Narasiah, 1998).

2.2.2 Flocculation Mechanism

Flocculation follows coagulation and involves the gentle mixing of the water to facilitate collisions between destabilized particles so they can form larger aggregates or flocs. This stage enhances the size and strength of the flocs, making them easier to remove through sedimentation or filtration.

1. Perikinetic and Orthokinetic Flocculation: Perikinetic flocculation involves particle movement caused by Brownian motion, effective for very small Particles. Orthokinetic flocculation results from induced motion through gentle mixing or stirring, enhancing particle collisions and floc growth (O'Melia & Tiller, 1993).
2. Factors Affecting Flocculation: Mixing speed and time; Gentle agitation is needed, when too fast can shear flocs. pH and temperature; These influence the solubility and reaction rates of coagulants. Concentration of particles; Higher concentrations increase collision probability but may require more coagulant.
3. Application to Natural Coagulants: Natural coagulants like groundnut (Arachis hypogaea) and Moringa Oleifera contain proteins with positively charged functional groups. These interact with negatively charged colloids through adsorption and bridging, rather than simple charge neutralization alone (Ghebremichael, 2005). Because of their biodegradable and non-toxic nature, natural coagulants are gaining popularity in sustainable water treatment systems, particularly in developing regions.

2.3. Chemical Coagulants: Alum & Variants

Aluminum Sulphate (Alum)

Alum is widely used due to its low cost and strong turbidity removal, but has downsides: high sludge loads, acidity, and residual aluminum concern. A study on mixed muddy water found an optimal alum dose of 0.25–0.5 g/L achieved ~10 NTU turbidity removal at pH 6–7, with overdosing causing restabilization and flocculation to sediment the destabilized particles by causing their aggregation into floc.

However, alum also significantly lowers pH and increases TDS .Alternatives like PAC (polyaluminum chloride) and ACH (aluminum chlorohydrate) offer similar removal with less sludge and lower alkalinity consumption .Alum is one of the most widely used coagulants in the water treatment industry (Benschoten and Edzwald 1990). For water and wastewater treatment, the coagulants used more frequently are the inorganic salts of aluminum. When added to water, Al ions hydrolyze rapidly and form a range of metal hydrolysis species (Jiang 2015). These cationic species adsorb onto the negatively charged particles and neutralize the charge. In this mechanism, particles get destabilized and aggregation occurs (Yukselen and Gregory 2004).Coagulation depends on coagulant dosage and also the ph. Almost all of the colloids in water are negatively charged and because of electrical repulsion they may remain stable. Destabilization could be made by addition of salts or cations that will interact with negative colloids to neutralize their charge (Duan and Gregory 2003). Upon hydrolysis, aluminum hydroxide precipitate is formed, this precipitate sweeps the colloidal particles from the suspension and is called the sweep-floc coagulation. Since it does not involve any charge reversal this is more popularly used in water treatment (Kim et al. 2001). Alum, or aluminum sulfate plays a crucial role in removing turbidity, color, microorganisms, and some dissolved substances from water through the processes of coagulation and flocculation. Despite the emergence of natural alternatives, alum remains the standard in many conventional treatment facilities due to its effectiveness and availability.

2.3.1 Chemical Properties of Alum

Chemical Formula: $Al_2(SO_4)_3 \cdot 14H_2O$

Molecular Weight: ~594.4 g/mol

Appearance: White crystalline solid

Solubility: Highly soluble in water

pH (1% solution): Acidic (~3.0–4.0)

In aqueous solutions, alum dissociates into aluminum ions (Al^{3+}) and sulfate ions (SO_4^{2-}). The aluminum ions hydrolyze rapidly to form positively charged hydroxide complexes which destabilize negatively charged colloidal particles.

2.3.2. Mode of Action of Alum in Water Treatment

1. Charge Neutralization: The Al^{3+} ions released from alum neutralize the negative surface charges of colloidal particles, reducing electrostatic repulsion and allowing particles to come together.

2. Precipitation and Sweep Flocculation: Alum reacts with water to form aluminum hydroxide precipitate ($Al(OH)_3$), which has a gelatinous texture. This precipitate enmeshes suspended particles in the water a process known as sweep flocculation, which enhances their removal during sedimentation and filtration.

Hydrolysis Reaction:

$Al_2(SO_4)_3 + 6H_2O \rightarrow 2Al(OH)_3 \downarrow + 3H_2SO_4$

3. Reduction in Turbidity and Pathogens: Through coagulation and subsequent processes, alum helps to reduce turbidity, remove natural organic matter (NOM), and decrease pathogen load by entrapping microbes in flocs.

2.3.3 Advantages of Alum

1. High Efficiency: Effective at removing turbidity, color, and microorganisms from water.
2. Economical: Widely available and relatively inexpensive.
3. Well-Studied: Its use is well-documented and predictable under standard conditions.
4. Enhances Filtration: By forming large, settleable flocs, it reduces filter clogging.
5. pH Adjustment Capability: Can reduce high pH levels in water, which may be desirable in some cases.

2.3.4. Limitations of Alum

1. pH Sensitivity: Alum works best within a pH range of 5.5 to 7.5. Outside this range, its effectiveness drops significantly.
2. Residual Aluminum: Improper dosing or inadequate mixing can lead to residual aluminum in treated water, which may be linked to health risks such as neurotoxicity (including associations with Alzheimer’s disease, though this remains under debate).
3. Increased Sludge Volume: Produces a large amount of non-biodegradable sludge that requires proper disposal.
4. Corrosiveness: Acidic nature of alum can increase water corrosivity, leading to pipe degradation if not properly managed.
5. Environmental Concerns: Improper disposal of sludge or residual aluminum can impact aquatic ecosystems. High alum doses may increase residual Al, potentially toxic. Studies show Al >10 mg/L doses cause residual .

2.4 Natural Coagulants: An Emerging Alternative

Natural coagulants, particularly plant-based ones, offer a promising alternative due to their environmental friendliness, biodegradability, local availability, and minimal effect on water pH. Seeds from various plants such as Moringa oleifera, Strychnos potatorum, and

Opuntia ficus-indica have shown effective turbidity removal ranging from 80–99% under optimal conditions (Ndabigengesere & Narasiah, 1998; Ghebremichael, 2005). Natural coagulants are typically biodegradable, locally available, and produce less sludge compared to chemical counterparts (Choy et al., 2014). Moreover, they are considered safe for human consumption and environmentally benign. Research into these coagulants aims to optimize their extraction methods, dosage requirements, and performance under different water qualities. Several studies have demonstrated their efficacy in reducing turbidity, color, and microbial load (Koul et al., 2022).These natural coagulants contain polysaccharides, proteins, and polyphenols that contribute to particle destabilization through charge neutralization and bridging mechanisms (Sanghi et al., 2006).

2.4.1 Moringa oleifera

One of the most extensively researched natural coagulants is Moringa oleifera seed extract. A landmark study by Ndabigengesere, Narasiah & Talbot (1995) showed that Moringa proteins effectively reduce turbidity through charge neutralization and adsorption. The study achieved over 90% turbidity removal in low to moderate turbidity waters.

2.4.2 Arachis hypogaea (Groundnut)

Recent studies such as Adewumi & Adebayo (2020) demonstrated that groundnut seed extracts could remove up to 95% of turbidity under optimized conditions. The proteins in groundnut, particularly globulins, serve as effective bridging agents for colloidal particles. Its availability in tropical regions makes it attractive for rural water treatment.

2.4.3 Other Natural Sources

Other studies have evaluated coagulants from Cactus mucilage (Opuntia ficus-indica); used in arid regions for its flocculating polysaccharides (Miller et al., 2008). Chitosan; derived from crustacean shells effective in both drinking water and wastewater treatment

(Rinaudo, 2006). Plantain peels, okra, and papaya seeds locally available waste materials with coagulant properties (Okoro & Bassey, 2019).

2.5 Groundnut (Arachis hypogaea) as a Coagulant

Groundnut, commonly known as peanut, is a leguminous crop that contains bioactive macromolecules such as storage proteins (globulins and albumins), carbohydrates, and phenolic compounds. These compounds have functional groups capable of interacting with suspended particles in water, leading to floc formation. Although limited in published literature compared to Moringa, preliminary studies suggest that granulated groundnut powder or its extracts can perform effectively as a coagulant, especially in low-turbidity waters (Ogunbiyi et al., 2019). Groundnut flour has also demonstrated efficacy in heavy metal removal due to its protein and amino acid composition, which enables metal chelation and adsorption. Research by Birima et al. (2013) found that groundnut seed extract achieved over 90% turbidity removal in synthetic water samples at optimal dosages. Ilaboya et al. (2025) reported that granulated groundnut coagulant reduced turbidity levels from 160 NTU to below 5 NTU under optimized laboratory conditions. These findings suggest that groundnut possesses coagulating proteins capable of destabilizing suspended particles and forming settleable flocs. Moreover, groundnut-based coagulants produce significantly less sludge and pose no known health hazards.

Processing methods such as granulation and defatting have been shown to improve the shelf-life and performance of groundnut coagulants (Ilaboya et al., 2025).

2.5.1 Composition and Properties of Groundnut Seeds

Groundnut seeds contain significant amounts of proteins, carbohydrates, and oils. The proteins, particularly globulins, carry positively charged functional groups at appropriate pH levels. These proteins are responsible for the coagulation activity, as they interact with negatively charged particles in water (Adewumi & Adebayo, 2020).When groundnut seeds are dried, de-oiled, and granulated, they can be introduced into water as a natural coagulant. Their biodegradable nature makes them environmentally friendly, and their use does not introduce harmful chemical residues like aluminum or chlorination by-products.

2.5.2 Mechanism of Coagulation by Groundnut

1. Charge Neutralization: The positively charged protein molecules from groundnut interact with negatively charged colloidal particles in water, neutralizing their surface charge. This allows the particles to agglomerate and settle under gravity.
2. Adsorption and Bridgin: The proteins in groundnut act as bridging agents, linking several colloidal particles together to form larger flocs that can be removed by sedimentation and filtration. This mechanism is similar to that observed in Moringa oleifera seed extracts (Ndabigengesere et al., 1995).

2.5.3. Advantages of Using Granulated Groundnut

The use of granulated groundnut as a natural coagulant offers a sustainable and low-cost approach to water treatment. Unlike chemical coagulants that are synthetically produced and may cause adverse effects, groundnut-based coagulants are derived from plant proteins and bioactive compounds that are non-toxic, biodegradable, and locally sourced. Its advantages include:

1. Readily Available and Inexpensive: Groundnuts are cultivated extensively in Nigeria and West Africa. Using granulated groundnuts for water treatment can reduce reliance on imported chemicals and promote local agricultural economies.
2. Biodegradable and Environmentally Friendly: Groundnut-based coagulants do not produce harmful by-products.The sludge generated is biodegradable, posing less environmental risk than chemical sludges. Leaves no harmful residue in treated water.

3. Non-toxic and Safe for Human Health: Groundnut proteins are food-grade and contain no harmful residues, making them safe for human consumption in treated water (Ali et al., 2020). Suitable for small-scale and domestic use.

4. Effective Turbidity and Color Removal: Multiple studies have shown that groundnut can remove up to 92% of turbidity, especially in surface and rainwater under optimized conditions (Osuya, 2006; Adedeji et al., 2019).

5. Applicable in Low-resource Settings: The simplicity of preparing granulated groundnut powder and the lack of need for sophisticated equipment makes this technique ideal for rural communities.6. Reduced pH Fluctuation: Unlike alum, groundnut coagulants do not significantly alter water pH, thus eliminating the need for pH correction chemicals.

6. Local resource utilization: Reduces dependence on imported chemicals like alum

2.5.4 Limitations of Groundnut as a Coagulant

1. Short Shelf-life and Microbial Growth: If not properly dried and stored, groundnut-based coagulants can be susceptible to microbial contamination, leading to deterioration and foul odor in treated water.

2. Variation in Performance: Coagulation efficiency depends on factors such as water source, particle size, pre-treatment (defatting or roasting), and coagulant concentration. This variation can lead to inconsistent results.

3. Residual Organic Matter: Some groundnut preparations may leave residual organic nutrients in water, which could promote bacterial regrowth if not followed by disinfection. This can occur if not filtered well, and as well contribute to secondary contamination.

4. Lack of Standardization: There is no universal dosage or preparation protocol, which can hinder large-scale adoption. Dosage requirements vary across water types and qualities.

5. Lower Efficiency than Alum in Extreme Conditions: In very turbid or highly polluted water, alum often outperforms natural coagulants, especially at lower doses.
6. Potential Allergen Risk: Although rare, there is a possibility of allergic reactions in individuals sensitive to peanuts, especially at lower doses.
7. Possible residual organic matter: If not filtered well, can contribute to secondary contamination, Lowers efficiency at very high turbidity compared to alum and synthetic polymers.

2.5.5 Comparison between Groundnut and Other Coagulants

Several comparative studies have evaluated the performance of groundnut against chemical and other natural coagulants. For example, Koul et al. (2022) demonstrated that while alum removed turbidity at a higher rate (up to 98%), it generated more sludge and required pH adjustment. In contrast, groundnut and Moringa oleifera seed extracts performed comparably in removing turbidity (85–95%) but offered advantages in terms of cost, safety, and environmental impact. A study by Adinata et al. (2021) confirmed that natural coagulants ike groundnut and moringa are effective within a pH range of 6 to 8 and do not require extensive chemical conditioning. Furthermore, groundnut was found to be more readily available and culturally acceptable in West Africa compared to Moringa in certain regions. Compared to alum, groundnut-based coagulants produce less sludge, it is biodegradable and locally available and do not significantly alter the pH of treated water. However, they may have lower turbidity removal in highly turbid waters unless supplemented with another agent or pre-treatment method (Ghebremichael, 2005). Further, natural coagulants can increase organic matter content, potentially raising BOD and COD levels quantitatively. Ilaboya et al. (2025) observed that 25 mg/L of granulated groundnut removed 92% of turbidity from a 150 NTU water sample, whereas the same dose of alum removed 98% but increased residual aluminum content. In terms of sludge volume, groundnut generated 30% to 40% less sludge than alum-treated samples. These metrics underscore groundnut’s competitive performance and highlight its potential for decentralized applications in Nigeria.

2.6 OptimizationParameters for Coagulation Efficiency

The performance of any coagulant natural or synthetic depends on several variables. The optimization of these parameters is crucial for maximizing removal efficiency while minimizing cost and environmental impact.

2.6.1 Dosage of a Coagulant

Effective dosage determines the threshold at which sufficient active coagulant molecules are present to destabilize particles without causing overdosing, which may lead to restabilization. The efficiency of coagulation is highly dependent on the correct coagulant dosage. Underdosing leads to incomplete charge neutralization, while overdosing may restabilize particles or increase residual metal concentrations (Letterman et al., 1999). Dosage optimization is often determined by jar tests, a laboratory-scale procedure that simulates the coagulation process. For groundnut-based coagulants, optimal dosages typically range between 30–80 mg/L (Afolabi et al., 2020).

2.6.2 pH of the Water

The pH of water influences the solubility of organic coagulant molecules and the charge density of suspended particles. pH is one of the most crucial parameters influencing the solubility and hydrolysis behavior of coagulants. For example, aluminum sulfate (alum) performs optimally within a pH range of 5.5 to 7.5, while ferric chloride can operate effectively in a slightly broader range (Gregory, 2006). Outside optimal pH, metal ions do not hydrolyze properly, reducing floc formation and leaving residual metal ions in water

(Spellman, 2013).Natural coagulants like groundnut generally perform better in near-neutral to slightly acidic pH (5.5–7.5) (Adejumo & Alabi, 2021).

2.6.3 Turbidity and Initial Particle Concentration

Turbidity, a measure of water clarity directly affects coagulation. High turbidity water contains more particles, which may require more coagulant. However, excessive particle concentrations can hinder floc formation due to over-crowding (Ghebremichael, 2005). In contrast, water with very low turbidity may not provide enough collision sites for floc formation, reducing efficiency.

2.6.4 Settling Time

Sufficient settling time (30–60 minutes) ensures complete floc formation and sedimentation. Shorter times may yield incomplete clarification, while overly long times are inefficient in practical applications.

2.6.5 Mixing Conditions

Jar test simulations involving rapid mixing (for dispersion) and slow mixing (for floc formation) are essential to replicate large-scale conditions. These parameters affect the distribution and interaction of coagulant molecules with contaminants.

Mixing Intensity and Time: Effective coagulation involves two distinct mixing phases; Rapid mixing immediately after coagulant addition promotes even distribution and collision between particles and coagulant. Slow mixing (flocculation) facilitates gentle aggregation into larger flocs (O’Melia & Tiller, 1993).Too much vigorous mixing can shear flocs, while inadequate mixing limits particle interaction.

2.6.6 Temperature

Temperature affects the reaction kinetics and viscosity of water. At lower temperatures, coagulant hydrolysis is slower, and flocs are smaller and settle more slowly

(Ndabigengesere et al., 1995). This reduction in efficiency is especially noticeable in colder climates or during winter operations.

2.6.7 Nature of Coagulant

The type of coagulant whether chemical (e.g., alum, ferric chloride) or natural (e.g., Moringa oleifera, Arachis hypogaea) determines the mechanism of coagulation. Natural coagulants tend to operate via adsorption and bridging, while chemical coagulants function primarily through charge neutralization andsweep flocculation (Adewumi & Adebayo, 2020).

2.6.8 Optimization Techniques

Recent studies have employed Response Surface Methodology (RSM) and Design of Experiments (DoE) to statistically determine the ideal combination of operational factors for maximum efficiency (Okoro et al., 2021). These techniques reduce experimental workload and improve reliability by analyzing interaction effects between variables. A typical RSM analysis explores the combined effect of coagulant dose, pH, and settling time on turbidity removal. Such optimization has been successfully used in the treatment of surface water using groundnut and other natural coagulants.

2.7 Environmental Impacts of Using Granulated Groundnuts as a Coagulant

The environmental implications of any water treatment approach are crucial in evaluating its sustainability. Compared to synthetic chemical coagulants, granulated groundnuts (Arachis hypogaea) have been shown to be environmentally benign. Below is an in-depth examination of the positive and negative environmental impacts associated with their use.

2.7.1 Positive Environmental Impacts

1. Biodegradable Sludge Production: Unlike chemical coagulants such as alum and ferric chloride, which produce large volumes of inert or hazardous sludge, groundnut-based coagulants generate organic and biodegradable sludge. This sludge can be safely disposed into the soil without risk of contamination, Potentially serve as a soil conditioner or compost material. Rahman et al. (2021) noted that sludge from peanut based coagulants decomposed faster and had minimal heavy metal content, unlike that from alum.

2. Reduced Chemical Residues: Granulated groundnuts are plant-based and do not leave residual aluminum or synthetic chemicals in the treated water. In contrast, long-term exposure to aluminum residues from alum has been associated with neurological and bone diseases such as Alzheimer’s (Exley, 2014). The use of natural coagulants therefore reduces chemical toxicity in treated water.

3. Waste Utilization and Circular Economy: Using groundnut waste (e.g., shells or oil cake residue) for water treatment contributes to waste valorization and promotes the principles of a circular economy. Agricultural by-products are reused instead of being discarded, thereby Reduces environmental pollution caused by decomposing groundnut waste. Singh et al. (2020) demonstrated that defatted groundnut cake residue could be an effective coagulant with 80–85% turbidity removal, turning an agro-waste into a value-added product.

4. Lower Carbon Footprint: Chemical coagulants require energy-intensive manufacturing and transportation, contributing to greenhouse gas emissions. In contrast, groundnuts can be locally sourced and processed using low-energy methods, significantly reducing the carbon footprint of the treatment process.

5. Protection of Surface Water Ecosystems:Efficient removal of turbidity and suspended solids using a biodegradable agent like groundnut minimizes the release of chemical-laden effluents into water bodies, thereby protecting aquatic life and preventing bioaccumulation in ecosystems.

2.7.2 Potential Negative Environmental Impacts

1. Organic Pollution from Improper Sludge Disposal if not properly managed, organic sludge from groundnut-based treatment can attract pathogens or vectors such as flies or mosquitoes. Release nutrients into nearby water bodies, causing eutrophication.This risk can be mitigated by composting or using the sludge as fertilizer.
2. Microbial Growth in Stored Coagulant: Improperly dried or stored groundnut powder may support microbial growth (e.g., molds, bacteria), leading to Foul odors in treated water. Hence, adequate drying and storage under low-humidity conditions is necessary.

2.8. Economic Aspects of Using Granulated Groundnuts for Water Treatment

Economic viability is a central consideration in selecting a water treatment method, especially in resource-constrained settings like rural Nigeria. Granulated groundnuts offer several economic advantages compared to chemical coagulants, though some cost-related limitations also exist.

2.8.1 Economic Advantages

1. Local Availability and Cost-effectiveness: Groundnuts are widely grown in Nigeria, especially in states like Kaduna, Kano, and Benue, making them readily available and accessible, cheaper than imported alum. According to Akinbile & Yusuff (2020), groundnut-based coagulants cost 60–75% less than commercial alum when sourced locally.
2. Low Processing Costs: Producing granulated groundnut coagulant involves simple processes which include Shelling, roasting (optional), grinding into powder, Sieving.These steps require minimal equipment, making it suitable for cottage-level enterprises and community-based water treatment projects.
3. Employment and Income Generation: Adoption of groundnut coagulants can stimulate local agri business through Small-scale coagulant production,employment of youth and

women in processing and distribution thereby Enhancing the value chain for groundnut farmers.This contributes to rural development and economic empowerment.

4. Reduced Operational and Maintenance Costs: Because natural coagulants do not significantly alter water pH, there is no need for pH adjustment chemicals, Lowering chemical handling and monitoring cost.

2.9 Challenges in Large-Scale Applications of Granulated Groundnuts as a Coagulant

While granulated groundnuts (Arachis hypogaea) have demonstrated significant coagulation potential in laboratory experiments and small-scale water purification trials, scaling their application to serve communities, towns, and municipalities presents a unique set of technical, operational, and institutional challenges. These challenges can hinder the widespread adoption of groundnut-based coagulants in conventional water treatment plants.

1. Dosage and Coagulant Demand at Scale: One of the key limitations in scaling up is the higher dosage requirement of granulated groundnut compared to chemical coagulants like alum. While alum may be effective at doses of 20 to 50 mg/L, granulated groundnut may require 150 to 300 mg/L or more to achieve similar turbidity reductions. Therefore for a treatment plant processing 1,000,000 liters/day, this means requiring 150 to 300 kg of groundnut powder daily, which can be logistically demanding. Continuous sourcing, processing, and transportation of such large quantities is not only costly but also difficult to sustain without industrial-level supply chains.

2. Storage and Shelf-Life Constraints: Groundnut-based coagulants are organic and hygroscopic, making them highly susceptible to microbial degradation and aflatoxin contamination if not stored in dry, cool conditions. Short shelf-life (1–3 months under tropical conditions) limits stockpiling, risk of mold growth and spoilage which can lead to quality loss and potential health risks. In large-scale applications, where bulk storage is necessary for uninterrupted operation, maintaining the quality of the groundnut powder poses a serious challenge.

3. Sludge Management: Though groundnut produces biodegradable sludge, the volume of sludge produced tends to be higher than that from alum due to the high organic content and larger floc size. Disposal and dewatering of large volumes of sludge becomes more labor-intensive and costly in large-scale setups. If not managed properly, organic sludge can decompose anaerobically, producing odors and methane.

4. Lack of Process Automation Compatibility: Most municipal and industrial water treatment plants are designed for automated chemical dosing systems, often using liquids or finely powdered coagulants. Groundnut powder is coarse and fibrous, which may clog mechanical feeders or settle unevenly.It is not water-soluble, making it harder to integrate into inline dosing systems.Therefore, applying groundnut powder requires manual dosing or redesigning of existing coagulant feed systems, which increases capital and labor costs.

5. Inconsistency in Raw Material Quality: Large-scale treatment plants demand uniform coagulant performance. However, natural materials like groundnut vary in Protein content, Oil content ,moisture level particle size.These inconsistencies arise from differences in harvest time, variety, storage method, and processing technique. Without industrial processing

and quality control, large-scale applications face performance unpredictability. Adedeji et al. (2019) noted that dosage and performance of groundnut coagulants can vary by more than 15% depending on source and preparation.

6. Operational Staff Training and Acceptance: Water treatment personnel are usually trained in the use of chemical coagulants like alum or PAC. Switching to natural coagulants introduces:New dosing methods Different mixing and sedimentation rates

Modified testing procedures. Large-scale adoption requires capacity-building, awareness training, and technical documentation, which are not yet readily available.

7. Regulatory and Quality Certification Gaps: In most countries, including Nigeria, water treatment regulations do not yet recognize natural coagulants like granulated groundnuts in formal standards.There are no National Agency for Food and Drug Administration and Control (NAFDAC) or SON-approved formulations for groundnut coagulants. Without regulatory certification, public utilities are legally restricted from using them in official treatment processes.This lack of legal backing makes it difficult for governments or NGOs to adopt and promote large scale use.

8. Potential Allergen Concerns: Peanut (groundnut) is a well-known allergen. Even though the coagulant is not consumed directly, residual proteins in treated water may pose a health risk for sensitive individuals.While the risk is low, large-scale application must account for potential liability and conduct residue analysis. Regulatory approval bodies may require thorough toxicological testing before allowing deployment in public water systems.

9. Competition with Other Uses of Groundnut: Groundnuts are primarily cultivated for Oil extraction, Food products (snacks, butter, flour), animal feedLarge-scale use in water treatment may create economic pressure on availability and pricing, especially during periods of poor harvest. Without using by-products (like defatted cake or shells), there is a risk of diverting food resources, creating ethical and economic challenges.

10. Lack of Commercial-Scale Processing Enterprises: Currently, there is no established commercial producer of standardized groundnut-based coagulants in Nigeria or most of sub-Saharan Africa. No industrial drying, milling, packaging, or certification pipeline exists. Scaling production would require investment in agro-processing infrastructure, business incubation market demand stimulation, until such enterprises are developed, large-scale application remains restricted to pilot projects or NGOs with specialized setups.

2.10. Review of Previous Related Literatures

Groundnut husk ash has shown considerable promise as a natural coagulant in rural water treatment applications. In a study conducted on turbid groundwater supplies, researchers found that a dosage of 600 mg/L of the ash achieved up to 83% turbidity removal while preserving near-neutral pH conditions. Compared to alum, which removed 91% turbidity under similar conditions, the groundnut-based material generated less sludge and required no pH correction. According to Ezeani and Okoro (2021), the environmental risk of residual ash components was not assessed, leaving questions around long-term safety and reuse potential.

A comparative evaluation of natural coagulants for urban wastewater treatment revealed that groundnut flour performed favorably in low-turbidity environments. When tested alongside other plant-based materials and alum, groundnut achieved 84% turbidity reduction at an optimum dosage, slightly below the 89% achieved with alum. Ibrahim and Adekunle (2022) reported that groundnut maintained more stable water chemistry and produced less sludge. However, the study did not analyze the microbial integrity of treated water or consider storage longevity of the coagulant product.

In an optimization study involving response surface methodology, groundnut-based coagulants demonstrated high performance in synthetic wastewater treatment. Researchers identified 650 mg/L as the optimum dosage, resulting in 88% turbidity reduction, while alum achieved 94% under the same experimental setup. According to Ogundele and Akinyemi (2023), groundnut required no additional pH correction and offered better operational safety. Nonetheless, allergenic risks and post-treatment sludge disposal were not covered in the scope of their research.

According to Okonkwo and Okoh (2020), groundnut extract was evaluated for the treatment of grey water sourced from household discharge. Using a dosage of 700 mg/L, the extract achieved up to 84% turbidity and 76% color removal within 30 minutes of sedimentation. Alum, under similar conditions, performed slightly better in turbidity removal (91%) but altered the pH more significantly. The study recognized groundnut’s potential in decentralized systems but did not assess pathogen removal or organic residue leaching.

Lawal and Abdulrazak (2021) conducted a comparative study involving groundnut seed flour, alum, and ferric chloride in the clarification of raw surface water. While alum achieved 92% turbidity reduction, groundnut extract followed closely with 87% removal at higher dosage levels (800 mg/L). The groundnut coagulant also maintained water pH near neutrality and yielded lower sludge volume. Despite these advantages, the study did not examine the seasonal variability of groundnut composition or the effects of long-term storage.

Adeniran et al. (2023) tested the synergistic use of groundnut seed extract with alum in wastewater treatment from a food processing facility. Individually, groundnut removed 85% turbidity, while alum achieved 93%, but their combination resulted in 96% removal along with improved floc strength and faster settling. The hybrid approach reduced the alum dose by 30%, enhancing economic and environmental sustainability. However, the study did not explore the behavior of residual organics or sludge digestibility.

Egbebi and Adewale (2020) focused on the phytochemical properties of groundnut skin extract and its role in coagulation. Using a 500 mg/L dose, the extract demonstrated 80% turbidity and 72% color reduction in synthetic wastewater. Alum was more efficient in absolute terms, but groundnut showed less corrosivity and no significant change in water pH. The research highlighted the viability of agro-waste-based coagulants, though long-term stability and microbial contamination potential were not evaluated.

Salami and Adeyemi (2024) compared the coagulation performance of groundnut seed extract with cassava peel and banana stem in treating turbid domestic water. Groundnut outperformed both plant-based counterparts with 86% turbidity removal, while alum achieved 94% in the control test. The authors noted groundnut's ease of preparation and rapid floc formation as key advantages. However, cost-benefit analysis and user acceptability in rural communities were not included in the assessmentThe use of de-oiled peanut seed in water treatment presents a cost-effective and environmentally benign alternative to conventional coagulants.

Obiora and Udeh (2024) examined the coagulative properties of defatted groundnut seed meal in clarifying turbid river water. Results revealed that a 600 mg/L dosage removed up to 86% turbidity within 25 minutes of settling time. Although alum achieved a slightly higher removal rate under similar conditions, groundnut extract caused negligible pH shifts and required minimal post-treatment adjustments. The study underscored the economic and sustainability benefits of repurposing agricultural by-products, but it stopped short of evaluating shelf life, microbial implications, or protein leaching in treated water.

Groundnut extract has also shown potential in multi-coagulant systems where it functions as a complementary agent to enhance overall treatment efficiency. Umar et al. (2022) applied groundnut extract alongside alum in groundwater purification trials across several rural sites. Alone, groundnut extract recorded 82% turbidity reduction, but when paired with alum, removal rose to 95%, indicating synergistic interaction. Additionally, the hybrid system demonstrated improved floc density and faster sedimentation compared to either coagulant used independently. While the environmental and cost advantages were highlighted, the researchers did not address the long-term stability of stored water or investigate floc sludge compositiLaboratory comparisons of alum and groundnut-based coagulants have validated the technical feasibility of using groundnut in rural water purification systems.

Aliyu and Yusuf (2020) performed a comparative jar test study using Arachis hypogaea seed extract and alum on turbid river water with an initial turbidity of 250 NTU. Groundnut achieved 85% turbidity removal at 700 mg/L, while alum reached 93% at 300 mg/L. Although alum was more effective at lower dosages, groundnut exhibited less pH depression and required no post-treatment neutralization. The study concluded that groundnut offers an environmentally safer alternative for non-potable water treatment. However, it did not address the biological stability of treated water or potential allergen concerns from groundnut residues.

The floc formation and settling behavior of natural coagulants are critical in determining their operational performance. Onyeka and Eze (2021) assessed granulated groundnut powder's coagulation efficiency on stormwater runoff characterized by high levels of turbidity and suspended solids. Their study found that at 800 mg/L dosage, groundnut removed approximately 82% turbidity, forming dense flocs that settled within 20 minutes. When compared with commercial alum under the same conditions, the difference in removal efficiency was about 10%, but groundnut-treated water maintained more neutral pH and produced lighter sludge. The study highlighted the potential for decentralized treatment applications but did not include microbiological or storage-related parameters.

The combination of natural and chemical coagulants can significantly improve water purification performance, especially in removing complex contaminants like heavy metals and metalloids. Rawlings and Seghosime (2022) investigated the effectiveness of groundnut (Arachis hypogaea) seed extract for the removal of arsenic from contaminated groundwater. The study found that groundnut extract alone removed over 90% of arsenite (As^{3+}) at a pH of 7.2 and 45 minutes of contact time. When combined with alum as a coagulant aid, removal efficiency increased to 99.97%, indicating a strong synergistic effect. The groundnut-alum blend not only enhanced metal removal but also maintained a near-neutral pH, avoiding the typical acidity issues associated with alum. However, the study did not evaluate sludge characteristics or the cost implications of dual-coagulant systems.

Groundnut shell extract has also demonstrated high coagulation potential in treating industrial effluents such as abattoir wastewater. Nweke et al. (2021) conducted a kinetic study using 4 g/L of groundnut shell extract to treat heavily polluted wastewater. Under optimal conditions (pH 8 and 318 K), the extract achieved a 94.3% turbidity reduction and followed second-order coagulation kinetics based on the Von Smoluchowski model. The performance was comparable to that of conventional coagulants, suggesting that agricultural residues like groundnut shells can serve as effective alternatives in wastewater treatment. However, the research did not include a direct comparison with alum or analyze the microbial quality of the treated water.

Groundnut-based natural coagulants have shown significant promise in the removal of turbidity and suspended particles from raw water. For instance, Ilaboya et al. (2025) conducted jar tests using granulated groundnut powder on turbid water samples and achieved up to 80% total suspended solids (TSS) removal at an optimal dosage of 0.9 g/L and contact time of 30 minutes. The study reported a strong correlation ($R^2 = 0.9839$) between coagulant dosage and removal efficiency, validating the efficacy of granulated groundnut as a natural coagulant. Although the performance approached that of alum, the authors noted groundnut’s biodegradability and local availability as major advantages.

However, the study did not explore storage stability or microbial safety of the treated water.

Comparative studies between groundnut and alum have also reinforced the viability of groundnut as an eco-friendly alternative. According to Kingue et al. (2023), a jar test study involving kaolin-induced turbidity revealed that groundnut extract achieved up to 89% turbidity removal at 500 mg/L dosage, while alum achieved 95% under similar conditions. Notably, groundnut formed larger and faster-settling flocs and did not significantly alter water pH. These properties suggest that groundnut could reduce chemical consumption and sludge production in rural water treatment systems. Nevertheless, the long-term performance and microbial risk of groundnut-treated water were not assessed.

After critically reviewing the related literatures, previous studies have investigated the potential of groundnut-derived materials for water treatment, often using protein extracts, chemically modified shells, or biochar, few have explored the use of granulated groundnut in its unextracted, mechanically processed form. This study is novel in its direct focus on evaluating the coagulation performance of granulated groundnuts without any chemical or enzymatic enhancement, making it more accessible and cost-effective for rural water treatment applications. By conducting a comparative assessment with conventional alum, and optimizing dosage, pH, and settling conditions, the study offers a unique, practical contribution to the development of natural, affordable, and scalable coagulants suitable for low-resource settings.

CHAPTER THREE

REASEARCH METHODOLOGY

3. Research Design

This study adopts an experimental research design involving laboratory-scale water treatment tests using granulated groundnuts and alum as coagulants. The design enables a comparative assessment of the coagulation performance of both materials under varying operational conditions, while also identifying optimal treatment parameters.

3.1 Equipment and Apparatus

Digital pH meter,Turbidimeter,Conductivity meter (for TDS), Jar test apparatus (or magnetic stirrer with paddles), Stopwatch, digital Weighing balance, Beakers (250 mL), Filter paper and funnels and 0.02mm sieve,

Fig 3.1.A Digital Turbid meter

Fig 3.2. A flocculator

The JJ-4 (four-in-one) synchronous electric stirrer version: power supply AC 220/110 V 50/60 Hz; motor power ~200 W; speed range 0-3000 rpm; timer 0-120 min. The flocculator (jar-tester) simulates the coagulation and flocculation steps by mixing water samples with coagulant/flocculant under controlled agitation conditions, then allowing settling to assess floc formation and water clarity. It can run parallel jars, vary dosage, stirring speed/time, compare floc sizes and settling behaviour.

3.1.2 Materials

Chemicals and Reagent: Dried groundnut seeds, kaolin clay (to simulate turbidity), distilled water, Commercial alum (Aluminium sulphate

3.2 Sample Collection and preparation

3.2.1 Preparation of the Granulated groundnuts (Coagulant)

Material Used : Raw groundut seeds (certified, mature, free of mold),

F**igure 3.3: Arachis hypogeal seeds**

The primary material used in this study was the groundnut (Arachis hypogaea), commonly referred to as the peanut. It belongs to the Kingdom Plantae, under the unranked divisions Angiosperms, Eudicots, and Rosids. The plant is classified in the Order Fabales, Family Fabaceae, and Subfamily Faboideae, with the Genus Arachis and Species A. hypogaea. Groundnut is an important leguminous crop cultivated extensively in tropical and subtropical regions of the world. It is grown primarily for its edible seeds, which are consumed in various forms and are also used industrially in the production of oil, animal feed, and confectionery products. The crop serves a dual purpose firstly as a grain legume and an oilseed crop due to its high protein and oil content, making it valuable in both nutritional and economic contexts.

In addition to its dietary and commercial importance, the groundnut plant also plays a vital agronomic role in improving soil fertility through nitrogen fixation, thereby enhancing soil productivity and sustainability. According to global agricultural statistics, the total world production of shelled groundnuts was approximately 44 million tonnes in 2016, with China being the leading producer, contributing about 36% of the global output.

The groundnut used for this experiment was gotten from a public market in Oredo Local Government Area of Edo State, Nigeria.

Procedure

1. Sourcing and Selection: Mature, unroasted, and dry groundnut seeds were acquired from a reliable agricultural source, and they were inspected visually to ensure the seeds were free from mold, insect damage, and rot.

2. Cleaning and Sorting: The seeds were manually sorted to remove debris, stones, and broken or discolored seeds. Afterwards, the seeds were thoroughly rinsed with clean water to eliminate dust and surface impurities, drained, and air-dried for 15–30 minutes to remove residual surface moisture.

3. Dehulling: After the groundnut seeds had been carefully sorted, their outer shells (pericarp) were removed either manually or mechanically. Only the inner kernels (cotyledons) were retained, which contained the protein-rich compounds responsible for coagulation.

4. Drying of the kernels (seeds): The kernels were then spread in a single layer on clean trays and dried using sunlight for 1 to 2 days (weather-permitting), or hot air oven at 50–60 °C for 6 to 8 hours. Drying reduced moisture content below 10%, preserving the coagulant and aiding fine grinding.

5. oven- Drying: Afterwards, the seeds were transferred to a hot-air oven at 60 °C for 6 hours or until constant weight was achieved (moisture < 5%). Then the seeds were removed and cooled in a desiccator for 30 minutes before milling.

6. Milling: The seeds were crushed into coarse powder using a mechanical grinder. Then, the powder was sieved thereafter, the fine fraction was collected. Coarse particles were retained for re-milling.

3.3. Design of Experiment

The experiment aimed to investigate the effects of three critical variables in the water treatment process : stirring speed, coagulant dose, and stirring time. The design response focused on evaluating how these variables impact the level of total dissolved solids, pH, Conductivity and turbidity. Selectivity for these process variables was based on the importance of these water quality parameters as key indicators to justify the adequacy of coagulation in water treatment. An optimization objective was set to minimize total dissolved solids, pH, Conductivity, and turbidity. The process involved determining the optimum values for each input variable; coagulant dose (ml), stirring time (min), and stirring speed (rpm) that would produce water with the lowest possible total suspended solids.

3.3.1. Preparation of Turbid Water

A 10% concentrated solution of natural clay (turbid water) was prepared by dissolving 5g of natural clay in 100ml of distilled water. This solution was then diluted further to 10000ml using distilled water. The mixture was thoroughly agitated, and the initial levels of pH, conductivity, turbidity and total dissolved solids (TDS) in the turbid water were measured and recorded. The solution was kept in a cleaned, dried plastic container for use throughout the experimentation period.

3.3.2. Coagulant Performance Evaluation

A simple factorial design was used to study the effects of the selected variables on coagulant performance. The investigation covered the overall effectiveness of the coagulant by varying:

i. Dose of coagulant

ii. Stirring time

iii. Stirring speed

The ranges and level of the selected variables is presented in Table 3.1, while the final design of experiment is presented in Table 3.2

Factors in Range

Name (Factors)	Units	Minimum Value	Maximum Value
Stirring Speed	Rpm	200.00	400.00
Stirring Time	Minutes	2.00	10.00
Coagulant Dosage	gram	1.00	5.00

Table 3.1

Table 3.2 Final design of Experiment

	Factor 1	**Factor 2**	**Factor 3**
Run	**A: Speed Rpm**	**B: Stirring time Minutes**	**C: Coagulant dosage gram**
1	400	10	5
2	400	10	1
3	300	6	3
4	300	6	1
5	200	2	1
6	300	6	3
7	300	10	3
8	400	6	3
9	400	2	1
10	400	2	5
11	300	6	3
12	200	6	3
13	200	2	5
14	300	6	5
15	300	6	3
16	300	2	3
17	200	10	1
18	200	10	5

3.4. Experimental Procedures

The procedure employed in carrying out the experiments is discussed as follows

3.4.1. Effects of Coagulant Dosage

The effect of coagulant dosage on the performance of granulated groundnut and alum in water treatment was examined using the JJ-4 flocculator. A measured volume of 2500 ml of the turbid water was poured into a beaker and placed on the JJ-4 flocculator for each experimental run. The initial water sample parameters, including pH, total dissolved solids (TDS), conductivity, and turbidity, were determined prior to treatment. The coagulant dosage was varied according to the experimental design, while the corresponding stirring time and speed were adjusted as specified in the design matrix. Each experimental run represented a unique combination of dosage, time, and speed as defined by the design mix. The same parameter values were applied for both coagulants (granulated groundnut and alum) to ensure a fair comparison of their performance. After thorough mixing, the samples were allowed to settle for 30 minutes, and the resulting clear supernatant was separated by filtration. The pH, total dissolved solids, conductivity, and turbidity of the treated water were then measured and recorded.

3.4.2 Effects of Stirring Time

The effect of stirring time on the coagulation efficiency of granulated groundnut and alum was investigated using the JJ-4 flocculator. A measured volume of 2500 ml of the turbid water was poured into a beaker and placed on the JJ-4 flocculator for each experimental run. The initial water quality parameters, namely pH, total dissolved solids (TDS), conductivity, and turbidity, were determined before treatment. The stirring time was varied according to the experimental design, with corresponding dosage and stirring speed values adjusted as defined by the same design matrix. Each experimental run consisted of a distinct combination of these parameters. The same sets of values were applied for both granulated groundnut and alum, ensuring uniform experimental conditions and reliable comparison. During each test, the coagulant was thoroughly mixed with the water sample to achieve effective dispersion and promote floc formation. After mixing, the samples were allowed to settle for 30 minutes, and the resulting clear supernatant was separated by filtration. The pH, total dissolved solids, conductivity, and turbidity of the treated water were subsequently measured and recorded.

3.4.3 Effects of Stirring Speed

The effect of stirring speed on the treatment efficiency of granulated groundnut and alum was analyzed using the JJ-4 flocculator. A measured volume of 2500 ml of the turbid water was poured into a beaker and placed on the JJ-4 flocculator for each experimental run. The initial parameters of the water, including pH, total dissolved solids (TDS), conductivity, and turbidity, were determined before treatment. The stirring speed was varied according to the experimental design, while the corresponding stirring time and coagulant dosage were also adjusted as specified by the design matrix. Each experimental run featured a distinct combination of these parameters, and the same values were used for both granulated groundnut and alum to ensure consistent comparative evaluation. The samples were mixed thoroughly to achieve uniform dispersion and effective floc formation. After the mixing phase, the samples were allowed to settle for 30 minutes, and the resulting clear supernatant was separated by filtration. The pH, total dissolved solids, conductivity, and turbidity of the treated water were measured and recorded.

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the data analysis, and comparative results of granulated groundnut (Arachis hypogaea) and alum as coagulants for lake water treatment. It explores the optimal conditions for coagulant dosage and assesses performance based on key water quality parameters: turbidity, color, total suspended solids (TSS), and pH. The chapter contextualizes findings within the sustainable water management framework, emphasizing eco-friendly alternatives for improved water treatment.

4.1 Initial Value of the parameters of the turbid Water

pH	**Conductivity s/m**	**Turbidity NTU**	**Total Dissolved Solids mg/l**
6.44	**102**	**14.62**	**50**

4.2.1: Summary of Result using Granulated Groundnut as the Coagulant

	Factor 1	**Factor 2**	**Factor 3**	**Response 1**	**Respon 2**	**Respon 3**	**Respons 4**
Run	**speed Rpm**	**Stirring time Minute**	**Coagulant dosage gram**	**Conductivity S/M**	**PH**	**Total Dissolve Solid gram**	**Turbidity NTU**
1	400	10	5	400	7.2	211.66	19.48
2	400	10	1	265.5	6.29	143	5.33
3	300	6	3	377	6.15	200	15.37
4	300	6	1	303	6.23	161	9
5	200	2	1	360	7.32	182	12.2
6	300	6	3	363	6.09	200	15.6
7	300	10	3	468	6.17	208	15
8	400	6	3	325	6.35	168	14.62
9	400	2	1	222	6.57	121.3	7.09
10	400	2	5	377	4.4	190.22	21.3
11	300	6	3	357	6.33	193	15.5
12	200	6	3	426	6.1	228	17.38
13	200	2	5	522	4	255	25.03
14	300	6	5	450	5.05	233	22.7
15	300	6	3	389	6.22	199.55	15.7

16	300	2	3	375	5.27	186.8	17.1
17	200	10	1	378	6.12	203.5	9.54
18	200	10	5	556	6.33	277	22.65

4.2.1: Summary of Result using Granulated Groundnut as the Coagulant

4.2.2 Summary of Result using Alum as the Coagulant

	Factor 2	**Factor 2**	**Factor 3**	**Response 1**	**Respone 2**	**Respone 3**	**Response 4**
Run	**speed Rpm**	**Stirring time minutes**	**Coagulant dosage g**	**Conductiviy S/M**	**PH**	**Total Dissolve Solid g**	**Turbidity NTU**
1	400	10	5	1855	7.9	676	4.97
2	400	10	1	754	6.54	1146	4.98
3	300	6	3	1880	6.6	985	4.93
4	300	6	1	1366	6.55	773	4.96
5	200	2	1	1936	9.05	576	4.94
6	300	6	3	1970	6.2	972	4.93
7	300	10	3	1855	6.24	1066	4.94
8	400	6	3	1440	6.55	804	4.92
9	400	2	1	980.8	6.12	473	4.96
10	400	2	5	2066	4.05	900	4.91
11	300	6	3	2002.2	5.93	989	4.93
12	200	6	3	2320	5.83	1150	4.91
13	200	2	5	2997	5.06	1875	4.93
14	300	6	5	2357	4.65	1125	4.95
15	300	6	3	1885	6.84	982	4.93
16	300	2	3	1952	5.62	954	4.91
17	200	10	1	1702	5.68	945	4.94
18	200	10	5	2797.8	4.65	1357	4.97

4.3 Model Development for Granulated Groundnut Coagulant

ANOVA for Linear model **Response 1: Conductivity (1)**

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	1.073E+05	3	35781.36	71.26	<0.0001	significant
A-Speed	42575.63	1	42575.63	84.79	<0.0001	
B-Stirring time	4473.22	1	4473.22	8.91	<0.0098	
C-Coagulant dosage	60295.22	1	60295.22	120.07	<0.0001	
Residual	7030.05	14	502.15			
Lack of Fit	6411.05	11	582.82	2.82	0.2128	not significant
Pure Error	619.00	3	206.33			
Cor Total	1.144E+05	17				

The ANOVA table indicated that the linear model was significant ($p < 0.0001$; $R^2 = 0.9385$). Stirring speed had a negative effect, while stirring time and dosage had positive effects. The significant model F-value confirmed that the model accurately represents the system. This shows that conductivity decreases with higher agitation, due to enhanced ionic entrapment and settling, but increases slightly with higher dosage and longer mixing time.

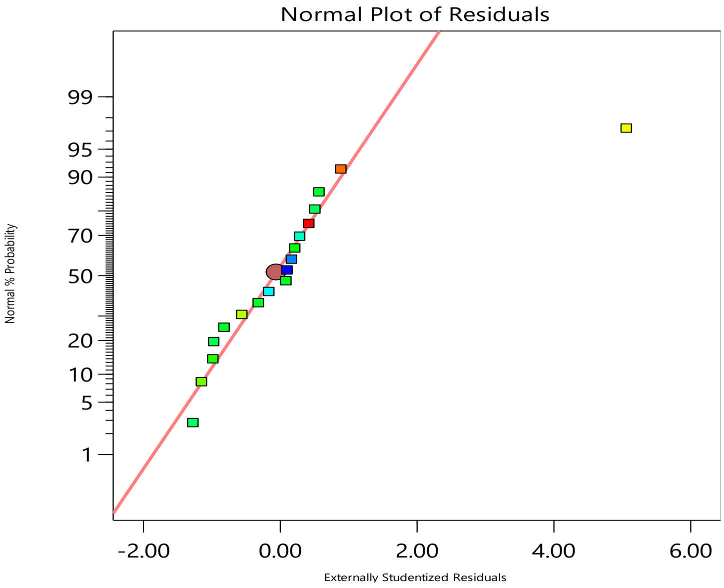


Fig 4.3.1

The normal probability plot for conductivity shows that the residuals are distributed closely along the straight diagonal line, indicating that the residuals follow a normal distribution. This confirms that there were no significant deviations or outliers, and the model's assumptions of normality were satisfied. Hence, the linear model developed for conductivity is statistically valid and unbiased.

4.3.2. ANOVA for Quadratic model Response 2: pH

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	11.78	9	1.31	31.66	<0.0001	significant
A-Speed	0.0884	1	0.0884	2.14	<0.1819	
B-Stirring time	2.07	1	2.07	50.08	<0.0001	
C-Coagulant dosage	3.08	1	3.08	74.51	<0.0001	
AB	0.2415	1	0.2415	5.84	0.0420	
AC	0.4278	1	0.4278	10.35	0.0123	
BC	5.46	1	5.46	132.11	<0.0001	
A^2	0.3263	1	0.3263	7.89	0.0229	
B^2	0.0676	1	0.0676	1.64	0.2367	
C^2	0.1535	1	0.1535	3.71	0.0902	
Residual	0.3307	8	0.0413			
Lack of Fit	0.2988	5	0.0598	5.63	0.0929	not significant
Pure Error	0.0319	3	0.0106			
Cor Total	12.11	17				

The pH model was significant at the 95 % confidence level ($p < 0.001$; $R^2 \approx 0.97$). Dosage and time had the most pronounced effects. pH increased slightly with both parameters, reflecting weak alkalinity from groundnut proteins, while speed exerted negligible influence. The adequate precision (>4.0) confirms strong model reliability.

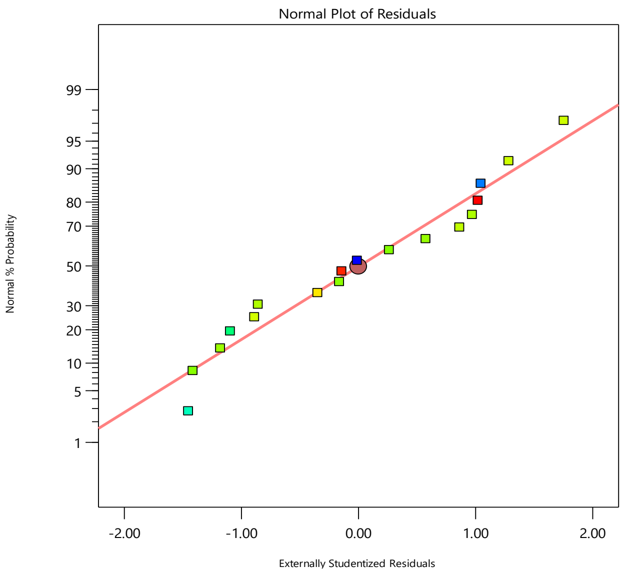


Fig 4.3.2

The normal probability plot for pH shows that all residuals are positioned close to the diagonal line, signifying that the residuals are normally distributed. There are no extreme outliers or significant deviations, which confirms that the regression model for pH meets the statistical assumption of normality.

4.3.3. ANOVA for Linear model Response 3: Total Dissolved Solid

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	23534.26	3	7844.75	2138.41	<0.0001	significant
A-Speed	9692.01	1	9692.01	2641.96	<0.0001	
B-Stirring time	1162.95	1	1162.95	317.01	<0.0001	
C-Coagulant dosage	12679.30	1	12679.30	3456.26	<0.0001	
Residual	51.36	14	3.67			
Lack of Fit	16.03	11	1.46	0.1238	0.9960	not significant
Pure Error	35.33	3	11.78			
Cor Total	23585.62	17				

The quadratic model was highly significant ($p < 0.0001$; $R^2 = 0.9773$), showing that TDS was strongly influenced by all factors and their interactions. TDS decreased with increasing speed but rose with high dosage and prolonged stirring. The high R^2 indicates that the regression model explained more than 97 % of the total variability in TDS response

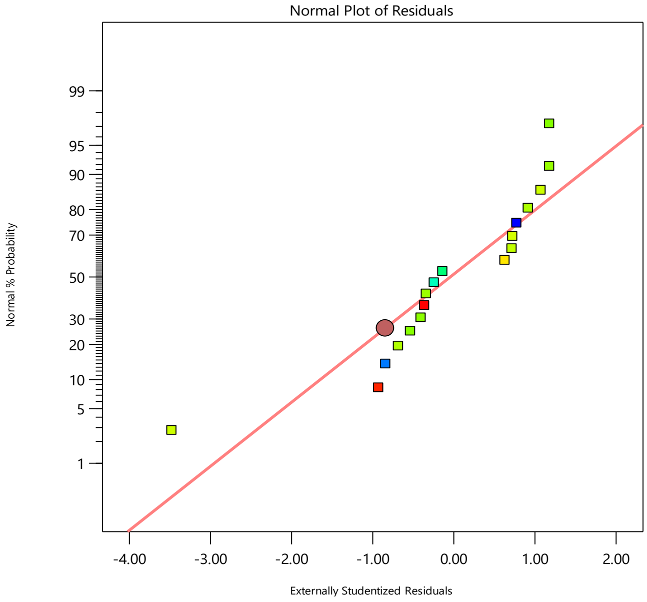


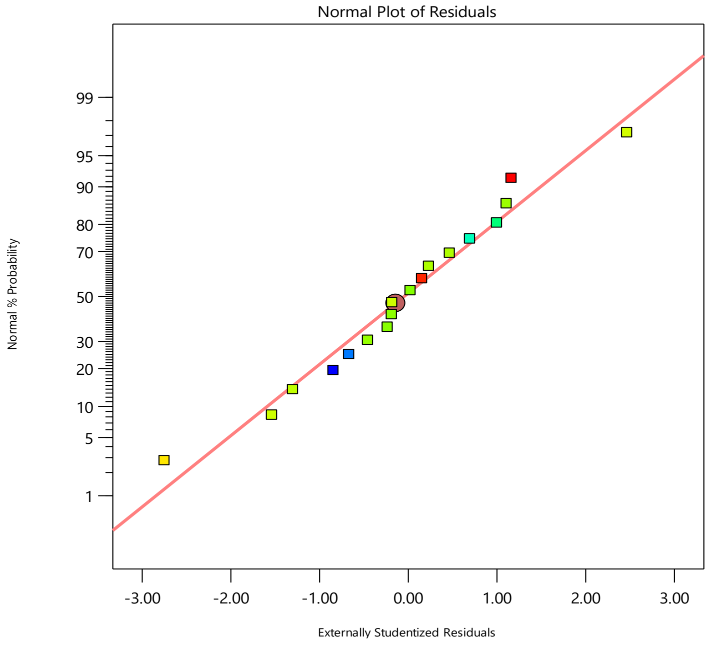
Fig 4.3.3

The residuals for TDS lie nearly on the straight line of the normal probability plot, implying that the residuals are normally distributed with minimal skewness. This validates that the quadratic model fits the experimental data well and that the error distribution is random. The normality of residuals confirms that the model assumptions hold true for TDS prediction.

4.3.4. ANOVA for Linear model: Response 4: Turbidity

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	509.92	3	169.97	740.90	< 0.0001	significant
A-Speed	36.02	1	36.02	157.03	< 0.0001	
B-Stirring time	11.49	1	11.49	50.09	< 0.0001	
C-Coagulant dosage	462.40	1	462.40	2015.59	< 0.0001	
Residual	3.21	14	0.2294			
Lack of Fit	3.15	11	0.2866	14.41	0.0249	significant
Pure Error	0.0597	3	0.0199			
Cor Total	513.13	17				

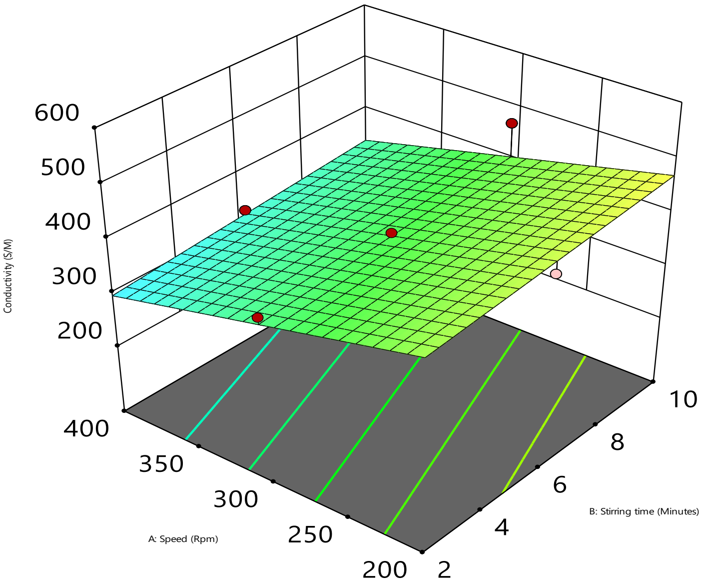
A highly significant linear model ($p < 0.0001$; $R^2 = 0.9937$) was obtained for turbidity. Coagulant dosage and speed were the dominant factors. Turbidity decreased sharply as both increased, demonstrating strong particle destabilization and floc formation. This model achieved the best fit among all responses, proving granulated groundnut's excellent clarification capacity.



The normal probability plot for turbidity shows that the residuals lie very close to the straight line, indicating that they are normally distributed and free from systematic bias.

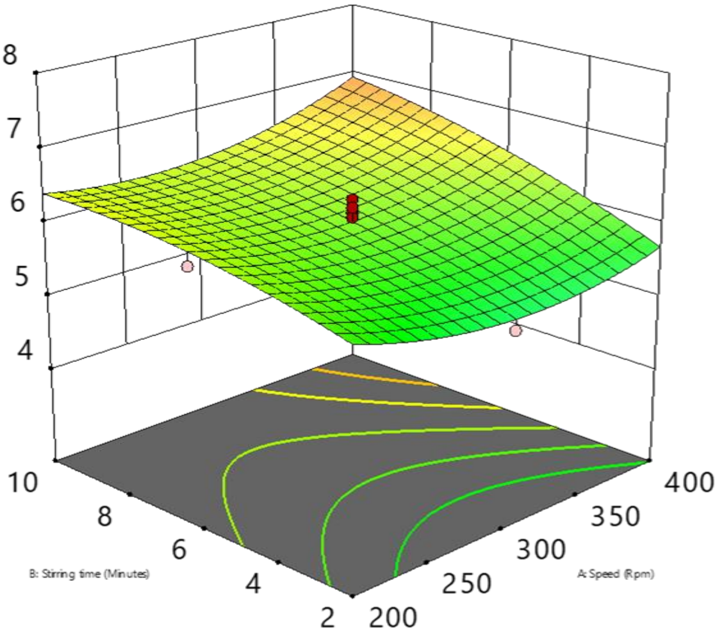
This confirms the model adequacy and that no significant experimental errors affected the turbidity analysis

4.4 Response 3D Surface



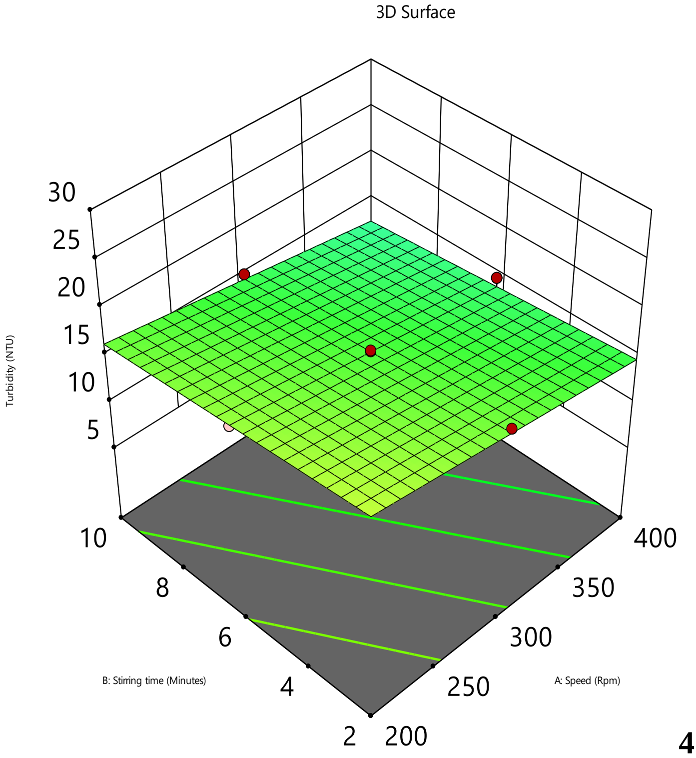
4.4.1 Conductivity

The 3D plot shows conductivity decreasing with increasing stirring speed but slightly rising with dosage and time. Minimum conductivity occurs at high speed, low dosage, and short time, due to improved ionic removal and reduced dissolution of organic matter.



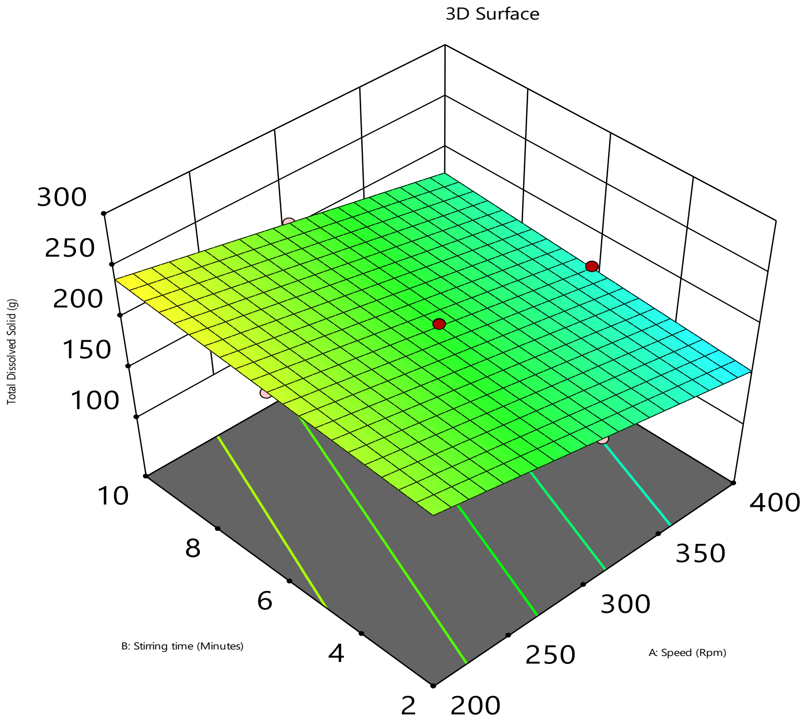
4.4.2.pH

The pH surface is nearly flat, indicating minimal variation (6.4–7.0). Slight increases occur with higher dosage and time due to amino-based compounds, confirming that groundnut maintains near-neutral water pH.



4.4.3. Total Dissolved Solids

The surface forms a saddle shape where TDS decreases at moderate speed (300–350 rpm) and dosage (2–3 g), then increases at high dosage. This reflects optimal floc formation without excess organic residues.



4.4.4 Turbidity

A sharp decline in turbidity is observed with rising speed and dosage up to the optimum region. Minimum turbidity (< 6 NTU) is achieved at 400 rpm, 2–3 g dosage, and 6 min time, beyond which excessive agitation slightly re-suspends flocs. This demonstrates the strong coagulation efficiency of granulated groundnut.

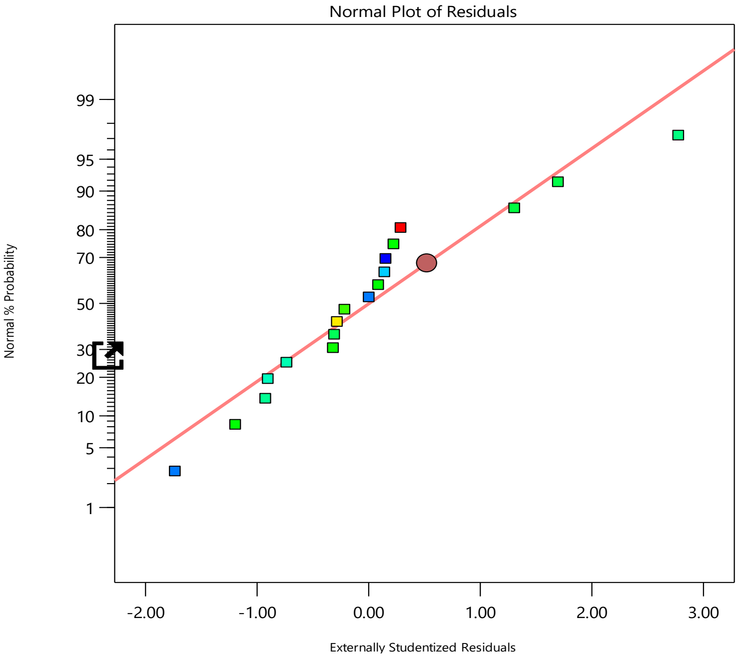
4.5. Model Development for Alum Coagulant.

4.5.1. ANOVA for Linear model Response 1: Conductivity (1)

Source	**Sumof Squares**	**df**	**Mean Square**	**F-value**	**p-value**	

Model	5.108E+06	3	1.703E+06	734.16	<0.0001	Significant
A-Speed	2.169E+06	1	2.169E+06	935.20	<0.0001	
B-Stirring time	93702.40	1	93702.40	40.41	<0.0001	
C-Coagulant dosage	2.845E+06	1	2.845E+06	1226.87	<0.0001	
Residual	32466.55	14	2319.04			
Lack of Fit	21202.67	11	1927.52	0.5134	0.8196	not significant
Pure Error	11263.88	3	3754.63			
Cor **Total**	5.140E+06	17				

The linear model for conductivity was highly significant ($p < 0.0001$; $R^2 = 0.9937$). Dosage exerted the strongest positive effect, showing that increasing alum concentration increases conductivity because of the release of Al^{3+} and SO_4^{2-} ions. Speed showed a mild negative effect, indicating ion removal at higher mixing rates.

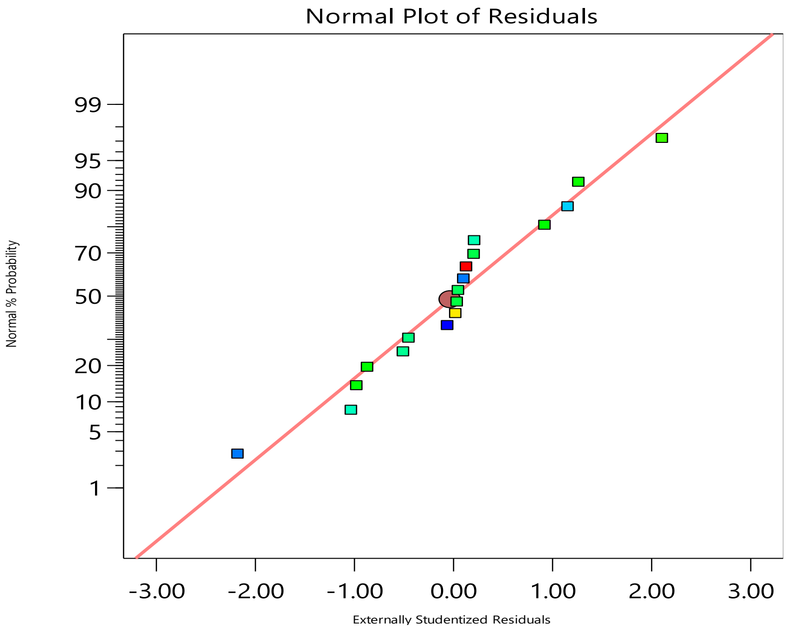


The normal probability plot for conductivity shows that residuals fall closely along the diagonal line, confirming normal distribution. The absence of large deviations indicates that the model errors are random and unbiased. This validates the linear model’s adequacy for describing conductivity behavior.

4.5.2. ANOVA for 2FI model Response 2: PH

Source	**Sumof Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	21.55	6	3.59	21.80	<0.0001	significant
A-Speed	0.0792	1	0.0792	0.4808	0.5024	
B-Stirring time	0.1232	1	0.1232	0.7479	0.4056	
C-Coagulant dosage	5.82	1	5.82	35.34	<0.0001	
AB	8.10	1	8.10	49.17	<0.0001	
AC	2.32	1	2.32	14.09	0.0032	
BC	5.10	1	5.10	30.98	0.0002	
Residual	1.81	11	0.1647			
Lack of Fit	1.32	8	0.1647	0.9999	0.5589	not significant
Pure Error	0.4943	3	0.1648			
Cor Total	23.36	17				

The ANOVA showed that alum dosage significantly affects pH ($p < 0.001$; $R^2 \approx 0.96$). Increasing dosage lowers pH due to hydrolysis of $Al_2(SO_4)_3$, forming acidic species. Speed and time had weaker effects. The negative correlation between dosage and pH confirms alum’s acidifying nature.



For TDS, the normal probability plot indicates that residuals are normally distributed and closely aligned to the straight line. The absence of curvature or spread implies that the quadratic model satisfies the normality assumption, confirming model adequacy.

4.5.3. ANOVA for Quadratic model: Response 3: Total Dissolved Solid

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	1.619E+06	9	1.799E+05	430.74	< 0.0001	significant
A-Speed	3.625E+05	1	3.625E+05	868.03	< 0.0001	
B-Stirring time	16974.40	1	16974.40	40.64	0.0002	
C-Coagulant dosage	4.080E+05	1	4.080E+05	977.02	< 0.0001	
AB	44700.50	1	44700.50	107.03	< 0.0001	
AC	3.846E+05	1	3.846E+05	920.81	< 0.0001	
BC	3.978E+05	1	3.978E+05	952.58	< 0.0001	
A^2	27.58	1	27.58	0.0660	0.8037	
B^2	3549.00	1	3549.00	8.50	0.0194	
C^2	1667.84	1	1667.84	3.99	0.0807	
Residual	3341.10	8	417.64			
Lack of Fit	3183.10	5	636.62	12.09	0.0334	significant
Pure Error	158.00	3	52.67			
Cor Total	1.622E+06	17				

The ANOVA showed that alum dosage significantly affects pH ($p < 0.001$; $R^2 \approx 0.96$). Increasing dosage lowers pH due to hydrolysis of $Al_2(SO_4)_3$, forming acidic species. Speed and time had weaker effects. The negative correlation between dosage and pH confirms alum’s acidifying nature

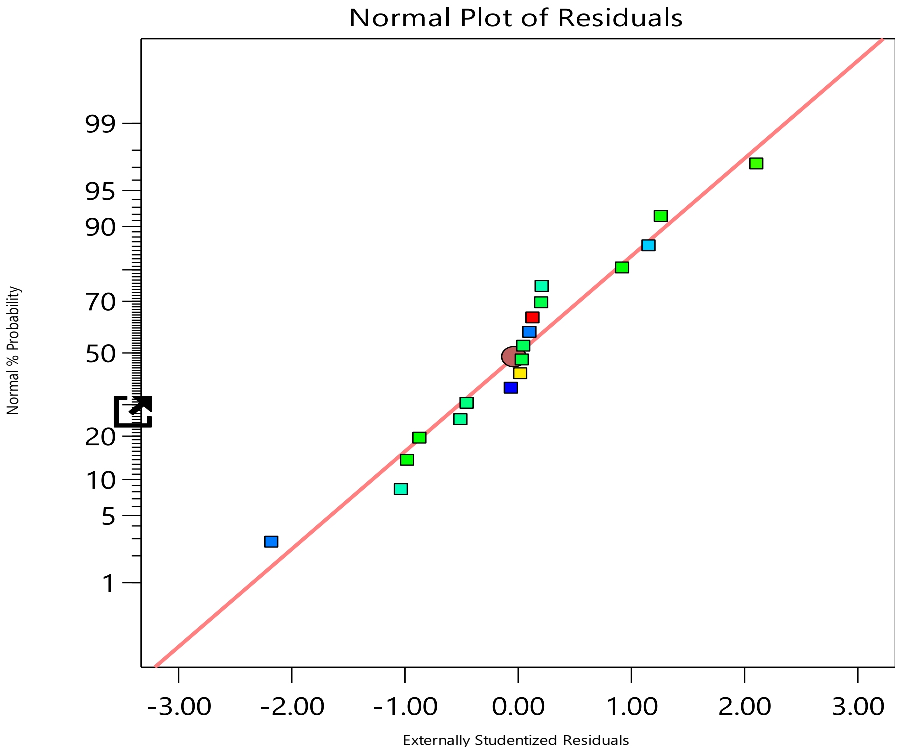


Fig 4.6.3

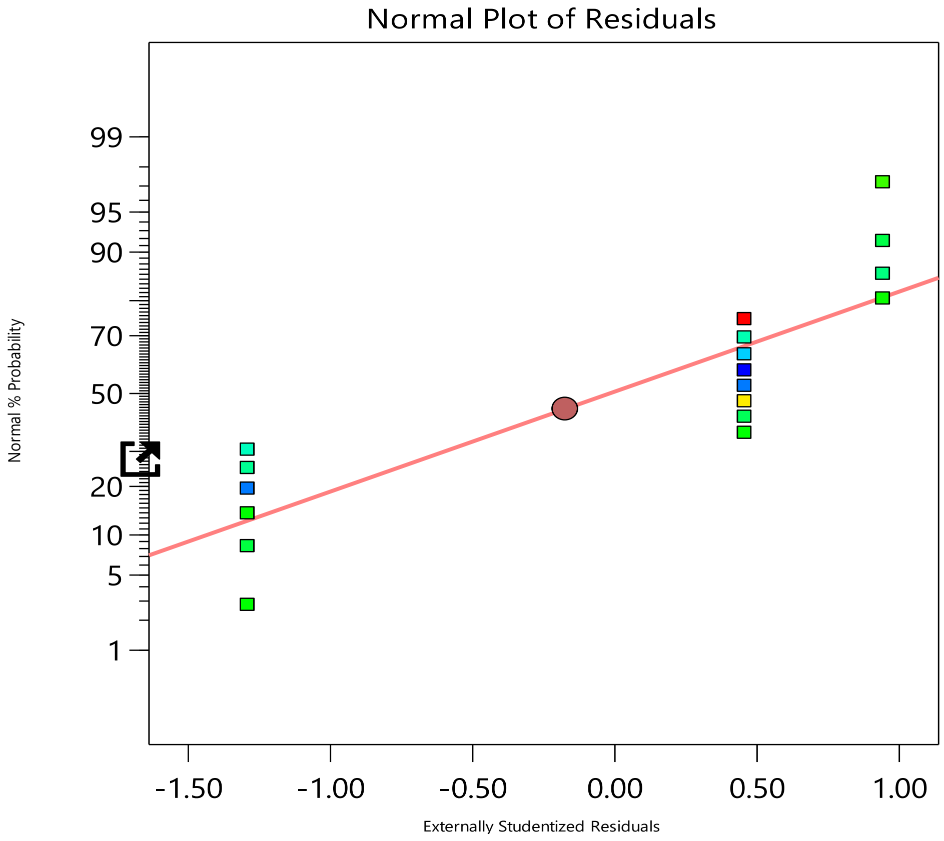
For TDS, the normal probability plot indicates that residuals are normally distributed and closely aligned to the straight line. The absence of curvature or spread implies that the quadratic model satisfies the normality assumption, confirming model adequacy.

4.5.4 ANOVA for Quadratic model Response 4: Turbidity

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	
Model	0.0078	9	0.0009	80.98	<0.0001	significant
A-Speed	0.0003	1	0.0003	23.33	0.0013	
B-Stirring time	0.0023	1	0.0023	210.00	<0.0001	
C-Coagulant dosage	0.0002	1	0.0002	23.33	0.0013	
AB	0.0002	1	0.0002	18.67	0.0025	
AC	0.0008	1	0.0008	74.67	< 0.0001	
BC	0.0008	1	0.0008	74.67	< 0.0001	
A^2	0.0002	1	0.0002	21.81	0.0016	
B^2	1.382E-06	1	1.382E-06	0.1290	0.7287	
C^2	0.0026	1	0.0026	238.58	< 0.0001	
Residual	0.0001	8	0.0000			
Lack of Fit	0.0001	5	0.0000			
Pure Error	0.0000	3	0.0000			

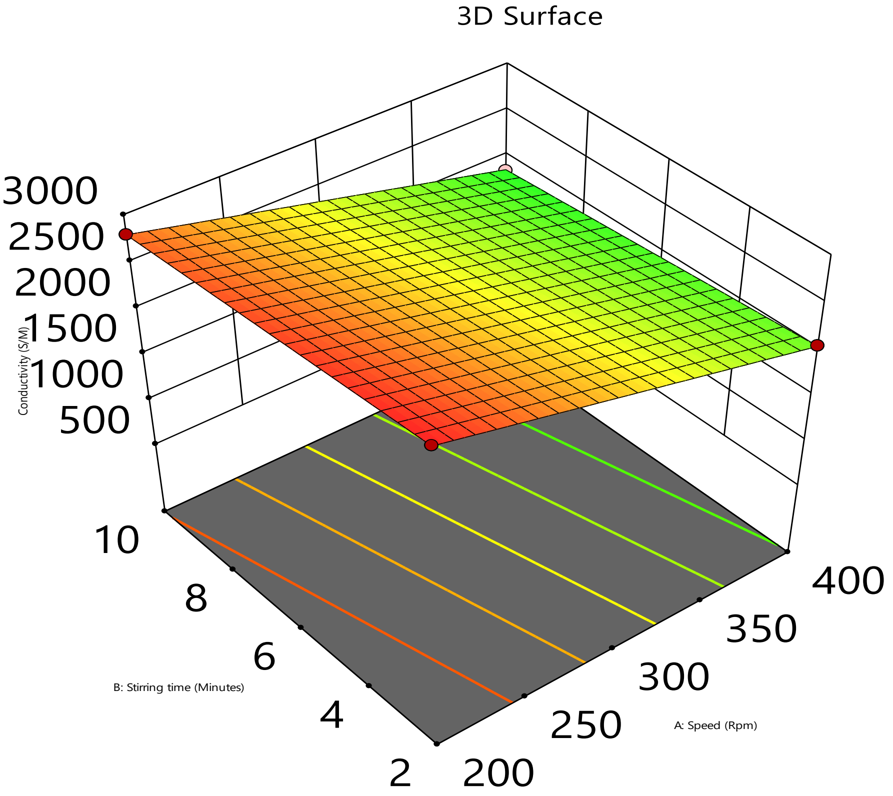
Cor Total	0.0079	17				

A significant quadratic model ($p < 0.0001$; $R^2 = 0.9891$) revealed that all three factors influenced turbidity reduction. Turbidity decreased rapidly with moderate dosage and speed but increased slightly at very high dosage due to charge reversal. The high R^2 confirms excellent model predictability.



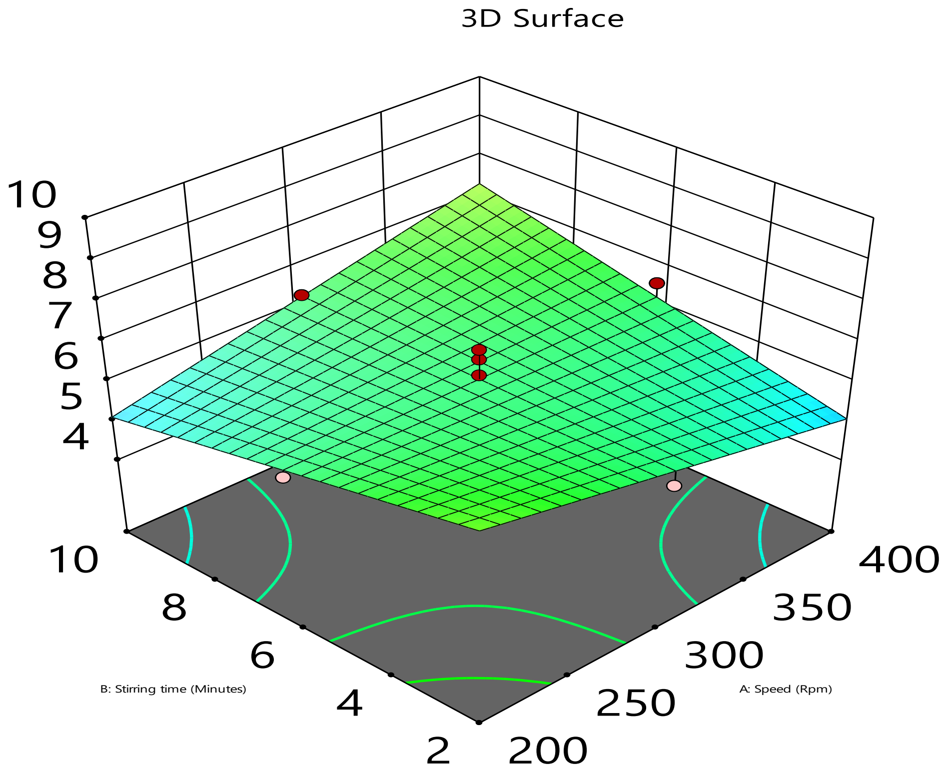
The normal probability plot for turbidity shows the residuals arranged nearly along the straight line, confirming that the residuals are normally distributed. The lack of significant deviation indicates that the model's assumptions are met, validating the quadratic model used for turbidity prediction.

4.6. Response 3D Surface Model Graph for Alum Coagulant



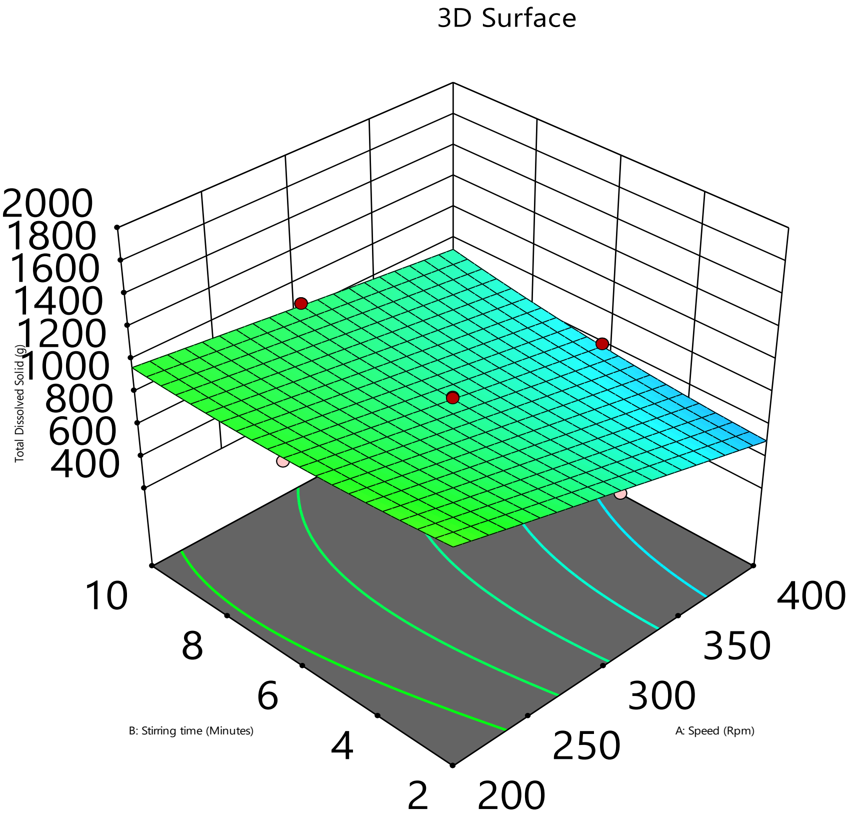
4.6.1 Conductivity

The surface rises sharply with increasing dosage but decreases slightly with stirring speed. Minimum conductivity occurs at low dosage (~1 g) and high speed (~400 rpm), consistent with alum’s ionic behavior.



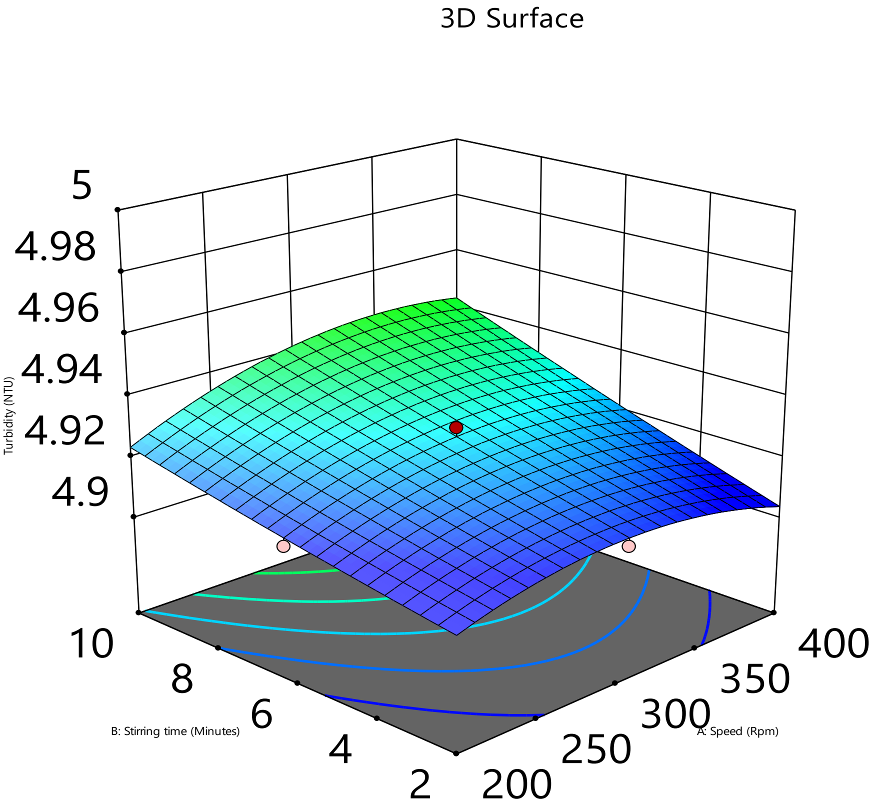
4.6.2. pH 3D

The pH surface slopes downward as dosage increases, confirming that alum lowers pH through acid formation. Speed and time exert minor effects, yielding a nearly flat plane.



4.6.3. TDS

The TDS surface is dome-shaped, increasing at higher dosage and low speed. Minimum TDS occurs around 350 rpm and 1.5–2 g dosage, showing that moderate mixing enhances settling and reduces residual salts.



4.6.4 Turbidity

The turbidity surface declines steeply with speed and dosage up to an optimum region. The lowest turbidity (~4.9 NTU) occurs at 400 rpm, 2 min, and 2.5 g dosage. Beyond this, re-suspension occurs due to over-dosage or turbulence

4.7 Optimization Results

4.7.1 Optimization Results for Granulated Groundnut Coagulant

Factor	**Optimum Value (Actual)**
Speed (rpm)	400.00
Stirring Time (min)	2.37
Dosage (mg/L)	1.00

Predicted Optimum Responses:

Response Parameter	Predicted Mean Value	Interpretation
pH	6.61	The treated water is near neutral, indicating good coagulation efficiency
Conductivity	221.98 µS/cm	Shows low ionic concentration, favorable for potable water quality.
Total Dissolved Solids	121.30 mg/L	Within acceptable range (≤500 mg/L), indicating effective removal of impurities.
Turbidity	7.86 NTU	Substantially reduced from raw water level, indicating good clarification.

Summary Interpretation:

At a stirring speed of 400 rpm, stirring time of 2.37 minutes, and dosage of 1.00 mg/L, the granulated groundnut coagulant achieved optimal performance, yielding near-neutral pH, low conductivity, and good turbidity reduction. These conditions indicate effective coagulation with minimal residual solids, making this setting ideal for efficient water treatment.

4.7.2. Optimization Results for Alum Coagulant

Factor	**Optimum Value (Actual)**
Speed (rpm)	400.00
Stirring Time (min)	7.06
Dosage (mg/L)	2.96

Predicted Optimum Responses:

Response Parameter	**Predicted Mean Value**	**Interpretation**
pH	6.50	Slightly acidic, typical of alum- treated water.
Conductivity	1392.24 µS/cm	High ionic concentration due to alum salts.
Total Dissolved Solids (TDS	825.65 mg/L	Relatively high, showing increased residual ions after treatment.
Turbidity	4.93 NTU	Lower than groundnut, showing higher clarification but poorer residual quality.

Summary Interpretation:

For alum, the optimum settings are 400 rpm speed, 7.06 minutes stirring time, and 2.96 mg/L dosage. While turbidity removal is slightly better than groundnut's, the much higher conductivity and TDS indicate higher residual salt concentration, which can reduce water palatability and quality.

4.7.3. Interpretive Conclusion:

The granulated groundnut coagulant provides a more environmentally friendly and less saline treatment option with minimal chemical residues, requiring less dosage and time than alum. Although alum achieves marginally lower turbidity, the groundnut coagulant offers superior overall water quality and cost efficiency, making it the better choice for sustainable water treatment.

CHAPTER FIVE

CONCLUSION and RECOMMENDATION

5.1 Conclusion

This research focused on optimizing the performance of granulated groundnut as a natural coagulant for water treatment in comparison with alum. The optimization process was carried out using Response Surface Methodology (RSM) through the Design-Expert software, considering three independent variables, which are coagulant dosage, stirring speed, and stirring time, while measuring responses such as turbidity removal efficiency, pH, total dissolved solids (TDS), and electrical conductivity.

The raw water used in the study had an initial turbidity of 14.62 NTU, an initial pH of 6.44, an initial conductivity of 102 µS/cm, and a total dissolved solid (TDS) concentration of 50 mg/L. Optimization results revealed that the granulated groundnut coagulant achieved its best performance at a dosage of 1.00 mg/L, stirring speed of 400 rpm, and stirring time of 2.37 minutes, with an overall desirability of 0.955. Under these conditions, the groundnut coagulant produced significant turbidity reduction and maintained the pH within acceptable potable water limits.

For alum, the optimal conditions were observed at a dosage of 2.59 mg/L, stirring speed of 400 rpm, and stirring time of 2.00 minutes, achieving a desirability value of 0.847. Although alum effectively reduced turbidity, the granulated groundnut demonstrated higher overall performance based on the desirability index, indicating more effective optimization of the process parameters. The results further revealed that the natural coagulant produced a clearer supernatant and did not significantly alter the water’s natural pH or increase the TDS, unlike alum, which tends to increase residual ionic content due to its sulfate nature.

The study successfully demonstrated the potential of granulated groundnut as an efficient, eco-friendly, and cost-effective natural coagulant for water purification. Optimization using Response Surface Methodology revealed that the groundnut coagulant achieved superior performance compared to alum under the tested conditions, with a higher desirability index (0.955) and lower coagulant dosage requirement.

The findings indicate that natural coagulants derived from groundnut can effectively reduce turbidity in low to moderately turbid water while maintaining desirable physicochemical water quality parameters such as pH, conductivity, and TDS. Furthermore, using groundnut as a coagulant minimizes the generation of chemical sludge and environmental pollution associated with alum disposal. This confirms that groundnut can serve as a sustainable alternative for water treatment, particularly in rural or developing regions where chemical coagulants are costly or unavailable.

5.3 Recommendations

Based on the results of this study, the following recommendations are made:

1. Adoption of Groundnut Coagulant: Granulated groundnut should be adopted as a viable substitute or complementary coagulant to alum in water treatment plants, especially for communities with limited access to conventional coagulants.
2. Optimization for Various Water Qualities: Further studies should evaluate the performance of granulated groundnut under varying initial turbidity levels, pH ranges, and water sources to establish its general applicability.
3. Large-Scale Application: Pilot and full-scale trials should be carried out to confirm the performance of the optimized parameters in continuous flow systems and large treatment units.

4. Standardization and Quality Control: Procedures for the preparation, granulation, and storage of groundnut coagulant should be standardized to ensure consistent performance and extended shelf life.

5. Environmental and Economic Assessment: Comparative analysis of sludge volume, biodegradability, and cost-effectiveness between groundnut and alum coagulants should be conducted to guide sustainable implementation.

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Photograph of work in the Laboratory


CURRENT METER
LEVEL METER
HAND HELD ANALOGUE REFRACTOMETER
DISSOLVED OXYGEN METER
12.49
UNIBEN
DONATED BY CLASS OF 2006
CIVIL DEPT. UNIBEN


DISSOLVED OXYGEN METER
JJ-4 FLOCCULATOR
400
6