Journal of Mines, Metals and Fuels, *71(12C) : 426-433; 2023. DOI: 10.18311/jmmf/2023/47280*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

A Review on Available Herbal Coagulants for Grey Water Treatment in India

K. N. Gunasheela[1], K. Venkatesha Raju[1] and Mani Ramakrishnan[2]

[1]Presidency University, Yelahanka, Bangalore - 560064, Karnataka, India; venkatesharaju.k@presidencyuniversity.in
[2]Presidency College, Hebbal, Bangalore - 560024, Karnataka, India

Abstract

Coagulation is a crucial and simple technique to purify water and wastewater as well as to utilize point-of-use solutions. The popularity of Herbal coagulants has increased in recent times due to their numerous benefits and their ability to address many of the problems associated with chemical coagulants. Research and evaluations have shown that plant-based coagulants are a viable and sustainable substitute to chemical coagulants. This review paper reveals about major plant-based coagulants that are most popularly used in grey water treatment in recent years. Additionally, information on the effectiveness of herbal coagulants at removing impurities from grey water is provided. Herbal coagulants present several key advantages: they are environmentally friendly, cost-effective, pose fewer health risks, and provide a viable alternative to chemical coagulants. Significant drawbacks are increasing the microbial activity and amount of organic matter in the water

Keywords: *Coagulation Process, Grey Water, Herbal Coagulants, Water Reuse, Water Treatment*

1.0 Introduction

Researchers are interested in wastewater recycling as a result of rising worldwide water demand, water scarcity owing to insufficient rainfall, and economic and environmental problems[1]. By the year 2050, the world's freshwater supply will not be able to meet the demand[2]. In addition to raising the demand for freshwater, rising economic activity, industrialization, and population have also led to serious abuse of this natural resource[3].

The primary source of water is surface water, which comes from either rivers or ponds that receive their water from rain. This water is susceptible to many types of contamination caused by various factors, including habitation, agriculture, and industry. Before raw water may be disinfected for human consumption, organic and inorganic particles must be removed[4]. Rainwater harvesting is one of the most productive methods for water conservation, although it has several drawbacks, such as the fact that it is only effective in regions that receive significant annual rainfall[5]. On the other side, seawater desalination disturbs the nearby marine ecosystem and produces an increase in the atmospheric emissions of CO_2 and other pollutants[6].

The reutilize of grey water is a practical choice that may be highly beneficial in water-dry and semi-dry places. Greywater recycling is widely recognized as a viable answer to the world's rising freshwater demand, water scarcity issues, and environmental preservation[7]. The most popular use for recycled grey water is toilet flushing, which may save water use in homes by up to 30%. Other uses, however, include air conditioning, vehicle washing, fire protection, and irrigation for parks, schools, cemeteries, and golf courses[8]. Greywater recycling has gained attention in recent decades, especially as a potential remedy for water scarcity in underdeveloped nations, and it is currently seeing a rapid global expansion.

Grey water is the water collected from appliances such as clothes washers, bathtubs, and sinks used for showers,

**Author for correspondence*

except for toilet waste[9]. Many of the same contaminants are present in grey water as in black water, although at lower concentrations than in sewage water. When compared to septic wastewater, which makes up 15–20% of the total sewage generated and has a high percentage of organic matter (1%), grey water makes up around 80% to 85% of the total residential sewage produced[10]. It also has a lower concentration of organic matter (0.01%) and fewer pathogens. On a global and national scale, many experts have conducted in-depth research into the different wastewater treatment techniques[11]. In a variety of applications in residential, commercial, institutional, as well as industrial structures, the reuse of grey water has considerable promise[12].

The world's water supplies are in danger due to natural deterioration as well as overuse and bad management. Untreated wastewater and chemical wastes are routinely dumped into rivers, lakes, and drains, making it impossible for these aquatic bodies to handle the pollution load[13]. Globally, urban areas and industries are utilizing more water regularly, which may be harmful to the environment and public health.

There are other remediation methods available to treat contaminated water, but coagulation is the most sought out method due to its low cost, operational simplicity, and convenience of usage[14]. The primary physical process aims to precipitate (Settle down) the suspended colloidal particles that are the primary physical source of the turbidity in the wastewater system[15]. Typically, the process is carried out in a chemical reactor, where wastewater reaches the reservoir, is combined with coagulant agents using a mechanical mixer, and is then exposed to sedimentation to eliminate particles by gravity settling. There are several varieties of coagulants. The ferric salts and alums are examples of the most common chemical coagulants used for this purpose. However, using these chemical coagulants has some drawbacks, including the production of hazardous quantities of sludge[16].

Herbal alternatives are both relatively safe and environmentally friendly. They can be extracted from animals, plants, and microbes. These coagulants are effective in various coagulation processes, including charge neutralisation on colloidal particles and facilitating bridging the polymers[17].

In the pursuit of sustainable development, there has been a global shift towards adopting natural and eco-friendly solutions. Coagulation, a critical step in water treatment, plays a pivotal role in removing colloidal particles often associated with organic and microbiological contaminants. Despite extensive research on various coagulants, a comprehensive database summarizing all the coagulants investigated remains absent. This study addresses this gap by presenting an extensive database of prominent plant-based coagulants which can potentially be used in the treatment of grey water, providing valuable insights into their effectiveness and possible applications.

2.0 Coagulation Process

Turbidity, organic matter, and other impurities from water and wastewater are removed via coagulation processes. To combine tiny particles into bigger flocs that may be sediment, the coagulation process necessitates the use of plant-based coagulants. Clustering and quick mixing occur during coagulation[18]. The operational parameters for coagulation mechanisms include mixing rate, temperature, settling time, dose, and coagulant type. The four basic methods used by the coagulation process to destabilize the pollutants with the coagulants are neutralization of charge, bridging of polymers, sweep coagulation, and compression by double layer[19].

Although there has been advancement in the discovery and study of the plant-based coagulants, the development of these therapeutic methods are in full-scale investigations. The water-soluble plant-based coagulants showed outstanding efficiency in settling the colloidal particles and controlling the growth of microorganisms from the turbid water. Additionally, the water's increased physicochemical characteristics were also reduced[20].

3.0 Herbal Coagulants Used for Water Treatment

This section aims to explore the most extensively researched herbal coagulants, focusing on their selective properties and the compounds crucial for effective coagulation activity. Table 1 provides an overview of the plant-based coagulants widely utilized in grey water treatment, while Table 2 outlines the chemical coagulants commonly used in industrial grey water treatment processes.

3.1 Moringa oleifera Lam

Moringa oleifera Lam., a well-known and widely cultivated species, originates from the southern foothills of the

Himalayas in northwestern India, as well as Afghanistan, Pakistan, and Bangladesh. Belonging to the Moringaceae family, *Moringa oleifera* is now predominantly produced in India, which caters to 80% of the global demand for this versatile plant[21]. The water-soluble lectins in *Moringa oleifera* seeds, which are also responsible for their sedimenting and flocculating properties, are what give them their coagulant potential. Compared to chemical coagulating agents like alum and synthetic organic polymers, which can be harmful to living organisms and the environment, seed-based coagulants offer a safer and more sustainable alternative. They are effective in reducing turbidity, microparticle content, metal content, and microbial load in water treatment processes[21]. High turbidity water can benefit from moringa seeds, which have a comparable water cleaning power as alum and can reduce turbidity by 92% to 99% [22].

3.2 Hibiscus sabdariffa

Hibiscus sabdariffa seeds, known for their high protein content compared to other plant components, are often used as an herbal coagulant. The seeds perform optimally at a pH of 2, with a coagulant dose of 100 mg/L, and mixing speeds of 30 rpm for slow mixing and 140 rpm for rapid mixing. Under these conditions, they achieve turbidity and COD removal efficiencies of 93.83% and 57.98%, respectively. While *Hibiscus sabdariffa* is slightly less effective than alum, which removes 97.48% of turbidity and 65.26% of COD at a pH of 6, with a coagulant dose of 200 mg/L, and mixing speeds of 40 rpm for slow mixing and 150 rpm for rapid mixing, it remains a competitive alternative for water treatment[23].

3.3 Ficus indica

With more than 250 indigenous species from Central America, the genus Opuntia is the biggest in the Cactaceae family. The nopals are succulent plants that can reach heights of 3 to 5 meters, frequently forming a tangled and thick structure. It may be identified by its thick, long, green pads that resemble tennis rackets. They develop one after the other and can be regarded as both stalks and leaves. Spines on the plant's surface aid to transmit water and minimize water loss. For synthetic water, 20 mg/L of *Ficus indica* was shown to be the ideal dose. When treated with this coagulant, turbidity was reduced from 500 NTU to 1.3 NTU, and the effectiveness of turbidity removal was 99.74% for synthetic water at the recommended dosage[24].

3.4 Manilkara zapota

The Cheeku is an indigenous, naturally occurring coagulant that is used to purify grey water for domestic reuse. It is made from seed material from the multifunctional tree. An ointment for the skin is made from seed kernel oil. After the oil has been extracted, the seed's leftover material can be used as a poultice for severe skin conditions. This fruit's crushed seeds work as a diuretic, aiding in the elimination of bladder and kidney stones[25]. Grey water's turbidity and COD were significantly reduced after being treated with sapodilla seeds. 65% of the turbidity and 45% of the COD in the grey water are removed by the sapodilla seed coagulant. The removal effectiveness of herbal coagulants is increased by the use of alum as the coagulant aid. The greater removal efficiency was attained using coagulation assistance and coagulant concentration modulation[26].

3.5 Brassica juncea

Mustard seeds are cruciferous vegetables that are often utilized in food and medicine all over the world. Chinese mustard is the name given to mustard seeds. These seeds contain a variety of phytochemicals that may be the cause of coagulation activity[27] discovered that plant seeds contain positively charged proteins responsible for their coagulation activity, enabling them to remove up to 85% of water turbidity. Mustard seeds, in particular, are cost-effective and rich in bioactive compounds and their breakdown byproducts, making them a viable option for water treatment applications[28].

3.6 Dolichos lablab

They are members of the Fabaceae family and are known as Indian beans. As a common food crop, these plants may be found in tropical regions[29]. The characteristics of hyacinth bean peels for use as a protein source are described. The protein content in hyacinth bean peels is considerable at (17.1 ± 1.5%). For synthetic water, 20 mg/L of hyacinth bean was shown to be the ideal dose. When treated with this coagulant, turbidity was reduced from 500 NTU to 4.3 NTU, and the effectiveness of turbidity removal was 99.14% for synthetic water at the recommended dosage[30].

3.7 Abelmoschus esculentus

An annual plant of the Malvaceae family (also known as *Hibiscus esculentus*) is also known by the names ladies' finger, okra, bhindi, or gumbo[31]. The maximum turbidity

reduction achieved using okra leaf extracts was 54.5% with distilled water and 92% with a 1.0 N NaCl solution[32]. Scientists employed the okra's gums as a coagulant and removed 72% of the turbidity[33]. When similar experiments were conducted by Raji et al, they concluded that the turbidity was removed with an efficiency of 99% under optimal neutral pH conditions[34].

3.8 Cymbopogon citratus

The tall, perennial grass known as lemongrass (*Cymbopogon citratus*) is one of roughly 45 kinds of grasses that are indigenous to tropical and subtropical regions of Asia, Australia, and Africa. India is the country that produces the most lemongrass, where it is grown beside the WesternGhats mountain range and the foothills of Arunachal Pradesh and Sikkim in the Himalayan Mountains[35]. When compared to other herbal coagulants tested in this research, lemongrass had the greatest efficiency in turbidity reduction (92.8%). The water turbidityin the sample was lowered up to 15NTU with a lemon grass dosage of 90mg/L and was found to be the highest at pH 12.

3.9 Ananas comosus

The pineapple is the most commercially significant plant in the Bromeliaceae family. It is a tropical plant with edible fruit. The pineapple is a native of South America, where it has been grown for a very long time. It yields edible fruit that is fleshy and varies in color from almost white to yellow. A study by Mohsenpour *et al.*[36] on the efficiency of pineapple leaves as a plant-based coagulant on pond water revealed a considerable reduction in COD and turbidity percentage, which varied between 94.1 and 94.6 and 88.3 and 88.4% correspondingly at pH 8 (50 mg/L).

3.10 Solanum lycopersicum

The tomato plant's fruit, which is edible, originally came from Western South America, Mexico, and Central America. The experiment on coagulation and flocculation revealed that the coagulation process is influenced by the concentration of Fe (II) and that the disinfectant properties rely on bioactive natural compounds from the plant. The study showed turbidity reductions of 96%, 97%, and 75% for raw water with initial turbidity levels of 450, 300, and 105 NTU, respectively[37].

3.11 Ocimum tenuiflorum

A perennial plant in the Lamiaceae family called Tulasi has a pleasant aroma. It is widely planted in Southeast Asia's tropical regions and is indigenous to the Indian subcontinent. As an herbal coagulant for the treatment

Table 1. List of major plant-based coagulants that are used extensively in treatment of grey water

Sl. No.	Scientific name	Common name	Family	Plant part	References
1	*Carica papaya*	Papaya	Caricaceae	Seeds	39
2	*Phaseolus vulgaris*	Common bean	Fabaceae	Seeds	40
3	*Manihot esculenta*	Cassava	Euphorbiaceae	Roots	41
4	*Pisum sativum*	Pea	Fabaceae	Seeds	42
5	*Tamarindus indica*	Indian tamarind	Fabaceae	Seeds	43
6	*Cassia alata*	Candle bush	Fabaceae	Leaves	44
7	*Lallemantia royleana*	Mint	Lamiaceae	Mucilage	45
8	*Mangifera indica*	Mango	Anacardiaceae	Seeds	46
9	*Glycine max*	Soybean	Fabaceae	Seeds	47
10	*Cactus latifaria*	Cacti	Cactaceae	Mucilage	48
11	*Dillenia indica*	Elephant apple	Dilleniaceae	Seeds	49
12	*Ipomoea batatas*	Sweet potato	Caricaceae	Mucilage	50
13	*Lablab purpureus*	Hyacinth bean	Fabaceae	Seeds	51
14	*Pennisetum glaucum*	Millet	Poaceae	Seeds	52
15	*Zea mays*	Red maize	Poaceae	Grains	53
16	*Cuminum cyminum*	Cumin	Apiaceae	Seeds	54

of wastewater, holy basil leaf powder is used. The pH, turbidity, and chemical oxygen demand are all decreased. At 150 mg/100 ml, the reduction efficiencies of pH, turbidity, and COD are 69.82%, 43.11%, and 47.85%, respectively[38].

4.0 Advantages and Drawbacks of Herbal Coagulants

Herbal coagulants present distinct advantages over chemical coagulants, primarily in terms of safety and environmental impact. One key factor is the potential residue left behind by chemical coagulants, such as alum (aluminum sulfate), in treated water. This residue can pose health risks, including a potential link to neurodegenerative conditions like Alzheimer's disease, if consumed over time. In contrast, herbal coagulants, derived from natural plant sources, are generally considered safer due to their biodegradable nature and lower risk of harmful residues. These qualities make herbal coagulants a promising choice for viable and safe water treatment. Further research and optimization are necessary to fully realize their potential in large-scale applications[63]. The use of herbal coagulants offers several advantages over chemical coagulants, particularly in terms of safety and cost-effectiveness. Unlike chemical coagulants such as alum, which can leave potentially harmful residues in treated water, herbal coagulants do not pose such risks. Additionally, herbal coagulants are often more affordable than chemical alternatives, especially in the context of treating highly turbid water, where chemical coagulants require coagulant aids, thereby increasing costs. This economic benefit is particularly significant in developing countries, where resources may be limited. Herbal coagulants can be sourced from various plant wastes, further reducing treatment costs[64].

However, the practical application of herbal coagulants depends on the availability of abundant and locally accessible resources. A notable drawback of using herbal coagulants is the potential increase in organic matter in the water, which can lead to heightened microbial activity. Consequently, additional chlorine may be required to disinfect the treated water. Despite these challenges, the advantages of herbal coagulants, such as lower costs and safer residues, make them a promising option for sustainable water treatment solutions[65]. Some coagulants possess antibacterial properties that can help treat water contaminated with *E. coli*; however, their efficacy in completely removing the bacteria is not absolute, potentially leading to secondary bacterial growth. Herbal coagulants, such as *Moringa oleifera*, typically require longer sedimentation periods compared to chemical coagulants. This extended sedimentation time can be a limitation in the treatment process, impacting the overall efficiency and speed of water purification. Despite these challenges, the use of herbal coagulants remains a valuable area of exploration, particularly for their sustainable and eco-friendly benefits in water treatment[66]. Design of a unit of water treatment plant is in accordance with the process that occur in it, which includes inflow, retention

Table 2. List of chemical coagulants used in industries for grey water treatment

Sl. No.	Coagulant	Industry	Removal efficiency	References
1	$(Al_2(SO_4)_3+FeSO_4)$ and Aluminium salt $Al_2(SO_4)$	Sugar	COD - 75%	55
2	Poly-Aluminum-Silicate-Chloride	Pulp and paper	Turbidity and COD - 93.13% and 91.12%	56
3	PAC	Textile	COD, TDS and Turbidity - 90.17%, 74.09% and 93.47%	57
4	Alum and Iron salts	Distillery waste water	COD and Colour - 82.5% and 67.6%	58
5	Ferric Chloride	Molasses waste water	COD and Colour - 86% and 96%	59
6	Polyferric chlorides (PFCs)	Dye waste water	COD - 55%	60
7	Alum and Ferric chloride	Municipal waste water	COD and Phosphorus - 50% and 90%	61
8	Aluminium sulfate and Turmeric extract	Aqueous solution	Boron - 95%	62

time, etc. When a chemical coagulant is replaced by an herbal coagulant, in most cases the water treatment plant didn't perform well.

5.0 Conclusions

The water and wastewater industries have adopted coagulants derived from a variety of natural sources, and they are frequently utilized as primary coagulants. The advantages of herbal coagulants over chemical coagulants are their affordability, benevolence to the environment, and lack of human health risks. The use of coagulants made from plants, animals, and microorganisms has long been studied and has gained acceptance in underdeveloped nations. This review provides a thorough summary of the effectiveness of various plant-based coagulants, including Roselle, Drumstick (*Moringa oleifera*), Papaya, Common Bean, Cassava, Pea, Indian Tamarind, Candle Bush, Mint, Mango, Soybean, Cacti, Okra, Elephant Apple, Sweet Potato, Hyacinth Bean, Millet, Red Maize, and Cumin in the grey water treatment. The findings suggest that these plant-derived coagulants exhibit promising efficacy in removing pathogens, reducing color and eliminating organic particles and turbidity. This highlights the potential of natural sustainable solutions in the field of water purification. Researchers found that *Cicer arietinum* reduced turbidity the most out of all the herbal coagulants they had previously studied. For extremely turbid water, it reduced up to 95.89%, which is virtually as much as the alum's potential to reduce. This makes it the most effective. To create inherent technologies, it is concluded that more study is needed to examine herbal coagulants for water treatment. Additionally, improving the coagulation process and comprehending the characteristics of coagulants would provide a foundation for future research, allowing for a reduction in exploration efforts and an increase in research on closely related, focused aspects of coagulants. The commercialization of coagulants would be strengthened as a result of these initiatives.

6.0 References

1. Mittal R. Impact of population explosion on environment. WeSchool Knowledge Builder. 2013; 1(1).
2. Mishra S, Singh S, Srivastava R. Okra seeds: An efficient coagulant. Int J Res Appl Sci Eng. 2017; 5.
3. Sekhar C, Venkatesan N, Murugananthi D, Vidhyavathi A. Status of value addition and export of moringa produce in Tamil Nadu - A case study. Int J Hortic. 2018; 8. https://doi.org/10.5376/ijh.2018.08.0003
4. Kadhum MS, Abdulbari HA, Abbas AA. Treatment of pulp and paper mill wastewater by Poly- Aluminum-Silicate-Chloride (Pasic) through coagulation-flocculation process. Al-Qadisiya J Eng Sci. 2011; 4(4):546-55.
5. Lattemann, S, Höpner, T. Environmental impact and impact assessment of seawater desalination. Desalination. 2008; 220(13):1-15. https://doi.org/10.1016/j.desal.2007.03.009
6. Oteng-Peprah M, Acheampong MA, DeVries, NK. Greywater characteristics, treatment systems, reuse strategies and user perception-a review. Water Air Soil Poll. 2018; 229(8):255. https://doi.org/10.1007/s11270-018-3909-8
7. Peprah OM, Acheampong MA, DeVries NK. Greywater characteristics, treatment systems, reuse strategies and user perception - A review. Water Air Soil Pollut. 2018; 229(8):1-16. https://doi.org/10.1007/s11270-018-3909-8
8. Pidou M, Memon FA, Stephenson T, Jefferson B, Jeffrey P. Greywater recycling: treatment options and applications. Proc Inst Civ Eng Struct Build. 2007; 160(3):119-131. https://doi.org/10.1680/ensu.2007.160.3.119
9. Sapana MM, Sonal GC, Raut PD. Use of *Moringa oleifera* (drumstick) seed as natural absorbent and an antimicrobial agent for ground water treatment. Res J Recent Sci. 2012; (1):31-40.
10. Gunaratna KR, Garcia B, Andersson S, Dalhammar G. Screening and evaluation of natural coagulants for water treatment. Water Sci Technol: Water Supply. 2007; 7(5):19-25. https://doi.org/10.2166/ws.2007.147
11. Bashir I, Lone FA, Bhat RA, Mir SA, Dar ZA, Dar SA. Concerns and threats of contamination on aquatic ecosystems. Bioremediation and Biotechnology: Sustainable Approaches to Pollution Degradation; 2020. https://doi.org/10.1007/978-3-030-35691-0_1
12. Abedin MA, Collins AE, Habiba U, Shaw R. Climate change, water scarcity, and health adaptation in southwestern coastal Bangladesh. Int J Disaster Risk Sci. 2019; 4(10):28-42. https://doi.org/10.1007/s13753-018-0211-8
13. Mbogo SA. A novel technology to improve drinking water quality using natural treatment methods in rural Tanzania. J Environ Health. 2008; 70(7):46-50.
14. Rak AE, Ismail AAM. Cassia alata as a potential coagulant in water treatment. Res J Recent Sci. 2012; 1(2):28-33.
15. Rak, A. E, Ismail, A. A. M. Cassia alata as a potential coagulant in water treatment. Research journal of recent sciences. 2012; 1(2):28-33.
16. Ramamurthy C, Maheswari MU, Selvaganabathy N, Muthuvel SK, Sujatha V, Thirunavukkarasu C. Evaluation of eco-friendly coagulant from Trigonella foenum-graecum seed. Adv Biol Chem. 2012; 2(1):58-63. https://doi.org/10.4236/abc.2012.21007
17. Dhruva R, Suresh B. An investigation of effect of natural coagulant (Tulsi) for reduction of pH, turbidity and COD

from sewage water. Int Res J Eng Technol. 2016; 3(07):69-72.
18. Sáenz C, Sepúlveda E, Matsuhiro B. Opuntia spp mucilage's: A functional component with industrial perspectives. J Arid Environ. 2004; 57(3):275-290. https://doi.org/10.1016/S0140-1963(03)00106-X
19. Sasakova N, Gregova G, Takacova D, Mojzisova J, Papajova I, Venglovsky J, *et al*. Pollution of surface and ground water by sources related to agricultural activities. Front Sustain Food Syst. 2018; 2. https://doi.org/10.3389/fsufs.2018.00042
20. Desta WM, Bote ME. Wastewater treatment using a natural coagulant (*Moringa oleifera* seeds): optimization through response surface methodology. Heliyon. 2021; 7(11):08451. https://doi.org/10.1016/j.heliyon.2021.e08451
21. Karnena MK, Saritha V. Contemplations and investigations on green coagulants in treatment of surface water: A critical review. Appl Water Sci. 2022; 12(7):150. https://doi.org/10.1007/s13201-022-01670-y
22. Yani NFA, Ismail N, Oh KS. Potential of using *Hibiscus Sabdariffa* in treating greywater. AIP Conf Proc. 2019; 2137(1). https://doi.org/10.1063/1.5120993
23. Shilpa B, Akankshaa K, Girish P. Evaluation of cactus and hyacinth bean peels as natural coagulants. Int J Chem Eng Res. 2012; 3(3).
24. Shabeeb KM, Abdulbari HA, Abbas AA. Treatment of pulp and paper mill wastewater by poly-aluminum-silicate-chloride (Pasic) through coagulation- flocculation process. Al-Qadisiyah J Eng Sci. 2011; 4(4).
25. Nautiyal R, Uliana S, Raj I, Shah B, Rathore K, Singh A. Decentralized treatment of grey water by herbal coagulants in the presence of coagulation aid. Proceedings of the 2nd World Congress on Civil, Structural, and Environmental Engineering (CSEE'17), Barcelona, Spain, 2017. https://doi.org/10.11159/awspt17.158
26. Bodlund I, Pavankumar AR, Chelliah R, Kasi S, Sankaran K, Rajarao GK. Coagulant proteins identified in Mustard: A potential water treatment agent. Int J Environ Sci Technol. 2014; 11: 873-80. https://doi.org/10.1007/s13762-013-0282-4
27. Tassoula E, Diamadopoulos E, Vlachos C. Tertiary physico-chemical treatment of secondary effluent from the Chania municipal wastewater treatment plant. Global NEST J. 2007; 9(2): 166-73. https://doi.org/10.30955/gnj.000408
28. Antov MG, Šćiban MB, Adamović SR, Klašnja MT. Investigation of isolation conditions and ion-exchange purification of protein coagulation components from common bean seed. Acta Period Technol. 2007; 38:3-10. https://doi.org/10.2298/APT0738003A
29. Awad M, Wang H, Li F. Weaknesses of *Moringa oleifera* use in water treatment. Int J Curr Res. 2013; 5(5):1165-7.
30. Wifek M, Saeed A, Rehman R, Nisar S. Lemongrass: A review on its botany, properties, applications and active components. Int J Chem Biochem Sci. 2016; 9(1):79-84.
31. Fahmi MR, Hamidin N, Abidin CZA, Md Ali UF, Hatim MI. Performance evaluation of okra (*Abelmoschus esculentus*) as coagulant for turbidity removal in water treatment. Key Eng Mater. 2014; 594:226-30. https://doi.org/10.4028/www.scientific.net/KEM.594-595.226
32. Aziz A, Agamuthu P, Hassan A, Auta HS, Fauziah SH. Green coagulant from *Dillenia indica* for removal of bis (2-ethylhexyl) phthalate and phenol, 4, 4'-(1-methylethylidene) bis-from landfill leachate. Environ Technol Innov. 2021; 24:102061. https://doi.org/10.1016/j.eti.2021.102061
33. Raji YO, Abubakar L, Giwa SO, Giwa A. Assessment of coagulation efficiency of okra SeedExtract for surface water treatment. Int J Eng Res. 2016; 6(2):1-7.
34. Boretti A, Rosa L. Reassessing the projections of the world water development report. NPJ Clean Water. 2019; 2(1):15. https://doi.org/10.1038/s41545-019-0039-9
35. Choy SY, Prasad KMN, Wu TY, Raghunandan ME, Ramanan RN. Utilization of plant-based natural coagulants as future alternatives towards sustainable water clarification. J Environ Sci. 2014; 26(11):2178-89. https://doi.org/10.1016/j.jes.2014.09.024
36. Mohsenpour SF, Hennige S, Willoughby N, Adeloye A, Gutierrez T. Integrating micro-algae into wastewater treatment: A review. Sci Total Environ. 2021; (752):142-68. https://doi.org/10.1016/j.scitotenv.2020.142168
37. Rak AE, Ismail AAM. Cassia alata as a potential coagulant in water treatment. Res J Recent Sci. 2012; 1(2):28-33.
38. Dhruva R, Suresh B. An investigation of effect of natural coagulant (Tulsi) for reduction of pH, turbidity and COD from sewage water. Int J Res Eng Technol. 2016; 3(07):69-72.
39. Edokpayi JN, Odiyo JO, Durowoju OS. Impact of wastewater on surface water quality in developing countries: A case study of South Africa. Water Quality. 2017; 10(66561):10-5772. https://doi.org/10.5772/66561
40. Fard MB, Hamidi D, Yetilmezsoy K, Alavi J, Hosseinpour F. Utilization of *Alyssum mucilage* as a natural coagulant in oily-saline wastewater treatment. J Water Process Eng. 2021; 40:101-763. https://doi.org/10.1016/j.jwpe.2020.101763
41. Gautam S, Saini G. Use of natural coagulants for industrial wastewater treatment. Glob J Environ Sci Manag. 2020; 6(4):553-78.
42. Ghebremichael K. Overcoming the drawbacks of natural coagulants for drinking water treatment. Water Sci Technol: Water Supply. 2007; 7(4):87-93. https://doi.org/10.2166/ws.2007.144
43. Oteng-Peprah M, Acheampong MA, DeVries NK. Greywater characteristics, treatment systems, reuse strategies and user perception - A review. Water Air Soil Poll. 2018; 229(8):225. https://doi.org/10.1007/s11270-018-3909-8
44. Pidou M, Memon FA, Stephenson T, Jefferson B, Jeffrey P. Greywater recycling: Treatment options and

applications. Proceedings of the Institution of Civil Engineers-Engineering Sustainability. 2007; 160(3):119-31. https://doi.org/10.1680/ensu.2007.160.3.119
45. Nkurunziza T, Nduwayezu JB, Banadda EN, Nhapi I. The effect of turbidity levels and *Moringa oleifera* concentration on the effectiveness of coagulation in water treatment. Water Sci Tech. 2009; 59(8):1551-8. https://doi.org/10.2166/wst.2009.155
46. Gunaratna KR, Garcia B, Andersson S, Dalhammar G. Screening and evaluation of natural coagulants for water treatment. Water Sci Technol: Water Supply. 2007; 7(5):19-25. https://doi.org/10.2166/ws.2007.147
47. Halim AA, Thaldiri NH, Awang N, Latif MT. Removing boron from an aqueous solution using turmeric extract-aided coagulation-flocculation. Am J Environ Sci. 2012; 8(3):322-7. https://doi.org/10.3844/ajessp.2012.322.327
48. Husen R, Idris J, Wakimin ND, Mijim J, Eva L, Diman JL, *et al*. High cod and turbidity removal in the treatment of polluted pond water using low dosage of pineapple leaf coagulant: A preliminary study. Asian J Sci Res. 2021; 11(4):42-9. https://doi.org/10.18488/journal.2.2021.114.42.49
49. Hussain G, Haydar S. Exploring potential of pearl millet (*Pennisetum glaucum*) and black-eyed pea (*Vigna unguiculata subsp. unguiculata*) as bio-coagulants for water treatment. Desalin Water Treat. 2019; 143:184-91. https://doi.org/10.5004/dwt.2019.23255
50. Hutchinson E. Moringa vs. Acai: The consequences of global demand; 2014. https://blog.kulikulifoods.com/2014/09/02/moringa-vs-acai/
51. Inanc B, Ciner F, Ozturk I. Colour removal from fermentation industry effluents. Water Sci Technol. 1999; 40(1):331-8. https://doi.org/10.2166/wst.1999.0064
52. Iwuozor KO. Prospects and challenges of using coagulation-flocculation method in the treatment of effluents. Adv J Chem A. 2019; 2(2):105-27. https://doi.org/10.29088/SAMI/AJCA.2019.2.105127
53. Jiang JQ. The role of coagulation in water treatment. Curr Opin Chem Eng. 2015; (8):36-44. https://doi.org/10.1016/j.coche.2015.01.008
54. Juan YK, Chen Y, Lin JM. Greywater reuse system design and economic analysis for residential buildings in Taiwan. Water. 2016; 8(11):546. https://doi.org/10.3390/w8110546
55. Kaur H, Yadav S, Ahuja M, Dilbaghi N. Synthesis, characterization and evaluation of thiolated tamarind seed polysaccharide as a mucoadhesive polymer. Carbohydr Polym. 2012; 90(4):1543-49. https://doi.org/10.1016/j.carbpol.2012.07.028
56. Khan M, Kalsoom U, Mahmood T, Riaz M, Khan AR. Characterization and treatment of industrial effluent from sugar industry. Journal-chemical society of Pakistan, 2003; 25(3): 242-247.
57. Kusuma HS, Amenaghawon AN, Darmokoesoemo H, Neolaka YA, Widyaningrum BA, Anyalewechi CL, Orukpe PI. Evaluation of extract of Ipomoea batatas leaves as a green coagulant-flocculant for turbid water treatment: Parametric modelling and optimization using response surface methodology and artificial neural networks. Environ Technol Innov. 2021; (24):102005. https://doi.org/10.1016/j.eti.2021.102005
58. Liang Z, Wang Y, Zhou Y, Liu H. Coagulation removal of melanoidins from biologically treated molasses wastewater using ferric chloride. Chemical Engineering Journal. 2009; 152(1): 88-94. https://doi.org/10.1016/j.cej.2009.03.036
59. Sapana MM, Sonal GC, Raut PD. Use of *Moringa oleifera* (drumstick) seed as natural absorbent and an antimicrobial agent for ground water treatment. Res J Recent Sci. 2012; (1):31-40.
60. Manna S. Treatment of gray water for reusing in non-potable purpose to conserve water in India. Int J Appl Environ Sci. 2018; 13(8):703-16.
61. Priyankashri KN, Surendra HJ. Low cost bench scale community level water treatment system and adsorption method for removal of nitrate from groundwater. Sustain Water Resour Manag. 2020; 6(6):103. https://doi.org/10.1007/s40899-020-00465-w
62. Qureshi K, Bhatti I, Shaikh MS. Development of bio-coagulant from mango pit for the purification of turbid water. Sind Univ Res J (Sci Ser). 2011; 43(1).
63. Sabur MA, Khan AA, Safiullah S. Treatment of textile wastewater by coagulation precipitation method. J Sci Res. 2012; 4(3):623-33. https://doi.org/10.3329/jsr.v4i3.10777
64. Saritha V, Srinivas N, Vuppala NVS. Analysis and optimization of coagulation and flocculation process. Appl Water Sci. 2017; 7:451-60. https://doi.org/10.1007/s13201-014-0262-y
65. Sun Y, Zhou S, Chiang PC, Shah KJ. Evaluation and optimization of enhanced coagulation process: Water and energy nexus. Water-Energy Nexus. 2019; 2(1): 25-36. https://doi.org/10.1016/j.wen.2020.01.001
66. Tian Y, Deng F. Phytochemistry and biological activity of mustard (*Brassica juncea*): A review. Cyta-Journal of Food. 2020; 18(1):704-18. https://doi.org/10.1080/19476337.2020.1833988
67. Unnisa A, Abouzied AS, Baratam A, Lakshmi KC, Hussain T, Kunduru RD, *et al*. Design, synthesis, characterization, computational study and in-vitro antioxidant and anti-inflammatory activities of few novel 6-aryl substituted pyrimidine azo dyes. Arab J Chem. 2020; 13(12):8638-49. https://doi.org/10.1016/j.arabjc.2020.09.050
68. Vara S. Screening and evaluation of innate coagulants for water treatment: A sustainable approach. Int J Energy

Environ Eng. 2012; (3):1-11. https://doi.org/10.1186/2251-6832-3-29

69. Yu-li Y, Yue-zhong W, Xiao-ying Li, Si-zhen L. Treatment of wastewater from dye manufacturing industry by coagulation. J Zhejiang Univ Sci A. 2006; 7:340-4. https://doi.org/10.1631/jzus.2006.AS0340

70. Zaman NK, Rohani R, Yusoff II, Kamsol MA, Basiron SA, Rashid AIA. Eco-friendly coagulant versus industrially used coagulants: Identification of their coagulation performance, mechanism and optimization in water treatment process. Int J Environ Res Public Health. 2021; 18(17). https://doi.org/10.3390/ijerph18179164