Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

REVIEW PAPER

Effectiveness of natural coagulants in water and wastewater treatment

S. Nimesha[1], C. Hewawasam[1,*], D.J. Jayasanka[1], Y. Murakami[2], N. Araki[3], N. Maharjan[2]

[1]University of Sri Jayewardenepura, Gangodawila, Nugegoda, Sri Lanka

[2]Nagaoka National Institute of Technology, Nishikatakai, Nagaoka, Niigata, Japan

[3]Ichinoseki National Institute of Technology, Takanashi, Hagisho, Ichinoseki, Iwate, Japan

ARTICLE INFO

Article History:
Received 21 March 2021
Revised 28 May 2021
Accepted 06 July 2021

Keywords:
Coagulants
Efficiency
Mechanism
Plant-based coagulants

ABSTRACT

Natural waterways are contaminated due to industrialization, urbanization, population growth etc., degrading their quality. Contaminated waterways cause numerous health and environmental hazards. Therefore, it is imperative to remove contaminants. Coagulation is one of the efficient primary chemical treatment methods that could be used to treat such contaminants. Natural coagulants have gained popularity in the water and wastewater treatment industry due to their advantage over chemical coagulants. Natural coagulants are derived from either plants, animals, or microorganisms. This study has elaborated on the nature and mechanisms, and types of natural coagulants. In this review work, many studies have proposed several types of natural coagulants. However, plant-based natural coagulants extracted from different plant components have been extensively discussed and compared based on their application and efficiency in water and waste treatment. The primary purpose of this review is to refine the knowledge on the potential use and optimization of the effectiveness of eco-friendly and sustainable natural coagulants. Besides, the development efforts and the barriers reported by recent findings for the commercialization of natural coagulants are also discussed. Further, few modified natural coagulants have also been presented for exploring the other possible approaches to promote their usage in water and wastewater treatment in the future studies..

DOI: 10.22034/gjesm.2022.01.08

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
122	1	6

*Corresponding Author:
Email: *choolaka@sjp.ac.lk*
Phone: +947 771 84294
ORCID: 0000-0001-7367-2834

Note: Discussion period for this manuscript open until April 1, 2022 on GJESM website at the “Show Article.

INTRODUCTION

Water is the fundamental requirement for all human activities and biological activities. It is the main component in the hydrological cycle. The water resources are continuously decreasing around the world due to various environmental degradation activities, climate change (Konapala *et al*., 2020), population growth (Zubaidi *et al.*, 2020), and increasing standards of living and urbanization (Wu *et al*., 2013). Rapid population growth and haphazard waste disposal have resulted in the impending water crisis. In order to sustain the water requirements, various processes and technologies are being researched to improve the quality of water (Ullah *et al*., 2020). These technologies fall into three main categories, namely physical, chemical, and biological treatment methods. Physical methods include settling, media, and membrane filtration (Obotey Ezugbe and Rathilal, 2020), adsorption (Ali and Gupta, 2006), and UV processes (O'Malley *et al*., 2020). Coagulation (Alibeigi-Beni *et al*., 2021), disinfection (Collivignarelli *et al*., 2017), ion exchange (Ergunova *et al*., 2017), catalytic reduction (Guo *et al*., 2020; Sivakumar, 2015), oxidation (Gogate and Pandit, 2004), and softening processes (Brastad and He, 2013) are some of the chemical methods used in the wastewater treatment. Biological methods include microbial biodegradation (Huang *et al*., 2018), phytoremediation (Hu *et al*., 2020), bioreactor processes (Neoh *et al*., 2016), constructed wetlands (Wu *et al*., 2015) etc. Moreover, some processes are combined with others to improve efficiency (Ang and Mohammad, 2020). One of the most widely used processes in water and wastewater's primary treatment is coagulation for removing suspended particulate matter and colloids in wastewater (Staicu *et al*., 2015). Coagulation is considered one of the simple methods to remove suspended solids and impurities in water efficiently. Successful coagulation can be attained by using either chemical-based (inorganic and synthetic organic) coagulants or natural coagulants (de Paula *et al*., 2018). Natural coagulants have been recognized for their traditional local water purification (Choy *et al*., 2014; Dorea, 2006). Naturally occurring coagulants are sustainable, environmentally friendly, and less toxic than chemical coagulants (Teh *et al*., 2014). Natural coagulants have grasped the scientific community's attention in the past decades due to their significant health and environmental benefits, and it solves most of the common problems associated with chemical coagulants. Natural coagulants are produced or extracted from different sources such as microorganisms, animals, or plants (non-plant-based and plant-based). Now, several effective coagulants which have plant origin are being identified. Some of the common ones include *Hibiscus sabdariffa* (Roselle seeds) (Mohd-Esa *et al*., 2010), *Dolichos lablab* (Hyacinth bean) (Daverey *et al*., 2019), *Moringa oliefera* (Nonfodji *et al*., 2020), Nirmali seeds (Prabhakaran *et al*., 2020) watermelon seeds (Bhattacharjee *et al*., 2020) and cactus species (Rebah and Siddeeg, 2017). The drawbacks of chemical coagulants have resulted in the search for eco-friendly and sustainable natural coagulants in their usage and production. The main advantages of natural coagulants are renewability, biodegradability, nontoxicity, and cost-effectiveness. These studies have already proved the effectiveness of natural coagulants in wastewater treatment applications (Choy *et al*., 2014; Yin, 2010). However, the industrial usage of natural coagulants in wastewater treatment applications is limited. This is mainly due to the processing cost and the performance consistency of the extracted compounds from natural sources. Due to this, researchers tend to focus on modifying natural coagulants to get the maximum benefits (Muruganandam *et al*., 2017; Ahmed *et al*., 2016). This study aims to identify potential research gaps to refine the knowledge on natural coagulants and summarize the optimization methods for coagulants for improving their efficiency in water and wastewater treatment. This study also showcases the application of these coagulants for large-scale commercial usages and may assist in future studies. These will be discussed in sections as follows: the need for natural coagulants, mechanisms of natural coagulants, types of natural coagulants, barriers in the commercialization of natural coagulants, and examples of modified or blended natural coagulants. This study has been carried out in Colombo, Sri Lanka, in 2021.

Need for natural coagulants

Chemical coagulant used has raised controversial issues due to its toxic nature for living organisms and can be categorized into three types: hydrolyzing metallic salts, pre-hydrolyzing metallic salts, and synthetic cationic polymers (Freitas *et al*., 2018; Verma *et al*., 2012). Due to the low cost, easy handling, storage, and high availability, chemical coagulants are more prevalent in wastewater treatment processes.

$Al_2(SO_4)_3$, $Fe_2(SO_4)_3$, $AlCl_3$ and $FeCl_3$ are the most commonly used coagulant salts (Freitas *et al*., 2018; Matilainen *et al*., 2010; Sher *et al*., 2013). Despite the availability, low cost etc.; chemical coagulants are far behind in green chemistry due to high residual concentrations of aluminum found in treated wastewater (Freitas *et al*., 2018; Matilainen *et al*., 2010). According to Freitas *et al*., 2018; McLachlan 1995; Polizzi *et al*. 2002, Alzheimer's disease is linked with the neurotoxicity of aluminum. Synthetic polymer coagulants form hazardous secondary products such as acrylamide which is carcinogenic and neurotoxic, and also synthetic polymers have low biodegradability (Freitas *et al*., 2018; Kurniawan *et al*., 2020). Excessive concentrations of chemical coagulants such as aluminum reduce the pH of water tends and also, they can be accumulated to food chains (Kurniawan *et al*., 2020). Improper disposal of toxic sludge pollutes the groundwater and soil. Accumulation of toxic sludge, such as aluminum, iron etc., in natural water bodies causes adverse effects on aquatic organisms and plant species (Kurniawan *et al*., 2020). Hence there is a need for the efficient utilization of natural coagulants for water and wastewater treatment.

Mechanism of coagulation by natural coagulants

Coagulation occurs between the coagulant added, the impurities, and the alkalinity of the water, resulting in the formation of insoluble flocs. Flocs are the agglomerations of particulate suspended matter in the raw water, reaction products of the added chemicals, colloidal and dissolved matter from the water adsorbed by these reaction products. Unprocessed water from the reservoir contains organic and inorganic impurities, such as silt, rotten substance, alga, bacterium, etc. Hence coagulation is the essential step in water purification. In addition, coagulants make suspensions in water to gather and reduce the turbidity of water (Z. Song *et al*., 2009). The successful coagulation of natural coagulants (Ang *et al*., 2020) stands on these three pillars: characteristics of coagulant used, characteristics of water to be treated, characteristics of mixing process (Ang *et al*., 2020; Kumar *et al*., 2017). As Fig. 1 shows, these coagulation factors play a significant role in determining the most efficient coagulant required for the treatment. Coagulants' molecular weight (Ang *et al*., 2020; Gautam and Saini, 2020), types of equipment and reagents used, chemical and physical properties of the pollutants such as zeta potential (Ang *et al*., 2020), color, the concentration of the colloidal particles, the presence or absence of impurities (trace elements and dissolved salts (ions and chemicals) also affect the coagulation process (Ang *et al*., 2020; Kumar *et al*., 2017; Muruganandam *et al*., 2017). If the natural coagulant contain positive surface charge, its coagulation activity against negatively charged suspended particles will be higher and vice versa for negatively charged natural coagulants with positively charged suspended particles. Functional groups also contribute to surface charge (Ang *et al*., 2020). Molecular weight of natural coagulant is very important in particle bridging. If the molecular weight of natural coagulant is higher, it can form strong bridges with the particles and it leads to the formation of strong flocs and improve settling (Ang *et al*., 2020). Mixing is another critical step in the coagulation process. Fast mixing increases the interactions between coagulants and suspended particles and forms micro flocs. Slow mixing leads to the aggregation of micro flocs into large flocs (Kurniawan *et al*., 2020). Coagulation also affects the other steps of the treatment process. An efficient and effective coagulation process favors the microbiological quality (Kumar *et al*., 2017) of the end product and increases the lifetime of filters (Kumar et al., 2017), reducing the total cost of treated water.

Natural coagulants are composed of carbohydrates, protein, and lipids. The primary building blocks are the polymer of polysaccharides and amino acids. According to the previous research, the main mechanisms governing coagulation activity are charge neutralization and polymer bridging.

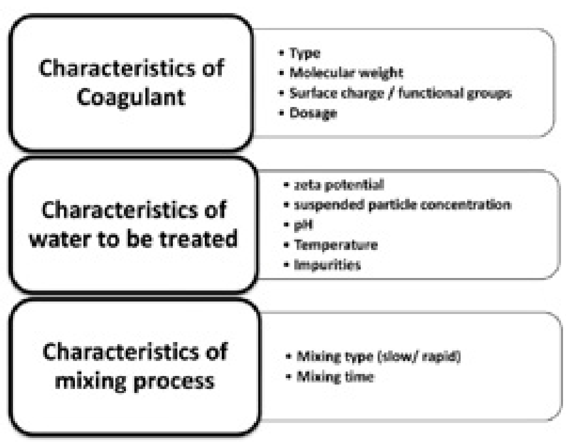

Fig. 1: Factors affecting coagulation
(Ang *et al*., 2020; Gautam and Saini, 2020; Kumar *et al*., 2017)

Polymer bridging is preceded by polymer adsorption. Because of the affinity between long-chain polymers and colloidal particles, long-chained polymers can attach to the colloidal particle's surface. A part of the polymer is attached to the particle while the other parts form loops and tails. These loops and tails are the main structure of polymer bridging loops, and tails allow attaching to other colloidal particles and form larger flocs. The basis of charge neutralization is known as the electrostatic patch mechanism. The patches of positive and negative regions on the particle's surface cause the additional attraction between particles. Ionizable polymer (polyelectrolytes) is used as a coagulant in the charge neutralization mechanism. It stabilizes the negatively charged colloidal particles. Polycation is used to stabilize the particles, gaining near to zero zeta potential. The optimum dosage of polyelectrolyte needed will be determined by the charge density of the polyelectrolyte (Amran *et al.*, 2018; Yin, 2010). Natural coagulants have varied mechanisms of action. Let us consider some of the coagulation mechanisms of natural coagulants.

As shown in Table 1 Chitin is a cellulose-like biopolymer. It is found in fungi, marine invertebrates, yeasts, and insects. Chitosan is formed by the deacetylation of chitin (Hassan *et al.*, 2009; Saranya *et al.*, 2014). It is efficient in cold waters at low concentrations, producing less sludge and sludge degraded by microorganisms. Both charge neutralization (has positively charged amino group) and bridging are the two coagulation mechanisms identified. Chitosan is a potential substitute for metallic salts and synthetic polyelectrolytes used in wastewater treatment (Nechita, 2017). Chitosan has a high content of amino groups. It provides a cationic charge at acidic pH, supports the destabilization of colloidal suspension, and promotes rapid-settling, large floc. Since Chitosan is a long-chain polymer with positive charges, it can also coagulate negatively charged particulate and colloidal materials via adsorption and hydrophobic flocculation (Roussy *et al.*, 2005; Saranya *et al.*, 2014; Karbassi and Heidari, 2015). Seed extracts of Nirmali (*Strychnos potatorum*) are anionic polyelectrolytes. It can destabilize the particles in water via inter-particle chemical bridges. Nirmali seed extract contains lipids, carbohydrates, and alkaloids. Hydroxyl groups found in the polymer chain provide adsorption sites for forming chemical bridges (Theodoro *et al.*, 2013; Yin, 2010) and –COOH and free –OH surface groups increase the coagulation competency (Yin, 2010). Polysaccharides mixtures of galactanii and galactomannani extracted from *Strychnos potatorum* seeds can reduce turbidity up to 80% (Adinolfi *et al.*, 1994). According to the study carried out by Ndabigengesere *et al.*, 1995, Moringa extracts consist of water-soluble cationic coagulant proteins. Coagulation activity is carried out via the mechanism of charge neutralization and adsorption (Ndabigengesere *et al.*, 1995; Theodoro *et al.*, 2013;

Table 1: Summary of functional groups and mechanism proposed for natural coagulants

Natural coagulant	Source of extraction	Mechanism proposed	Functional groups	Reference
Moringa oleifera	leaves, flowers, seeds, roots, bark	Adsorption and charge neutralization	Starch, cationic protein, fatty acids, phenolic compounds Amines, glucose, alcoholic compounds, and carboxylate groups	Kumar *et al.*, 2017; Kurniawan *et al.*, 2020; Yin, 2010
Nirmali (*Strychnos potatorum*)	seeds	Inter-particle bridging	galactan and galactomannan	Vijayaraghavan *et al.*, 2011
Cactus Musilage	Cactus pads	adsorption and bridging coagulation method	D-xylose, galacturonic acid, l-arabinose, l-rhamnose, and d-galactose.	Vijayaraghavan *et al.*, 2011; Yin, 2010
Chitosan	fungi, marine invertebrates, yeasts	Charge neutralization and bridging	N-acetyl-D-glucosamine (acetylated unit), β-(1-4)-linked D-glucosamine (deacetylated unit)	Saranya *et al.*, 2014
Tannins	Castanea, Acacia, or Schinopsis	Adsorption and charge neutralization	polyphenol compounds	Vijayaraghavan *et al.*, 2011; Yin, 2010

Yin, 2010). Tannins are secondary metabolites of plants, produced from the barks, leaves, fruits, seeds regarded as a potential natural coagulant for water and wastewater treatment (Yin, 2010; Grenda *et al*., 2020). These polyphenol compounds are obtained from Castanea, Acacia, or Schinopsis plants. Tannins contain phenolic groups of anionic nature. These phenolic groups can be deprotonated, and form phenoxide stabilized resonance, allowing coagulation (Özacar and Şengil, 2003; Yin, 2010). The effectiveness of tannin as an eco-friendly coagulant depends on the chemical structure of the extracted tannins and their degree of modification. If more phenolic groups are available in a tannin structure, the coagulation capability will increase (Yin, 2010). The high coagulation ability of the cactus is due to the presence of mucilage. It assumes as sticky and complex carbohydrates. Surface cactus pads have high water retention capability. Cactus mucilage is made up of galacturonic acid, galactose, arabinose, xylose, and irhamnose. It is stored in internal and external parts of the cactus (Sáenz *et al*., 2004; Theodoro *et al*., 2013). According to Miller *et al*., 2008, cactus mucilage coagulation occurs by forming chemical bridges via hydrogen bonds or dipole interactions. Polygalacturonic acid present in mucilage is responsible for forming chemical bridges (Miller *et al*., 2008). Polygalacturonic acid structure consisted of an anionic chain, Chemisorption is involved between the charged particles and –OH and –COOH groups due to their partial de-protonation in aqueous solutions (Theodoro *et al*., 2013; Yin, 2010).

Types of natural coagulants

The natural coagulants have characteristics that are not noxious to an aquatic environment. It includes microbial polysaccharides (Saleem and Bachmann, 2019), bio-wastes (Atchudan *et al*., 2020), alginate, gelatin, cellulose-based materials, and Chitosan (Vigneshwaran *et al*., 2020). Most of the natural coagulants are polysaccharides; hence they are also termed polymeric coagulants. According to the origin, natural coagulants can be divided into three categories, as shown in Table 2.

Animal-based natural coagulants

Chitosan (CS) is a linear copolymer produced by the deacetylation of chitin (Verma *et al*., 2012). Chitosan offers several advantages over traditional compounds. For example, it is widely available (higher after cellulose), sustainable, cost-effective, non-toxic, biodegradable, biocompatible, soluble in weak acids, pH-sensitive (Martău *et al*., 2019; Pontius, 2016), better biosorption, no secondary pollution, sludge can reuse as agricultural fertilizer etc. (Abreu *et al*., 2020; Huang *et al*., 2000). In addition, Chitosan is efficient in reducing chemical oxygen demand, suspended solids, and turbidity (Abdullah and Jaeel, 2019).

Plant-based natural coagulants

The use of natural plant extracts dates back to 2000 BC, where Egyptians have inscribed the evidence of plant materials used for water treatment (Sivaranjani and Rakshit, 2016). According to Fatombi *et al*., 2013, it is clear that nuts such as beans, almonds, and *Strychnos potatorum* were used in Sudan, Egypt, and India, respectively. These nuts are reported to stimulate the coagulation of turbid waters (Fatombi *et al*., 2013). Since the late 1970s, various plant-based polyelectrolytes and polymers have been researched as coagulants. Plant-based coagulants are generally derived from the various parts of the plants and are organic, water-soluble, ionic, and non-ionic polymers in nature (Bodlund *et al*., 2014; Dezfooli *et al*., 2016; Fatombi *et al*., 2013). In the colloid-free aqueous state and the colloidal particle solution consisting of restricted irreversible loop arrangements, they maintain random configurations and help in destabilization by forming micro or macro flocs through charge neutralization (Hameed *et al*., 2016). Some plant-based materials may also behave as flocculant by strengthening the flocs for better settleability (Al-Hamadani *et al*., 2011; Awang and Aziz, 2012). Several works of literature have reported applying plant-based coagulants for water and wastewater treatment (Kansal and Kumari, 2014; Kristianto, 2017; Oladoja *et al*., 2017). Most of the investigated coagulants are from family *Fabacea*, primarily extracted from the leaves (Rak *et al*., 2012)

Table 2: Types of natural coagulants

Plant-based	Animal-based	Microorganism-based
Moringa Oleifera	Chitosan	Xanthan gum
Cactus	Alginate	*Aspergillus sp.*
Nirmali seeds	Chitin	*Enterobacter*
Tannin		*Streptomonas*
Potato starch		
Banana peel		
Common beans		
Tamarind seeds		

and seeds (Jayalakshmi *et al*., 2017). One of the most popular and extensively researched plant-based coagulants is *Moringa oleifera* belonging to the family *Moringaceae* (Baptista *et al.,* 2017; Camacho *et al*., 2017). The other common coagulants are Nirmali seeds, Tannins, Roselle seeds, Hyacinth bean etc, which have been studied for turbidity reduction (Saharudin *et al*., 2014; Fermino *et al*., 2017; Choubey *et al*., 2012). As in Table 3 is shown, they are low cost, non-toxic, locally available, readily implementable, and show great potential. Plant-based coagulants are advantageous because i) They are not dependent on chemicals; ii) they generate smaller amounts of sludge and biodegradable; and (iii) less toxic and not corrosive (Rocha *et al*., 2019).

Many wastewater treatments have substituted chemical coagulants with plant-based coagulants because of their low price, abundant source, multi-purpose, and biodegradability (Othmani *et al*., 2020).

Table 3: Characteristics of natural coagulants

Parameters	Characteristics
Carbon footprint	Environmentally friendly
Toxicity	Less toxic
Heavy Metals	Settling will occur along with the coagulation process
Sludge	Sludge volume/amount reduction, Low sludge handling cost, and treatment cost with good biodegradability

Comparison of natural coagulants efficiency

The list of plant-based coagulants studied as natural coagulants are summarized in Table 4, with brief accounts of their optimal conditions, applications, and efficiencies. Roselle seeds (*Hibiscus sabdariffa)* were high in proteins (28 %) and soluble in water. When in solution, they carry an overall positive charge. These positively charged proteins bind to the turbidity causing negatively charged particles in the solution. According to the research, roselle seeds' highest turbidity removal efficiency is within 77 % - 87 % for synthetic wastewater at pH 10 and 81 % - 93 % at pH 4 (Saharudin and Nithyanandam, 2014). *Moringa oleifera* has been one of the best plant extracts for water purification. It is effective in removing Biological Oxygen Demand (BOD), turbidity, Chemical Oxygen Demand (COD), total coliforms removal, algal removal, Hardness, Total dissolved solids (TDS), and Total suspended solids (TSS) etc. According to the research carried out by (Choubey *et al*., 2012), *Moringa oleifera* removes turbidity from 100 NTU to 5.9 NTU and after dosing, and filtration to 5 NTU and total coliform remove by 96 % in synthetic raw water. Furthermore, in laundry, wastewater turbidity removed by 84 % and COD by 46% (Al-Gheethi *et al*., 2017). In Municipal wastewater, the reduction of turbidity, COD, BOD, hardness, TSS, and TDS are found to be 61 %, 65 %, 55 %, 25 %, 69 %, and 68%, respectively (Kumar Kaushal and Goyal, 2019). Hyacinth bean (*Dolichos lablab*) peels are characterized for usage as a protein source. Hyacinth bean peels have a moderate concentration of protein. Turbidity removal efficiency is 99% with the dosage of 20 mg/L in synthetic water (Bs and Papegowda, 2012). With the 200 mg/500 ml dosage, turbidity removes from 100 NTU (Nephelometric Turbidity Units) to 11.1 NTU and after dosing, filtration to 9.5 NTU, and total coliform removal 89% in synthetic water (Choubey *et al*., 2012). *Cactus* is another efficient natural coagulant. According to various research studies, cactus species prove efficient in removing turbidity, COD, and color. For example, in textile wastewaters, cactus removes turbidity by 92 %, COD by 89 %, and color by 99 % at the dosage of 40 mg/L and pH 7.25 (Bouatay and Mhenni, 2014). *Nirmali seeds* are another crucial natural coagulant used to remove turbidity and total suspended solids (TSS). It removes TSS by 76%, turbidity by 96% in laundry wastewater (Mohan, 2014). *Watermelon (Citrullus lanatus)* is the latest approach in developing an effective natural coagulant. The efficiency of turbidity removal was 88 % for the tannery effluent and 98% for synthetic wastewater. The other physicochemical parameters of tannery wastewater, such as TSS, BOD, and COD, were also reduced significantly. The COD removal efficiency was 50%, and the BOD of the wastewater was reduced by 55%. When employed as a coagulant, the watermelon seeds significantly decrease the synthetic wastewater's TSS, turbidity, BOD, and COD, and the tannery effluent (Sathish *et al*., 2018). Table 4 summarizes the facts on potential applications of plant-based materials that can be used as natural coagulants. This is significant in developing new mixed natural coagulants which deliver maximum efficiency.

Therefore, it can be said that natural coagulants have found their diverse application not only for physical and biological water and wastewater treatment but also as a disinfectant. From a

Table 4: Summary of the removal efficiencies of some natural coagulants for water and wastewater treatment

Natural coagulant	Wastewater source	Optimal Conditions		Performance		References
		Dosage	pH	Parameters	Removal Efficiencies	
		Industrial wastewater				
Hibiscus sabdariffa (Roselle seed extract)	Glove manufacturing wastewater	60 mg/L	10 ≤	Turbidity	87%	Saharudin and Nithyanandam, 2014
Moringa oleifera (Drumstick Tree)	Laundry wastewater	120 mg/L	5.7	COD Turbidity	43% 84%	Al-Gheethi *et al.*, 2017
Opuntia ficus indica (Cactus species)	Textile wastewater	40 mg/L	7.25	Turbidity COD Color	92% 89% 99%	Bouatay and Mhenni, 2014
Citrullus lanatus (Seeds of Water Melon)	Tannery wastewater	2000 mg/L	-	Turbidity BOD COD TSS	87% 55% 50% 69%	Sathish *et al.*, 2018
Strychnos potatorum (Nirmali seeds)	Laundry wastewater	8000 mg/L	-	Turbidity TSS	96% 76%	Mohan, 2014
Ocimum basilicum (Basil)	Textile wastewater	1600 mg/L	8.5	COD Color	62% 69%	Shamsnejati *et al.*, 2015
Corchorus Olitorius L. (Jute mallow)	Agricultural wastewater	3 mg/ L	-	Turbidity TOC (Total organic carbon)	95% 100%	Altaher *et al.*, 2016
Bamboo (*Bambusa vulgaris*)	Electroplating industry wastewater	1500 mg/L	5.5	BOD COD Cl- Sulphate TDS Ni	95 % 88 % 90 % 93 % 97 % 99 %	Sivakumar *et al.*, 2018
Cassia obtusifolia (Sickle pod seed gum)	Raw pulp and paper mill effluent	750 mg/L	5	TSS COD	87% 36%	Subramonian *et al.*, 2014
Pectin of orange peel pith	Surfactant	8000 mg/L	-	Turbidity TSS	90% 82%	Mohan, 2014
Dragon fruit foliage	Concentrated latex effluent	800 mg/L	10	Turbidity COD TSS	99% 95% 89%	Idris *et al.*, 2012
Papaya Seed	Textile wastewater	570 mg/L	2	Color	85%	Kristianto *et al.*, 2018
Chitosan	Olive mill wastewater	400 mg/L	-	TSS Turbidity	81 % 84 %	Rizzo *et al.*, 2008
	Paper and pulp wastewater	1800 mg/L	- - -	BOD COD Turbidity	90% 93 % 95 %	Thirugnanasambandham *et al.*, 2014
	Brewery wastewater	120 mg/L	-	COD	50% 73%	Gautam and Saini, 2020
	Textile wastewater	30 mg/L	- -	Turbidity COD	95% 65%	Hassan *et al.*, 2009
Aspergillus niger	Tannery industry wastewater	4.0 g	3	Cr(VI) TDS TS COD BOD Sulphates	96 % 92 % 98 % 85 % 90 % 94 %	Sivakumar, 2016
		Municipal wastewater				
Moringa oleifera (Drumstick Tree)	sewage, gray water (water from sinks and showers)	-	-	Turbidity COD BOD TSS TDS Hardness	61% 65% 55% 69% 68% 25%	Kumar Kaushal and Goyal, 2019
Citrullus lanatus (Seeds of Water Melon)	Sewage wastewater	72.3 mg/L	5	BOD TSS	92% 93%	Joaquin *et al.*, 2021
Cucumis melo (Cantaloupe seeds)		76.7 mg/L	7	BOD TSS	80% 88%	
Okra seeds (ladies' fingers) coagulant	sewage, gray water (water	-	-	Turbidity BOD	65% 56%	Kumar Kaushal and Goyal, 2019

Continued Table 4: Summary of the removal efficiencies of some natural coagulants for water and wastewater treatment

	from sinks and showers)			COD TDS TSS Hardness	67% 69% 72% 30%	
		Synthetic water				
Moringa oleifera (Drumstick Tree)	Raw water synthetic	100 mg/L	10 ≤	Turbidity Total coliforms	94 % 96%	Choubey *et al.*, 2012
Dolichos lablab (Hyacinth bean)	Turbid water (synthetic)	400 mg/L	-	Turbidity Total coliforms	89 % 89%	Choubey *et al.*, 2012
	River water (Synthetic)	20 mg/L	-	Turbidity	99%	Bs and Papegowda,
Cicer arietinum (Chickpea)	Turbid water (synthetic)	400 mg/L	-	Turbidity Total coliforms	96 % 90%	Choubey *et al.*, 2012
Opuntia ficus indica (Cactus species)	River water (Synthetic)	20 mg/L	-	Turbidity	99%	Bs and Papegowda, 2012
Mango pith	Turbid water (Synthetic)	500 mg/L	13	Turbidity	98%	Qureshi *et al.*, 2011
Trigonella foenum-graecum (Fenugreek seeds)	Turbid water (synthetic)	300 mg/L	8.0	Turbidity	98%	ELsayed *et al.*, 2020
Citrullus lanatus (Seeds of Water Melon)	Turbid water (Synthetic)	2000 mg/L	-	Turbidity	98%	Sathish *et al.*, 2018
Jatropha curcas seed	Turbid water (Synthetic)	120 mg/L	3	Turbidity	96%	Abidin *et al.*, 2011
Lens culinaris (Red lentil)	Turbid water (Synthetic)	26.3 mg/L	4	Turbidity	99%	Chua *et al.*, 2019
Cassia fistula (Golden shower)	Synthetic paint industry wastewater	160 mg/L	8.4	Color Turbidity	96% 98%	Vishali *et al.*, 2020
Alginate	Turbid water synthetic	10 mg/L	-	Turbidity	98%	Devrimci *et al.*, 2012
		Surface water				
Moringa oleifera (Drumstick Tree)	Raw surface water	150 mg/L	7	Algal removal	65%	Ali *et al.*, 2008
	Surface water	150 mg/L	7.5	Turbidity	97%	Pritchard *et al.*, 2010
Cassia alata (Christmas candles)	Raw surface water	1000 mg/L	-	Turbidity	93%	Rak and Ismail, 2012
Opuntia dillenii (Cactus species)	Highly turbid lake water	1000 mg/L	-	Suspended solids Turbidity Color Suspended solids	56% 93% 15% 89%	Nougbodé *et al.*, 2013
Prunus armeniaca (Apricot)	Raw surface water	30 mg/L	7	Algal Removal	55%	Ali *et al.*, 2008
Mangifera indica, (Mango)	Raw surface water	30 mg/L	7	Algal Removal	68%	Ali *et al.*, 2008
Tannin	Surface water	30 mg/L	9	Turbidity	80%	Sánchez-Martín *et al.*, 2010
Banana pith	Polluted river water	100 mg/L	4	Turbidity COD Suspended Solids Sulphates Nitrates Cu Cr Fe Zn Pb Mn	99% 54% 96% 99% 89% 100% 100% 92% 81% 100% 60%	Kakoi *et al.*, 2016; Karbassi and Pazoki, 2015

disinfection point of view, comparing the chemical and natural coagulants is interesting, considering their different parameters during usage. The natural coagulants are biodegradable and have no toxic effect on the receiving water bodies, which is a significant issue for chemically disinfected waters. Moreover, compared to chemical coagulants, the natural coagulants generally are readily available and generally sourced from the local areas making an attractive alternative as a disinfectant, which eliminates the need for storage in a controlled room. A study by Amran *et al*. (2018) has also emphasized on the need to conduct more detailed studies on the efficiency of plant-based coagulants for water and wastewater treatment. Therefore, detailed studies are required to explore its possibilities as a disinfectant for commercial purposes.

Natural coagulants - barriers for the commercialization

Most natural extracts have proven their coagulation capabilities in removing COD, BOD, TSS, turbidity, etc.; not many have accepted and reached commercialization. Four main barriers hinder commercialization: Financial capability, regulatory approval, market awareness, and research development (Choy *et al*., 2014). Another study by Saleem and Bachmann (2019) has highlighted the coagulants' cationic, anionic, and non-ionic nature and explored its application and commercialization constraints. The existing research outcomes are mostly confined to laboratory scale, lacking in real industrial applications. Lacking financial freedom and understanding about the market hinder the investors from investing in a new product. Economically feasible extraction methods are essential for successful commercialization. Comprehensive studies on the coagulation mechanism are also limited. Approval from the local government authorities and other regulatory authorities must be granted to launch any new products successfully. Obtaining approval is not easy without ensuring product compliance to the respective standards. Strong motivation for green chemistry concepts and cleaner production of the investors are crucial for the natural coagulant development and their applications. Table 5 summarizes the barriers that affect the successful commercialization of natural coagulants.

The main barrier for the commercialization of natural coagulants is difficulty in bulk production of raw materials; plant species. Raw materials used to produce chemical coagulants such as aluminum, iron are abundant in nature. For a successful and realistic application, raw materials required to produce natural coagulant should be available in large scale. Technical support, expert support and new equipment are necessary in sustainable implementation of natural coagulants so that production cost will ultimately increase. In short run this is not very economical so that market acceptance will be less. Hence the absence of mass plantation of recourses hiders steady supply of raw materials and the long term applications (Kurniawan *et al*., 2020). As Table 5 shows, natural coagulants are not readily available. Plant materials pass few stages before convert in to a plant-based

Table 5: Barriers in the commercialization of natural coagulants

Environmental and Technical Constraints	Economic and Social Constraints
• Complex extraction process	• Lack of money and time to invest in research and development.
• Absence of mass plantation for bulk processing	• Lack of maintaining a steady supply of raw materials. • Lack of meeting the minimum quality requirement.
• Due to the organic properties of natural coagulants, COD levels might increase.	• Lack of regulatory approvals on plant-based coagulants.
• Lack of toxicological studies for purified coagulants.	• Lack of awareness and market interest.
• Seasonal variations in some plant resources. (Cactus grow in hot seasons)	• Well established, competitive market.
• Lack of research regarding the practical usage and issues occurring during the operations within the plant	• High initial establishment cost.
• Lack of proper arrangements for storage of the natural coagulants in stock.	• Industrial acceptance
• Improper estimation of the quality characteristics of the treated water	• Lack of knowledge on health improvements

natural coagulant. These stages includes: extraction of active compound, purification etc. Extraction processes are different form plant- based to animal-based coagulants. Hence these processes should be carefully analyzed and should produce simplified and economically feasible processing steps. So that further studies needed to be carried out to analyze the converting and handling of powdered forms of coagulants, storing and preservation as well as toxicity (Kurniawan *et al*., 2020). Therefore commercialization process is costly as well as may take more time than expected. As mentioned in Fig. 1 coagulation process depends on coagulant type and dosage, pH, temperature etc. Hence these parameters should be optimized before implementing to the industry and it is more time consuming so that it will be difficult to cope with the competitive market (Kurniawan *et al*., 2020). Government and non-government regulatory bodies should encourage the industry to use natural coagulants in wastewater treatment process by implementing environmental rules (Freitas *et al*., 2018; Kurniawan *et al*., 2020) and reducing tax payments (Kurniawan *et al*., 2020), introduce new loan schemes to cover the initial implementation costs, linking the connection between research organization and industry and give recognition for the use of natural coagulants. Due to the use of high optimal dosages of natural coagulants, high amounts of residual organic matter (Freitas *et al*., 2018; Oladoja, 2016) is found in treated wastewater hence the COD levels will increase. This will ultimately increase the microbial activity leading to change in color and emission of unpleasant odors (Kurniawan *et al*., 2020; Oladoja, 2015). When selecting a plant species as raw material for the production of natural coagulants, it is important to consider their seasonal variations and availability (Kurniawan *et al*., 2020). Hence research and development studies should be conducted to identify best, economically productive natural coagulants and also to identify feasible combinations of chemical and natural coagulants.

Modified natural coagulants

A breakthrough in the commercial profit-oriented market can be made by emphasizing the need for blended coagulants. Lately, Mohd-Salleh *et al*., (2019) indicated natural materials as aids for future coagulant production and discussed the potential to develop composite coagulants that are sustainable. Natural coagulants can be used in conjunction with modifying agents. Table 6 shows some of the modifying agents used in combination with natural coagulants. Many of them are also active as flocculants when combined with a modifying agent. Chitosan is biodegradable and eco-friendly in comparison with traditional coagulants and acts as a bio-flocculant. It is used as a substitute for conventional coagulants in water treatment. Chitosan has primary amino groups; these amino groups can remove various contaminants. Previous studies have shown that Chitosan removed around 99% of *Microcystis aeruginosa* cells. However, its low production yield leading to a high cost of operation has hindered its application as a sole coagulant in practical scenarios (Ma *et al*., 2016). Due to its insolubility in neutral and alkaline conditions, the application of Chitosan is usually limited. Chemically modified chitosan materials have been manufactured to overcome this issue (Dharani and Balasubramanian, 2015; Zhang *et al*., 2014). According to the study (Vigneshwaran *et al*., 2020), Moringa seeds are considered natural coagulants/flocculents. It is mainly comprised of lipids and protein. The protein molecules of moringa seeds can bridge $-NH_2$ groups and –OH groups present in the chitosan molecule. Bridging will leads to the destabilization and aggregation of the small stable colloidal impurities into larger particle units. Hence, it is known as floc. The floc can remove through several physicochemical processes such as solid-liquid separation, slow mixing, and rapid mixing (Vigneshwaran *et al*., 2020). Recently, natural polymeric coagulants, such as cellulose, Chitosan, starch, have drawn more attention due to their advantages of low price, biodegradability, vast resources, and low toxicity. In addition, attention was focused on starch-based coagulants because starch is one of the most abundant natural polymers globally and has been applied in various fields (Li *et al*., 2015).

According to Ma *et al.*, 2016 dual coagulant prepared by using chitosan and aluminum chloride is efficient in removing toxic cyanobacteria *Microcystis aeruginosa* found in water bodies. This novel mixed coagulant shows a strong bridging ability and high adsorption. This study suggests that CTASC is efficient, cost-effective, specific, and safe in removing *Microcystis aeruginosa.* Zhang *et al*., 2014, mentioned chitosan-based flocculent N-carboxyethylated chitosan (CEC) is eco-friendly coagulant produced by chitosan and acrylic acid. It flocculates copper (II) and tetracycline (TC). The advantages are in the aspects of optimal dosage,

Table 6: Summary of the literary works on the modified natural coagulants

Natural coagulants	Modifying agent	Wastewater source	Parameter	Optimal conditions		Removal efficiency (%)	References
				Dosage (mg/L)	pH		
Chitosan (CTS)	Aluminum chloride (AC)	Drinking water treatment	*(Microcystis aeruginosa) cyanobacteria removal*	2.6 CS + 7.5 AC	-	98	Ma *et al*., 2016
	Acrylic acid	Livestock wastewater	Copper (II) removal	50	8	98	Zhang *et al*., 2014
	Mercaptoacetic acid	Turbid water (Synthetic)	Turbidity	50	5	100	Zhang *et al*., 2015
			Copper ((II) removal	50	7.3	90	
	N-methyl piperazinium chloride	Tannery effluent	BOD	5	6.7	86	Dharani and Balasubramanian, 2015
			COD	5	6.7	96	
	Moringa oleifera	Turbid water (Synthetic)	Turbidity	200	8	84	Vigneshwaran *et al*., 2020
Starch	(2-hydroxypropyl) trimethylammonium chloride	Synthetic wastewater	Kaolin suspension removal	1000	4	93 %	Li *et al*., 2015

lowest residual concentrations, and floc properties. The charge neutralization mechanism is used for the removal of copper (II), and TC makes a coordination complex with copper(II) hydroxides and eliminates with copper (II) at pH 9. Mercapto - acetyl chitosan (MAC) is prepared by combining mercaptoacetic acid and chitosan. It has the ability of adsorption bridging so that water solubility is high (Zhang *et al*., 2015). Turbidity is removed by electrical neutralization of the turbidity substances. Heavy metal ions produce coordination complexes or chelate with MAC and form flocs (Zhang *et al*., 2015). According to Dharani and Balasubramanian, 2015 study, Chitosan-g-N-MPC is prepared by grafting N-methyl piperazinium chloride to chitosan. Flocculation mechanisms are charge neutralization and bridging. Due to the considerable molecular weight and high charge density, it requires low optimal dosages. According to Vigneshwaran *et al*., 2020, acid-treated carbonized chitosan-*Moringa oleifera* (ACCM) shows better adsorption ability, high coagulation capability, low sludge formation and low leaching level. Coagulation mechanisms are charge neutralization and adsorption. Li *et al*., 2015 discussed two kinds of starch-based flocculants. Though they have the same chemically modified functional groups, substitution degrees are different. CMS-CTA-P and CMS-CTA-N have opposite surface charge properties in water. CMS-CTA-N is efficient in the hematite suspension at neutral conditions. CMS-CTA-P shows a better flocculation activity in the kaolin suspension at neutral and acidic conditions. Patching, bridging, and charge neutralization are found as flocculation mechanisms.

CONCLUSION

Coagulants obtained from many natural sources have found their place in the water and wastewater industry world and are widely being used as primary coagulants or coagulant aids. Natural coagulants are environmentally friendly, inexpensive, less hazardous to human beings, and viable alternatives to chemical coagulants. Plant-based, animal-based, and microorganism-based coagulants have been researched for ages and have become popular in developing countries. This review summarized the efficiencies of common natural coagulants such as Roselle seeds, *Moringa oleifera*, Hyacinth bean, Cactus, Nirmali, Chitosan, Tannins and Watermelon seeds etc., used in the water and wastewater treatment and suggested that plant-based species showed good efficiencies in removing turbidity, color, organic matters as well as pathogens. It was noticed that many studies had investigated the application of plant-based coagulants in the primary treatment for turbidity removal and secondary treatment for organic pollutant (TSS, BOD, and COD) removal. However, its disinfection aspect is not well explored. Studying the plant-based coagulants or plant species for the tertiary treatment of water and wastewater could be an exciting area for future research. Further, plant-based coagulants are advantageous due to their low toxicity and eco-friendly sludge production. Despite having significant benefits, some crucial barriers to the commercialization of natural coagulants are identified in this review. The significant barriers are environmental, technical, economic, and social challenges. However, there have been efforts made to commercialize natural coagulants through modified natural coagulants. There are two modified coagulants summarized in this work: Chitosan and starch, which are considered an alternative way to enhance the efficiency of the coagulants and increase its market demand. The concept of modified or composite coagulants could be taken as an indirect example for tackling these constraints. However, there are limited studies on these barriers, and this review recommends that more investigations and assessment methods are required to find the origin of these constraints and solve it through more scientific approaches. Further, from a sustainability perspective, the demand for natural coagulants is destined to increase. Therefore, more researches in the modified coagulants hold promising prospects.

AUTHOR CONTRIBUTIONS

S. Nimesha has done most of the writing and preparing the manuscript. C. Hewawasam has done some part of writing, editing and supervision of works of first author. D.J. Jayasanka has done some part of writing, editing and supervision of works of first author. Y. Murakami is the advisor for the writing this review. N. Araki is the advisor for this research work. N. Maharjan has given significant intellectual inputs and supervised this work.

ACKNOWLEDGMENTS

This work was supported by the project "Development of Human Resources in Science and Technology "2021 Initiative for Realizing Diversity in the Research Environment (Leading Type)" from the Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, ethical issues, including plagiarism, informed consent, misconduct, data fabrication and falsification, double publication and submission, and redundancy, have been entirely witnessed by the authors.

OPEN ACCESS

ABBREVIATIONS

AC	Aluminum chloride
ACCM	Acid treated carbonized chitosan-*Moringa oleifera*
AD	Alzheimer's disease
BOD	Biological oxygen demand
CEC	Carboxy-ethyl Chitosan
Chitosan-g-N MPC	N-methyl piperazinium chloride grafted Chitosan
CMS-CTA-P / CMS-CTA-N	(2 hydroxypropyls) trimethylammonium chloride etherified carboxymethyl starch (two different substitution degrees)
COD	Chemical oxygen demand
-COOH	Carboxyl group
Cr	Chromium
CS	Chitosan
CTS	Chitosan to be modified
CTS- AC	Chitosan -aluminum chloride

Cu	Copper
Fe	Iron
g	Grams
MAC	Mercapto - acetyl chitosan
mg/L	Miligrams per liter
Mn	Manganese
-NH_2	Amine group
Ni	Nickel
NTU	Nephelometric turbidity units
-OH	Hydroxyl group
Pb	Lead
pH	Potential (power) of hydrogen
TC	Tetracycline
TDS	Total dissolved solids
TOC	Total organic carbon
TS	Total solids
TSS	Total suspended solids
Zn	Zinc
%	Percentage sign

REFERENCES

Abdullah, H.A.; Jaeel, A.J., (2019). Turbidity, color, and chemical oxygen demand removals from synthetic textile wastewater using Chitosan as a coagulant. Presented at the IOP Conference Series: Materials Science and Engineering, IOP Publishing, 584(012016): 1-8 **(8 pages).**

Abidin, Z.Z.; Ismail, N.; Yunus, R.; Ahamad, I.S.; Idris, A., (2011) A preliminary study on Jatropha curcas as a coagulant in wastewater treatment. Environ. Technol., 32(9): 971–977 **(7 pages).**

Abreu, M.; Montel, A.; Scapin, E., (2020). Use of natural coagulants/flocculants in the treatment of hospital laundry effluents **(27 pages).**

Adinolfi, M.; Corsaro, M.M.; Lanzetta, R.; Parrilli, M.; Folkard, G.; Grant, W.; Sutherland, J., (1994). Composition of the coagulant polysaccharide fraction from Strychnos potatorum seeds. Carbohydr. Res., 263(1): 103–110 **(8 pages).**

Ahmed, T.; Bhatti, Z.A.; Maqbool, F.; Mahmood, Q.; Faridullah, Qayyum, S.; Mushtaq, N., (2016). A comparative study of synthetic and natural coagulants for silver nanoparticles removal from wastewater. Desalin. Water Treat., 57(40): 18718–18723 **(6 pages).**

Al-Gheethi, A.A.; Mohamed, R.; Wurochekke, A.A.; Nurulainee, N.R.; Mas Rahayu, J.; Amir Hashim, M.K., (2017). Efficiency of Moringa oleifera Seeds for Treatment of Laundry Wastewater. MATECWeb Conferences., 103: 06001 **(8 pages).**

Al-Hamadani, Y.A.; Yusoff, M.S.; Umar, M.; Bashir, M.J.; Adlan, M.N., (2011). Application of psyllium husk as coagulant and coagulant aid in semi-aerobic landfill leachate treatment. J. Hazard. Mater., 190: 582–587 **(6 pages).**

Ali, G.; Fouad, H.; Elhefny, R., (2008). Comparative Study on Natural Products Used for Pollutants Removal from Water. J. Appl. Sci. Res., 5(8): 1020- 1029 **(10 pages).**

Ali, I.; Gupta, V., (2006). Advances in water treatment by adsorption technology. Nat. Protoc., 1(6): 2661-2667 **(7 pages).**

Alibeigi-Beni, S.; Zare, M.H.; Chenar, M.P.; Sadeghi, M.; Shirazian, S., (2021). Design and optimization of a hybrid process based on hollow-fiber membrane/coagulation for wastewater treatment. Environ. Sci. Pollut. Res., 28(7): 8235–8245 **(11 pages).**

Altaher, H.; Tarek, E.; Abubeah, R., (2016). An agricultural waste as a novel coagulant aid to treat high turbid water containing humic acids. Global Nest J., 18(2): 279–290 **(12 pages).**

Amran, A.; Zaidi, N.S.; Muda, K.; Liew, W.L., (2018). Effectiveness of Natural Coagulant in Coagulation Process: A Review. Int. J. Eng. Technol., 7: 34-37 **(4 pages).**

Ang, T.H.; Kiatkittipong, K., Kiatkittipong, W., Chua, S.-C., Lim, J.W., Show, P.-L., Bashir, M.J., Ho, Y.-C., (2020). Insight on extraction and characterization of biopolymers as the green coagulants for microalgae harvesting. Water. 12: 1388 **(31 pages).**

Ang, W.L.; Mohammad, A.W., (2020). State of the art and sustainability of natural coagulants in water and wastewater treatment. J. Clean. Prod., 262: 121267 **(18 pages).**

Atchudan, R.; Edison, T.N.J.I.; Perumal, S.; Muthuchamy, N.; Lee, Y.R., (2020). Hydrophilic nitrogen-doped carbon dots from biowaste using dwarf banana peel for environmental and biological applications. Fuel. 275: 117821 **(10pages).**

Awang, N.A.; Aziz, H.A., (2012). Hibiscus rosa-sinensis leaf extract as coagulant aid in leachate treatment. Appl. Water Sci., 2(4): 293–298 **(6 pages).**

Baptista, A.T.A.; Silva, M.O.; Gomes, R.G.; Bergamasco, R.; Vieira, M.F.; Vieira, A.M.S., (2017). Protein fractionation of seeds of Moringa oleifera lam and its application in superficial water treatment. Sep. Purif. Technol., 180:114–124 **(11 pages).**

Bhattacharjee, C.; Dutta, S.; Saxena, V.K., (2020). A review on biosorptive removal of dyes and heavy metals from wastewater using watermelon rind as biosorbent. Environ. Adv., 2(100007): 1-13 **(13 pages).**

Bodlund, I.; Pavankumar, A.R.; Chelliah, R.; Kasi, S.; Sankaran, K.; Rajarao, G.K., (2014). Coagulant proteins identified in Mustard: a potential water treatment agent. Int. J. Environ. Sci. Technol., 11(4): 873–880 **(8 pages).**

Bouatay, F; Mhenni, F., (2014). Use of the Cactus Cladodes Mucilage (Opuntia Ficus Indica) As an Eco-Friendly Flocculants: Process Development and Optimization using Statistical Analysis. Int. J. Environ. Res., 8(4): 1295–1308 **(14 pages).**

Brastad, K.S.; He, Z., (2013). Water softening using microbial desalination cell technology.
Desalination. 309: 32–37 **(6 pages).**

Bs, S.; Papegowda, G., (2012). Evaluation of Cactus and Hyacinth Bean Peels as Natural Coagulants,
Int. J. chem. Environ. Eng., 3(3): 187-191 (**5 pages).**

Camacho, F.P.; Sousa, V.S.; Bergamasco, R.; Teixeira, M., (2017). The use of Moringa oleifera as a natural coagulant in surface water treatment. Chem. Eng. J., 313: 226–237 **(12 pages).**

Choubey, S.; Rajput, S.; Bapat, K., (2012). Comparison of efficiency of some natural coagulants-bioremediation. Int. J. Emerg. Technol. Adv. Eng., 2: 429–434 **(6 pages).**

Choy, S.Y., Prasad, K.M.N., Wu, T.Y., Raghunandan, M.E., Ramanan, R.N.,(2014). Utilization of plant-based natural coagulants as future alternatives towards sustainable water clarification. J. Environ. Sci., 26: 2178–2189 **(12 pages).**

Chua, S.-C.; Malek, M.A.; Chong, F.-K.; Sujarwo, W.; Ho, Y.-C., (2019). Red lentil (Lens culinaris) extract as a novel natural coagulant for turbidity reduction: An evaluation, characterization and performance optimization study. Water, 11(1686): 1-18 **(18 pages).**

Collivignarelli, M.C.; Abbà, A.; Alloisio, G.; Gozio, E.; Benigna, I., (2017). Disinfection in wastewater treatment plants: evaluation of effectiveness and acute toxicity effects. Sustainability, 9(10): 1-13 **(13 pages).**

Daverey, A.; Tiwari, N.; Dutta, K., (2019). Utilization of extracts of Musa paradisica (banana) peels and Dolichos lablab (Indian bean) seeds as low-cost natural coagulants for turbidity removal from water. Environ. Sci. Pollut. Res., 26 (33): 34177–34183 **(7 pages).**

de Paula, H.M.; de Oliveira Ilha, M.S.; Sarmento, A.P.; Andrade, L.S., (2018). Dosage optimization of Moringa oleifera seed and traditional chemical coagulants solutions for concrete plant wastewater treatment. J. Clean. Prod., 174: 123–132 **(10 pages).**

Devrimci, H.A.; Yuksel, A.M., Sanin, F.D., (2012). Algal alginate: A potential coagulant for drinking water treatment. Desalination, 299: 16–21 **(6 pages).**

Dezfooli, S.M.; Uversky, V.N.; Saleem, M.; Baharudin, F.S.; Hitam, S.M.S.; Bachmann, R.T., (2016). A simplified method for the purification of an intrinsically disordered coagulant protein from defatted Moringa oleifera seeds. Process Biochem., 51(8): 1085–1091 **(7 pages).**

Dharani, M.; Balasubramanian, S., (2015). Synthesis and characterization of chitosan-gN-methyl piperazinium chloride: A hybrid flocculant. Int. J. Biol. Macromol., 81: 778–784 **(7 pages).**

Dorea, C., (2006). Use of Moringa spp. seeds for coagulation : a review of a sustainable option. Water Sci. Technol. Water Supply, 6(1): 219–227 **(9 pages).**

ELsayed, E.; El-Den, A.A.; Elkady, M.; Zaatout, A., (2020). Comparison of coagulation performance using natural coagulants against traditional ones. Sep. Sci. Technol., 56(10): 1779-1787 **(9 pages).**

Ergunova, O.; Ferreira, R.; Ignatenko, A.; Lizunkov, V.G.; Malushko, E., (2017). Use of ion exchange filters in wastewater treatment. Eur. Proc. Soc. Behav. Sci. (EpSBS): Responsible Res. Innov. (RRI 2016)—Nicosia 2017, 26: 541–549 **(9 pages).**

Fatombi, J.; Lartiges, B.; Aminou, T.; Odile, B.; Caillet, C., (2013). A natural coagulant protein from copra (Cocos nucifera): Isolation, characterization, and potential for water purification. Sep. Purif. Technol., 116: 35–40 **(6 pages).**

Fermino, L., Pedrangelo, A., Silva, P., Azevedo, R., Yamaguchi, N., Ribeiro, R.M., (2017). Water Treatment with Conventional and Alternative Coagulants. Chem. Eng. Trans., 57: 1189–1194 **(6 pages).**

Freitas, T.K.F.S.; Almeida, C.A., Manholer, D.D., Geraldino, H.C.L., de Souza, M.T.F., Garcia, J.C., (2018). Review of utilization plant-based coagulants as alternatives to textile wastewater treatment, in: Detox Fashion. Springer. 27–79 **(53 pages).**

Gautam, S.; Saini, G., (2020). Use of natural coagulants for industrial wastewater treatment. Glob. J. Environ. Sci. Manage., 6: 553–578 **(26 pages)**.

Gogate, P.R., Pandit, A.B., (2004). A review of imperative technologies for wastewater treatment I: oxidation technologies at ambient conditions. Adv. Environ. Res., 8(3-4): 501–551 **(51 pages).**

Grenda, K.; Arnold, J.; Gamelas, J.A.; Rasteiro, M.G., (2020). Up-scaling of tannin-based coagulants for wastewater treatment: performance in a water treatment plant. Environ. Sci. Pollut. Res., 27(2): 1202–1213 **(12 pages).**

Guo, Y.; Zelekew, O.A.; Sun, H.; Kuo, D.-H.; Lin, J.; Chen, X., (2020). Catalytic reduction of organic and hexavalent chromium pollutants with highly active bimetal CuBiOS oxysulfide catalyst under dark. Sep. Purif. Technol., 242(116769): 1-11 **(11 pages).**

Hameed, Y.T.; Idris, A.; Hussain, S.A.; Abdullah, N., (2016). A tannin-based agent for coagulation and flocculation of municipal wastewater: Chemical composition, performance assessment compared to polyaluminum chloride, and application in a pilot plant. J. Environ. Manage., 184: 494–503 **(10 pages).**

Hassan, M.A.A.; Hui, L.S.; Noor, Z.Z., (2009). Removal of boron from industrial wastewater by chitosan via chemical precipitation. J. Chem. Nat. Res. Eng., 4(1): 1–11 **(11 pages)**.

Hassan, M.A.A.; Li, T.P., Noor, Z.Z., (2009). Coagulation and flocculation treatment of wastewater in textile industry using chitosan. J. Chem. Nat. Resour. Eng., 4: 43–53 **(11 pages).**

Hu, H.; Li, X.; Wu, S.; Yang, C., (2020). Sustainable livestock wastewater treatment via phytoremediation: Current status and future perspectives. Bioresour. Technol., 315(123809): 1 -11 **(11 pages).**

Huang, C.; Chen, S.; Ruhsing Pan, J., (2000). Optimal condition for modification of Chitosan: a biopolymer for coagulation of colloidal particles. Water Res., 34(3): 1057–1062 **(6 pages).**

Huang, J.; Ling, J.; Kuang, C.; Chen, J.; Xu, Y.; Li, Y., (2018). Microbial biodegradation of aniline at low concentrations by Pigmentiphaga daeguensis isolated from textile dyeing sludge. Int. Biodeterior. Biodegrad., 129: 117–122 **(6 pages).**

Idris, J.; Md Som, A.; Musa, M.; Ku Hamid, K.H.; Husen, R.; Muhd Rodhi, M.N., (2012). Dragon Fruit Foliage Plant-Based Coagulant for Treatment of Concentrated Latex Effluent: Comparison of Treatment with Ferric Sulfate. J. Chem., 2013(230860): 1-8 **(8 pages).**

Jayalakshmi, G.; Saritha, V.; Dwarapureddi, B.K., (2017). A review on native plant based coagulants for water purification. Int. J. Appl. Environ. Sci. 12: 469–487 **(19 pages).**

Joaquin, A.A.; Nirmala, G.; Kanakasabai, P., (2021). Response Surface Analysis for Sewage Wastewater Treatment Using Natural Coagulants. Pol. J. Environ. Stud., 30(2): 1215–1225 **(11 pages).**

Kakoi, B.K.; Kaluli, J.W.; Ndiba, P.; Thion, O.G., (2016). Banana pith as a natural coagulant for polluted river water. Ecol. Eng., 95: 699–705 **(7 pages).**

Kansal, S.K.; Kumari, A., (2014). Potential of M. oleifera for the treatment of water and wastewater. Chem. Rev., 114: 4993–5010 **(18 pages).**

Karbassi, A.R.; Heidari, M., (2015). An investigation on role of salinity, pH and DO on heavy metals elimination throughout estuarial mixture. Global J. Environ. Sci. Manage., 1(1): 41-46 **(6 pages).**

Karbassi, A.R.; Pazoki, M., (2015). Environmental qualitative assessment of rivers sediments. Global J. Environ. Sci. Manage., 1(2): 109-116 **(8 pages).**

Konapala, G.; Mishra, A.K.; Wada, Y.; Mann, M.E., (2020). Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. Nat. Commun., 11(1): 1–10 **(10 pages).**

Kristianto, H., (2017). The potency of Indonesia native plants as natural coagulant: a mini review. Water Conserv. Sci. Eng., 2 (2): 51–60 **(10 pages).**

Kristianto, H.; Kurniawan, M.A.; Soetedjo, J.N., (2018). Utilization of papaya seeds as natural coagulant for synthetic textile coloring agent wastewater treatment. Int. J. Adv. Sci. Eng. Inf. Technol., 8: 2071–2077 **(7 pages).**

Kumar Kaushal, R.; Goyal, H., (2019). Treatment of Waste Water Using Natural Coagulants. Proc. Recent Adv. Interdiscip. Trends Eng. Appl. (RAITEA), 1-7 **(7 pages).**

Kumar, V.; Othman, N., Asharuddin, S., (2017). Applications of natural coagulants to treat wastewater− A review, in: MATEC Web of Conferences. EDP Sciences, 103(06016): 1-9 **(9 pages).**

Kurniawan, S.B.; Abdullah, S.R.S., Imron, M.F., Said, N.S.M., Ismail, N., Hasan, H.A., Othman, A.R., Purwanti, I.F., (2020). Challenges and Opportunities of Biocoagulant/Bioflocculant Application for Drinking Water and Wastewater Treatment and Its Potential for Sludge Recovery. Int. J. Environ. Res. Public. Health, 17: 9312 **(33 pages).**

Li, H.; Cai, T.; Yuan, B.; Li, R.; Yang, H.; Li, A., (2015). Flocculation of both kaolin and hematite suspensions using the starch-based flocculants and their floc properties. Ind. Eng. Chem. Res., 54(1): 59–67 **(9 pages).**

Ma, C.; Hu, W.; Pei, H.; Xu, H.; Pei, R., (2016). Enhancing integrated removal of Microcystis aeruginosa and adsorption of microcystins using chitosan-aluminum chloride combined coagulants: effect of chemical dosing orders and coagulation mechanisms. Colloids Surf. Physicochem. Eng. Asp., 490: 258–267 **(10 pages).**

Matilainen, A.; Vepsäläinen, M., Sillanpää, M., (2010). Natural organic matter removal by coagulation during drinking water treatment: A review. Adv. Colloid Interface Sci., 159: 189–197 **(9 pages).**

Martău, G.A.; Mihai, M.; Vodnar, D.C., (2019). The Use of Chitosan, Alginate, and Pectin in the Biomedical and Food Sector—Biocompatibility, Bioadhesiveness, and Biodegradability. Polymers, 11(11): 1837 **(28 pages).**

McLachlan, D., (1995). Aluminium and the risk for Alzheimer's disease. Environmetrics. 6(3): 233–275 **(43 pages)**.

Miller, S.M.; Fugate, E.J.; Craver, V.O.; Smith, J.A.; Zimmerman, J.B., (2008). Toward understanding the efficacy and mechanism of Opuntia spp. as a natural coagulant for potential application in water treatment. Environ. Sci. Technol., 42(12): 4274–4279 **(6 pages).**

Mohan, S.M., (2014).Use of naturalized coagulants in removing laundry waste surfactant using various unit processes in lab-scale. J. Environ. Manage., 136: 103–111 **(9 pages).**

Mohd-Esa, N.; Hern, F.S.; Ismail, A.; Yee, C.L., (2010). Antioxidant activity in different parts of roselle (Hibiscus sabdariffa L.) extracts and potential exploitation of the seeds. Food Chem., 122(4): 1055–1060 **(6 pages).**

Mohd-Salleh, S.N.A.; Mohd-Zin, N.S.; Othman, N., (2019). A review of wastewater treatment using natural material and its potential as aid and composite coagulant. Sains Malays., 48(1): 155–164 **(10 pages).**

Muruganandam, L.; Kumar, M.S.; Jena, A.; Gulla, S.; Godhwani, B., (2017). Treatment of waste water by coagulation and flocculation using biomaterials, in: IOP Conf. Series: Materials Sci. Eng., 263 (032006): 1-11 **(11 pages).**

Ndabigengesere, A.; Narasiah, K.S.; Talbot, B.G., (1995). Active agents and mechanism of coagulation of turbid waters using Moringa oleifera. Water Res., 29(2): 703–710 **(8 pages).**

Nechita, P., (2017). Applications of Chitosan in wastewater treatment. Biol. Act. Appl. Mar. Polysacch., 209-228 **(20 pages).**

Neoh, C.H.; Noor, Z.Z.; Mutamim, N.S.A.; Lim, C.K., (2016). Green technology in wastewater treatment technologies: integration of membrane bioreactor with various wastewater treatment systems. Chem. Eng. J., 283: 582–594 **(13 pages).**

Nonfodji, O.M.; Fatombi, J.K.; Ahoyo, T.A.; Osseni, S.A.; Aminou, T., (2020). Performance of Moringa oleifera seeds protein Moringa oleifera seeds protein-polyaluminum chloride composite coagulant in removing organic matter and antibiotic-resistant bacteria from hospital wastewater. J. Water Process Eng., 33(101103): 1-11 **(11 pages).**

Nougbodé, Y.; Agbangnan D.; Koudoro, Y.; Dèdjiho, C.; Aina, M.; Daouda, M.; Sohounhloue, D., (2013). Evaluation of the Opuntia dillenii as Natural Coagulant in Water Clarification: Case of Treatment of Highly Turbid Surface Water. J. Water Resour. Prot., 5(12): 1242–1246 **(5 pages).**

Obotey Ezugbe, E.; Rathilal, S., (2020). Membrane technologies in wastewater treatment: a review. Membranes. 10(5): 89 **(28 pages).**

Oladoja, N.A., (2016). Advances in the quest for substitute for synthetic organic polyelectrolytes as coagulant aid in water and wastewater treatment operations Sustain. Chem. Pharm., 3: 47–58 **(12 pages).**

Oladoja, N.A., (2015). Headway on natural polymeric coagulants in water and wastewater treatment operations. J. Water Process Eng., 6: 174–192 **(19 pages).**

Oladoja, N.A.; Saliu, T.D.; Ololade, I.A.; Anthony, E.T.; Bello, G.A., (2017). A new indigenous green option for turbidity removal from aqueous system. Sep. Purif. Technol., 186: 166–174 **(9 pages).**

O'Malley, E.; O'Brien, J.W.; Verhagen, R.; Mueller, J.F., (2020). Annual release of selected UV filters via effluent from wastewater treatment plants in Australia. Chemosphere, 247 (125887): 1-7 **(7 pages).**

Othmani, B.; Rasteiro, M.G.; Khadhraoui, M., (2020). Toward green technology: A review on some efficient model plant-based coagulants/flocculants for freshwater and wastewater remediation. Clean Technol. Environ. Policy, 22: 1025–1040 **(16 pages).**

Özacar, M.; Şengil, İ.A., (2003). Evaluation of tannin biopolymer as a coagulant aid for coagulation of colloidal particles. Colloids Surf. Physicochem. Eng. Asp., 229: 85–96 **(12 pages).**

Polizzi, S.; Pira, E., Ferrara, M., Bugiani, M., Papaleo, A., Albera, R., Palmi, S., (2002). Neurotoxic effects of aluminium among foundry workers and Alzheimer's disease. Neurotoxicology. 23: 761–774 **(14 pages).**

Pontius, F.W., (2016). Chitosan as a drinking water treatment coagulant. Am. J. Civ. Eng., 4: 205–215 **(11 pages).**

Prabhakaran, G.; Manikandan, M.; Boopathi, M., (2020). Treatment of textile effluents by using natural coagulants. Mater. Today Proc., 33: 3000–3004 **(5 pages).**

Pritchard, M.; Craven, T.; Mkandawire, T.; Edmondson, A.; O'Neill, J.G., (2010). A comparison between Moringa oleifera and chemical coagulants in the purification of drinking water – An alternative sustainable solution for developing countries. Phys. Chem. Earth. A/B/C, 35: 798–805 **(8 pages).**

Qureshi, K.; Bhatti, I.; Shaikh, M.S., (2011). Development of bio-coagulant from mango pit for the purification of turbid water. Sindh Univ. Res. J.-SURJ Sci. Ser., 43(1): 105-110 **(5 pages).**

Rak, A.E.; Ismail, A.A.M., (2012). Cassia alata as a potential coagulant in water treatment. Res. J. Recent Sci., 1(2): 28–33 **(6 pages).**

Rebah, F.B.; Siddeeg, S., (2017). Cactus an eco-friendly material for wastewater treatment: A review. J. Mater. Environ. Sci., 8: 1770–1782 **(13 pages).**

Rizzo, L.; Lofrano, G., Grassi, M., Belgiorno, V., (2008). Pre-treatment of olive mill wastewater by chitosan coagulation and advanced oxidation processes. Sep. Purif. Technol., 63: 648–653 **(6 pages)**.

Rocha, V.V.F.; dos Santos, I.F.S.; Silva, A.M.L.; Sant'Anna, D.O.; Junho, A.L.; Barros, R.M., (2019). Clarification of high-turbidity waters: a comparison of Moringa oleifera and virgin and recovered aluminum sulfate-based coagulants. Environ. Dev. Sustainability. 22(5): 4551-4562 **(12 pages).**

Roussy, J.; Van Vooren, M.; Dempsey, B.A.; Guibal, E., (2005). Influence of chitosan characteristics on the coagulation and the flocculation of bentonite suspensions. Water Res., 39: 3247–3258 **(12 pages).**

Sáenz, C.; Sepúlveda, E.; Matsuhiro, B., (2004). Opuntia spp mucilage's: a functional component with industrial perspectives. J. Arid Environ., 57: 275–290 **(16 pages).**

Saharudin, N.F.A.; Nithyanandam, R., (2014). Wastewater Treatment by using Natural Coagulant Wastewater Treatment by using Natural Coagulant. 2nd Eureca, 2-3 **(2 pages).**

Saleem, M.; Bachmann, R.T., (2019). A contemporary review on plant-based coagulants for applications in water treatment. J. Ind. Eng. Chem., 72: 281–297 **(17 pages).**

Sánchez-Martín, J.; González, M.; Beltrán, J., (2010). Surface water treatment with tannin-based coagulants from Quebracho (Schinopsis balansae). Chem. Eng. J., 165: 851–858 **(8 pages).**

Saranya, P.; Ramesh, S.T.; Gandhimathi, R., (2014). Effectiveness of natural coagulants from non-plant-based sources for water and wastewater treatment—a review. Desalination Water Treat., 52: 6030–6039 **(10 pages).**

Sathish, S.; Vikram, S.; Suraj, R., (2018). Effectiveness of turbidity removal from synthetic and tannery wastewater by using seeds of a natural coagulant citrullus lanatus. Nat. Environ. Pollut. Technol., 17: 551–553 **(4 pages).**

Shamsnejati, S.; Chaibakhsh, N.; Pendashteh, A.R.; Hayeripour, S., (2015). Mucilaginous seed of Ocimum basilicum as a natural coagulant for textile wastewater treatment. Ind. Crops Prod., 69: 40–47 **(8 pages).**

Sher, F.; Malik, A., Liu, H., (2013). Industrial polymer effluent treatment by chemical coagulation and
flocculation. J. Environ. Chem. Eng., 1: 684–689 **(6 pages)**.

Sivakumar, D., (2016). Biosorption of hexavalent chromium in a tannery industry wastewater using fungi species. Global. J. Environ. Sci. Manage., 2: 105–124 **(20 pages).**

Sivakumar, D., (2015). Hexavalent chromium removal in a tannery industry wastewater using rice
husk silica. Global J. Environ. Sci. Manage., 1(1): 27-40 **(14 pages).**

Sivakumar, D.; Nouri, J., Modhini, T., Deepalakshmi, K., (2018). Nickel removal from electroplating industry wastewater: A bamboo activated carbon. Global J. Environ. Sci. Manage., 4: 325–338 **(14 pages).**

Sivaranjani, S.; Rakshit, A., (2016). Indigenous Materials for Improving Water Quality. Nat. Environ. Pollut. Technol., 15(1): 171-176 **(6 pages).**

Song, Z.; Zhao, Y.; Song, X.; C. Liu, C., (2009). Research on prediction model of optimal coagulant dosage in water purifying plant based on nerual network. In 2009 ISECS International Colloquium on Computing, Communication, Control, and Management. 4: 258–261 **(4 pages).**

Staicu, L.C.; van Hullebusch, E.D.; Oturan, M.A.; Ackerson, C.J.; Lens, P.N., (2015). Removal of colloidal biogenic selenium from wastewater. Chemosphere, 125: 130–138 **(9 pages).**

Subramonian, W.; Wu, T.Y.; Chai, S.-P., (2014). A comprehensive study on coagulant performance and floc characterization of natural Cassia obtusifolia seed gum in treatment of raw pulp and paper mill effluent. Ind. Crops Prod., 61: 317–324 **(8 pages).**

Teh, C.Y.; Wu, T.Y.; Juan, J.C., (2014). Optimization of agro-industrial wastewater treatment using unmodified rice starch as a natural coagulant. Ind. Crops Prod., 56: 17–26 **(10 pages).**

Theodoro, J.P.; Lenz, G.F.; Zara, R.F.; Bergamasco, R., (2013). Coagulants and natural polymers: perspectives for the treatment of water. Plast. Polym. Technol., 2: 55–62 **(8 pages).**

Thirugnanasambandham, K.; Sivakumar, V., Maran, P.J., (2014). Bagasse wastewater treatment using biopolymer: A novel approach. J. Serbian Chem. Soc., 79(7): 897–909 **(13 pages).**

Ullah, A.; Hussain, S.; Wasim, A.; Jahanzaib, M., (2020). Development of a decision support system for the selection of wastewater treatment technologies. Sci. Total Environ., 731(139158): 1-12 **(12 pages).**

Verma, A.K.; Dash, R.R.; Bhunia, P., (2012). A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters. J. Environ. Manage., 93(1): 154–168 **(15 pages).**

Vigneshwaran, S.; Karthikeyan, P.; Sirajudheen, P.; Meenakshi, S., (2020). Optimization of sustainable chitosan/Moringa. oleifera as coagulant aid for the treatment of synthetic turbid water – A systemic study. Environ. Chem. Ecotoxicol., 2: 132–140 **(9 pages).**

Vijayaraghavan, G.; Sivakumar, T., Kumar, A.V., (2011). Application of plant based coagulants for waste water treatment. Int. J. Adv. Eng. Res. Stud., 1: 88–92 **(5 pages).**

Vishali, S.; Sakthivel, S.; Karthick, R.; Gowsigan, V.S., (2020). A sustainable approach for the treatment of industrial effluent using a green coagulant Cassia fistula vs. chemical coagulant. Desalination Water Treat., 196: 189–197 **(9 pages).**

Wu, H.; Zhang, J.; Ngo, H.H.; Guo, W.; Hu, Z.; Liang, S.; Fan, J.; Liu, H., (2015). A review on the sustainability of constructed wetlands for wastewater treatment: design and operation. Bioresour. Technol., 175: 594–601 **(8 pages).**

Wu, T.Y.; Mohammad, A.W.; Lim, S.L.; Lim, P.N.; Hay, J.X.W., (2013). Recent advances in the reuse of wastewaters for promoting sustainable development. Wastewater Reuse and Management. Springer, 47–103 **(57 pages).**

Yin, C.-Y., (2010). Emerging usage of plant-based coagulants for water and wastewater treatment. Process Biochem. 45: 1437–1444 **(8 pages).**

Zhang, C.; Zhang, M.; Chang, Q., (2015). Preparation of mercaptoacetyl Chitosan and its removal performance of copper ion and turbidity. Desalination Water Treat., 53(7): 1909–1916 **(8 pages).**

Zhang, T.; Wang, M.; Yang, W.; Yang, Z.; Wang, Y.; Gu, Z., (2014). Synergistic removal of copper (II) and tetracycline from water using an environmentally friendly chitosan-based flocculant. Ind. Eng. Chem. Res., 53(39): 14913–14920 **(8 pages).**

Zubaidi, S.L.; Ortega-Martorell, S.; Al-Bugharbee, H.; Olier, I.; Hashim, K.S.; Gharghan, S.K.; Kot, P.; Al-Khaddar, R., (2020). Urban water demand prediction for a city that suffers from climate change and population growth: gauteng province case study. Water, 12(1885): 1-17 **(17 pages).**

AUTHOR (S) BIOSKETCHES

Nimesha, S., M.Sc. Student, University of Sri Jayewardenepura, Gangodawila, Nugegoda, Sri Lanka.Email: *sajini.nimeshang@gmail.com*
ORCID: 0000-0002-5087-9880

Hewawasam, C., Ph.D., Associate Professor, University of Sri Jayewardenepura, Gangodawila, Nugegoda, Sri Lanka.
Email: *choolaka@sjp.ac.lk*
ORCID: 0000-0001-7367-2834

Jayasanka, D.J., Ph.D., Associate Professor, University of Sri Jayewardenepura, Gangodawila, Nugegoda, Sri Lanka.
Email: *dkjjayasanka@sjp.ac.lk*
ORCID: 0000-0003-2403-2077

Murakami, Y., Ph.D., Professor, Nagaoka National Institute of Technology, 888 Nishikatakai, Nagaoka, Niigata, Japan.
Email: *murakami@nagaoka-ct.ac.jp*
ORCID: 0000-0003-3669-3585

Araki, N., Ph.D., President, Ichinoseki National Institute of Technology, 021-8511, Takanashi, Hagisho, Ichinoseki, Iwate, Japan
Email: *araki@ichinoseki.kosen-ac.jp*
ORCID: 0000-0003-1417-0900

Maharjan, N., Ph.D., Assistant Professor, Nagaoka National Institute of Technology, 888 Nishikatakai, Nagaoka, Niigata, Japan.
Email: *namimaha@nagaoka-ct.ac.jp*
ORCID: 0000-0002-0000-0000

HOW TO CITE THIS ARTICLE

Nimesha, S.; Hewawasam, C.; Jayasanka, D.J.; Murakami, Y.; Araki, N.; Maharjan, N. (2022). Effectiveness of natural coagulants in water and wastewater treatment. Global J. Environ. Sci. Manage., 8(1): 101-116.

DOI: 10.22034/gjesm.2022.01.08

url: https://www.gjesm.net/article_244726.html