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Impact of Contaminated Water on Plants and Animals: Utilizing Natural and Chemical Coagulants for Treating Contaminated Water

Man Vir Singh,[1,*] Anil Kumar,[2] Neha Bhatt,[3] Juanna Ren,[4, 5] Hua Hou,[4] Zhe Wang,[6] Ben Bin Xu,[5] Zhanhu Guo[5] and Henry A. Colorado[7]

Abstract

This study delves into the mechanisms underlying coagulation as a primary treatment method, exploring the role of coagulants in destabilizing suspended particles, organic matter, and dissolved pollutants. It investigates the various types of coagulants commonly used, such as inorganic coagulants (Aluminum sulfate, ferric chloride) and organic coagulants (Poly-aluminum chloride, polyamine-based polymers), analyzing their specific functionalities and optimal application conditions. Furthermore, this study addresses the challenges associated with coagulant-based water treatment, including dosage optimization, coagulant selection, and the influence of water quality parameters on treatment efficiency. It examines the impact of pH, temperature, turbidity, and the presence of interfering substances on coagulation performance, emphasizing the need for tailored approaches in different water treatment scenarios.

Keywords: Water treatment; Coagulants; Contaminated water.

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1. Introduction

Water is essential for all life forms, but its availability is diminishing globally due to climate change and human activities that degrade the environment. Urbanization, industrialization, and rapid population growth are contributing to the continuous contamination of natural water sources.[1] Many people lack access to clean water, leading to the consumption of contaminated water. Common contaminants include arsenic and fluoride, which can cause health issues like diarrhea and fluorosis.[2] Additionally, polonium-210, a decay product of uranium-238, is found in some water sources,[3] and the prevalence of these contaminants varies by location. In Bangladesh, for example, 77 million people are affected by arsenic-contaminated drinking water, and globally, diarrhea claims the lives of approximately 1.9 million children under the age of five annually, with 78% of these deaths occurring in the developing world.[2] Polonium-210 radioactivity has been detected in the Langat River in Malaysia due to the natural weathering of granite rock and human activities like mining, agriculture, and industry.[3] Water treatment practices vary worldwide, with 70% of water treatment being carried out by municipal and industrial facilities in high-income countries, dropping to 38% and 28% in upper-middle-income and lower-middle-income countries, respectively.[1] In low-income countries, only 8% of water undergoes any form of treatment, and over 80% of wastewater is discharged untreated. Arsenic contamination affects nearly 70 million people globally, and approximately 842,000 people die from diarrhea each year globally.[4] Water contamination also arises from industrial and agricultural by-products, including heavy metals like mercury, copper, chromium, and

[1] *Department of Chemistry, School of Allied Science, Dev Bhoomi Uttarakhand University, Dehradun, Uttarakhand, 248007, India.*

[2] *Department of Chemistry, Rakesh (P.G.) College Pilani, Jhunjhunu, Rajasthan 333031, India.*

[3] *Department of Chemistry, Pt. L. M. S., Rishikesh Campus, SDS University, Tehri Garhwal, 249145, Uttarakhand, India.*

[4] *College of Materials Science and Engineering, Taiyuan University of Science and Technology, Taiyuan 030024, PR China.*

[5] *Department of Mechanical and Construction Engineering, Faculty of Engineering and Environment, Northumbria University, Newcastle Upon Tyne NE1 8ST, UK.*

[6] *Chemistry Department, Oakland University, Rochester, MI, 48309, USA.*

[7] *CC Composites Laboratory, Universidad de Antioquia UdeA, Calle 70N°. 52-21, Medellín, Colombia.*

**Email:* manvir24365@gmail.com (M.V. Singh)

lead, as well as hazardous chemicals, dyes, insecticides, and fertilizers. Improper storage or disposal of household chemicals can lead to groundwater contamination.[5] Effluents from the paper pulp industry, particularly lignin and its derivatives, are poorly degradable and contribute to water toxicity. Hyper-salinity can adversely affect microbial activity in non-salt-adapted microorganisms.[6] The characteristics of water, including physical (turbidity, color, temperature, and electrical conductivity), chemical (total dissolved oxygen, pH, and alkalinity), and biological factors, play a crucial role in determining water suitability for consumption.[7,8] Dissolved minerals, impurities, and suspended particles in water can increase its electrical conductivity.[7,9] Coagulation is a widely used primary treatment method for contaminated water, involving the use of natural or chemical-based coagulants, including inorganic and synthetic organic coagulants.[10] The coagulation mechanism is based on principles like the Schulze–Hardy rule and Smoluchowski's particle collision function, which explain coagulant demand and particle number changes during flocculation.[11] Natural coagulants are environmentally friendly, sustainable, and less toxic, making them a favorable choice that does not alter water pH.[10] Commonly used chemical coagulants include iron salts ($FeCl_3$ or $Fe_2(SO_4)_3$), aluminum salts ($Al_2(SO_4)_3$), hydrated lime, and magnesium carbonate,[12,13] along with polymers such as aluminum chloralhydrate, polyaluminium chloride (PAC), polyaluminium sulfate chloride, and polyferric sulfate.[14] Inorganic aluminum salts are frequently employed for treating contaminated water. When added to water, these salts quickly hydrolyze to form various metal hydrolysis species.[15] These cationic species adsorb to negatively charged particles, neutralizing their charge and causing particle destabilization and aggregation.[16] The effectiveness of coagulation in treating contaminated water depends on coagulant dosage and pH. Most colloids in water carry a negative charge, which can keep them stable due to electrical repulsion.[17] High coagulant dosages and elevated pH levels are required to prevent silica scaling on reverse osmosis (RO) membranes.[18]

The efficiency of coagulants among Tannin-based polymer (TBP), $FeCl_3$, and $Al_2(SO_4)_3$ are as follows- TBP > $FeCl_3$ > $Al_2(SO_4)_3$. TBP does not require any pH adjustment either on raw or on treated wastewater and achieves more than 87% COD and 99% colour removal than metal salts.[19] Zirconium-based salts are recommended as potentially feasible coagulants which lead to a reduction of 46% to 150% dissolved organic carbon (DOC), as compared to the Fe salt.[20-29] The WHO has provided the permissible limit of fluoride content (0.37–1.54 mg/l). In most areas, iron content is beyond WHO permissible limits (>0.1 mg/l), except in 3.1% area in the eastern region with 0.06–0.12 mg/l iron, although iron concentrations in groundwater are under the acceptable limit (<0.3 mg/l) as per BIS standard across the district. However, pH and total dissolved solids were within permissible limits.[30] Water is continuously contaminated by waste plastics. In this review, natural and synthetic coagulants are used for the treatment of contaminated water. the effects on animals and plants when using contaminated water for their life.

2. Physicochemical properties of water

Water possesses a high specific heat capacity, allowing it to absorb and retain substantial heat energy without experiencing significant temperature fluctuations. This characteristic serves to moderate environmental temperature changes and stabilize the body temperatures of living organisms. Water's remarkable solvent properties have earned it the moniker 'universal solvent.' This trait arises from its polarity, with water molecules bearing partial positive charges on hydrogen atoms and partial negative charges on oxygen atoms. Consequently, water can form hydrogen bonds with other polar or ionic substances. Water also exhibits surface tension, signifying the attraction between its molecules at the surface. This property enables water to create droplets, maintain liquid surface shapes, and support biological processes like capillary action. Water displays amphiprotic behavior, serving as both an acid and a base through self-ionization. During this process, water molecules can either donate a proton (H^+) to generate a hydroxide ion (OH^-) or accept a proton to form a hydronium ion (H_3O^+). Hydrogen bonding between water molecules, driven by the molecule's polarity, contributes to its distinctive characteristics, including its elevated boiling point, surface tension, and solvent capabilities.[31-34] The World Health Organization (WHO) has established guidelines for permissible drinking water limits. It is essential to recognize that these guideline values are designed to ensure the safety and quality of drinking water, and water quality standards and guidelines may vary across different countries and regions.[31] The standard parameters of the physicochemical of water are shown in Table 1.

The specific health risks and symptoms associated with these chemicals can vary depending on the concentration and duration of exposure. Authorities responsible for water treatment and regulation work diligently to maintain these contaminants within safe limits, minimizing potential health risks. Elevated lead levels in drinking water can lead to lead poisoning, which poses various health problems, particularly in children. These issues encompass developmental delays, learning difficulties, and behavioral disorders. In adults, lead exposure can contribute to cardiovascular complications, kidney damage, and reproductive issues. Arsenic contamination in water can result in arsenic toxicity, linked to an increased risk of several cancers, including skin, lung, bladder, and kidney cancer, with prolonged exposure. Arsenic exposure may also manifest as skin lesions, cardiovascular diseases, and neurological effects. Excessive nitrate levels in drinking water may lead to methemoglobinemia, often referred to as "blue baby syndrome," predominantly affecting infants, here nitrate is converted to nitrite within the body, interfering with blood's oxygen-carrying capacity, causing bluish skin discoloration and potential oxygen delivery issues to organs. An abundance of fluoride in drinking water can

Table 1. Standard physicochemical properties of water.[31]

S. No.	Biochemical Attribute	Refereed Method	Desirable Limit	Permissible Limit
1	pH	Digital pH Meter	6.5-8.5	No Relaxation
2	Electrical Conductance	Digital Conductivity Meter	400 µS/cm	No Relaxation
3	Turbidity, NTU.	2130 B. Nephelometric Method (APHA, 2005)	1 NTU	5 Max
4	Total Dissolved Solids	2540 B. Total Solids Dried at 103–105°C (APHA, 2005)	500 mg/liter	2000 Max
5	Total Hardness	2340 C. EDTA Titrimetric Method (APHA, 2005)	200 mg/litre	600 Max
6	Total Alkalinity	2320 B. Titration Method (APHA, 2005)	200 mg/litre	600 Max
7	Sulphate Content	4500-SO42- E. Turbidimetric Method (APHA, 2005)	200 mg/litre	400 Max
8	Nitrate Content	4500-NO3– B. Ultraviolet Spectrophotometric Screening Method (APHA, 2005)	45 mg/litre	No Relaxation
9	Total Phosphate Content	4500-P D. Stannous Chloride Method (APHA, 2005)	10-40 µg/litre	No Relaxation
10	Chloride Content	4500-Cl– B. Argentometric Method (APHA, 2005)	250	1000 Max.
11	Fluoride Content	4500-F– D. SPADNS Method (APHA, 2005)	1.0 mg/litre	1.5 Max
12	Sodium Content	3500-Na B. Flame Emission Photometric Method (APHA, 2005)	30 µg/litre	No Relaxation
13	Potassium Content	3500-K B. Flame Photometric Method (APHA, 2005)	12 µg/litre	No Relaxation
14	Ferrous Content	3111 B. Direct Air-Acetylene Flame Method (APHA, 2005)	0.3 mg/litre	No Relaxation
15	Copper Content	3111 B. Direct Air-Acetylene Flame Method (APHA, 2005)	0.1 mg/litre	0.3 Max

result in dental fluorosis, characterized by tooth mottling and discoloration. In severe cases, it can lead to skeletal fluorosis, causing joint discomfort, stiffness, and skeletal abnormalities. Chlorine-based water disinfection can yield disinfection byproducts (DBPs), including trihalomethanes (THMs) and haloacetic acids (HAAs). Prolonged exposure to high DBP levels in water has been linked to an increased risk of bladder and colorectal cancer, as well as potential reproductive and developmental effects.[35-38] In regions with low calcium (Ca) content in water, chronic Ca deficiency may occur, potentially leading to conditions like osteoporosis, characterized by fragile bones prone to fractures. Inadequate Ca intake can also heighten the risk of dental issues and contribute to muscle cramps and spasms. Insufficient magnesium (Mg) intake due to low mineral content in water may result in Mg deficiency. Magnesium plays crucial roles in enzymatic reactions, muscle and nerve function, blood pressure regulation, and bone health. Mg deficiency can lead to symptoms like muscle weakness, fatigue, irregular heartbeat, and mood disturbances. While fluoride is typically added to water to prevent tooth decay, regions with low fluoride content in water may experience an increased risk of dental cavities. Fluoride helps strengthen tooth enamel and guard against acid erosion caused by oral bacteria. Iodine deficiency may occur if water sources lack iodine, potentially leading to thyroid disorders such as goiter (enlarged thyroid gland) and hypothyroidism, characterized by fatigue, weight gain, and cognitive impairments.[39-72]

3. Coagulants used for contaminated water treatment

The coagulation process involves various factors, including coagulant dosage, the influence of coagulant aids, mixing conditions, additional ions in the wastewater, pH levels, order of chemical addition, cost considerations, effectiveness, and process control. Achieving optimal treatment outcomes hinges on determining the right conditions for the process. Inorganic coagulants, often referred to as metal coagulants, predominantly consist of aluminum and iron-based compounds. Examples of aluminum-based coagulants used in water treatment include aluminum sulfate, aluminum chloride, aluminum chlorohydrate, sodium aluminate, polyaluminum chloride, poly-aluminum sulfate chloride, poly-aluminum silicate chloride, and poly-aluminum chloride with organic polymers. Iron-based coagulants, also employed in water treatment, include ferric sulfate, ferric chloride, ferrous sulfate, poly-ferric sulfate ferric, chloride sulfate, and ferric salts combined with organic polymers.[24] These chemicals are favored in wastewater treatment due to their effectiveness, cost-efficiency, and ready availability. Coagulation plays a vital role in water treatment processes, facilitating the removal of suspended particles and contaminants. Coagulants are substances added to water to encourage the formation of larger aggregates, known as flocs, which can be easily separated from the water. Here are three common coagulants utilized in the treatment of contaminated water. Aluminum Sulfate (Alum) ($Al_2(SO_4)_3$) is a commonly used coagulant in water treatment. When alum is added to water, it undergoes hydrolysis. The aluminum ions (Al^{3+}) react with water molecules, forming aluminum hydroxide precipitates [$Al(OH)_3$]. These precipitates act as coagulant aids, binding to and neutralizing negatively charged particles and colloids in the water. Additionally, the hydrolysis process produces hydrogen ions (H^+), which lower the pH of the water, further aiding in coagulation. Aluminum salts react with water in subsequent reactions such as Eq. (1) to (9).[25,27]

$$Al_2(SO_4) + 6H_2O \rightleftharpoons 2Al(OH)_3 + 3H_2SO_4 \quad (1)$$

$$3Ca(HCO_3)_2 + 3H_2SO_4 \rightleftharpoons 3CaSO_4 + 6CO_2 + 6H_2O \quad (2)$$

Or

$$Al_2(SO_4) + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2 \quad (3)$$

Ferric Chloride ($FeCl_3$) is another effective coagulant used in water treatment. When ferric chloride is added to water, it dissociates into ferric ions ($Fe^{3+)}$ and chloride ions (Cl^-). The ferric ions hydrolyze, forming ferric hydroxide precipitates [$Fe(OH)_3$]. These precipitates function as coagulant agents, attracting and enmeshing suspended particles and impurities through charge neutralization and adsorption mechanisms—chemical reactions between Ferric Chloride salts with water.

Ferrous Sulfate (Copperas)

$$FeSO_4 + 7H_2O \rightarrow Fe^{2+} + SO_4^{2-} \quad (4)$$

$$Fe^{2+} + 2\ OH^- \rightarrow Fe(OH)_2 \quad (5)$$

$$4Fe(OH)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3 \quad (6)$$

Ferric Sulfate

$$Fe_2(SO_4)_3 \rightarrow 2Fe^{3+} + 3SO_4^{2+} \quad (7)$$

$$Fe^{3+} + 3OH^- \rightarrow Fe(OH)_3 \quad (8)$$

Ferric Chloride

$$2FeCl_3 + 3Ca(OH)_2 \rightarrow 2Fe(OH)_3 + 3CaCl_2 \quad (9)$$

Polyaluminum Chloride (PAC) is a coagulant composed of a range of aluminum species with varying degrees of polymerization. PAC is widely used due to its higher charge density compared to traditional coagulants like alum. When PAC is added to water, it undergoes hydrolysis, releasing aluminum species with positive charges. These positively charged species neutralize the negatively charged particles in the water, resulting in coagulation. PAC also forms larger flocs that settle more rapidly, enhancing the sedimentation process. The coagulation mechanism involves several steps: destabilization, coagulant addition, rapid mixing, and flocculation. During destabilization, the coagulant is added to water, and the charged particles in the water are neutralized or destabilized. The rapid mixing stage helps disperse the coagulant throughout the water, ensuring effective contact with the suspended particles. Flocculation involves gentle mixing, allowing the destabilized particles to collide and form larger aggregates called flocs. The flocs then settle or are removed through sedimentation or filtration processes, resulting in cleaner water. It's important to note that the selection of a specific coagulant and its dosage depends on the water quality parameters, target contaminants, and treatment objectives. Water treatment plants perform extensive testing and optimization to determine the appropriate coagulant and dosage for effective contaminant removal. The environmental impacts of petroleum are often negative because they are toxic to almost all lifestyles, and there is a possibility of causing climate change. Oil pollution in the air and in the water can be toxic and dangerous to the human body.[26]

The colloidal particles' sizes range from 0.001 to 1.0 µm due to them being negatively charged and the small size being suspended in water. Four mechanisms are used to destabilize these fine particles using a coagulant; charge neutralization, polymer bridging, sweep flocculation, and double-layer compression, which are shown in Fig. 1. The simple addition of iron or aluminum salts does not produce completely acceptable treatment results, especially in difficult waters. Activated silica and natural and synthetic polyelectrolytes might be added to stimulate floc formation.[28] The role of adsorption in the removal of heavy metals from water is beyond suspicion. The performance is always satisfied when the adsorbents are added in the coagulation process. However, the cost should be considered in the practical application. The combined action mechanism of ferric sulfate and calcite is, that the calcite surfaces are coated by small coagulants, which behave similarly to the calcite in gravitational sedimentation and filtration, and thus heavy metals are easily removed from the water, inorganic coagulants are reinforced through synthesizing them with other inorganic coagulants or organic flocculants, which are shown in Fig. 2.[29] The types of coagulant dosages are added to untreated water as shown in Table 2.

A deep understanding of the reaction between pollutants and coagulants is needed to achieve high performance in addition to decreasing the cost and sludge volume. Many parameters affect the efficiency of the coagulation process for water and wastewater treatments, and these parameters are varied to control the optimal conditions for the highest efficiency. Coagulant dosage, pH, turbidity, mixing speed and time, and temperature are the main operating factors affecting coagulation speed. These factors significantly impact the coagulation process, affecting the effectiveness and efficiency of coagulants in water and wastewater purification processes, as shown in Table 3.[72]

Following coagulation, flocculation takes place as the adjunct to the enhancement of the microflocs formation as indicated by steps three to five in Fig. 3. Unlike the former which occurs in\10 s, flocculation takes a longer period of approximately 20–45 min which is common in water treatment plants. Flocculation can be further classified into two stages: the first being perikinetic flocculation and the second being orthokinetic flocculation. Throughout flocculation, the size of the flocs will continue to grow until they reach the steady-state floc size distribution.

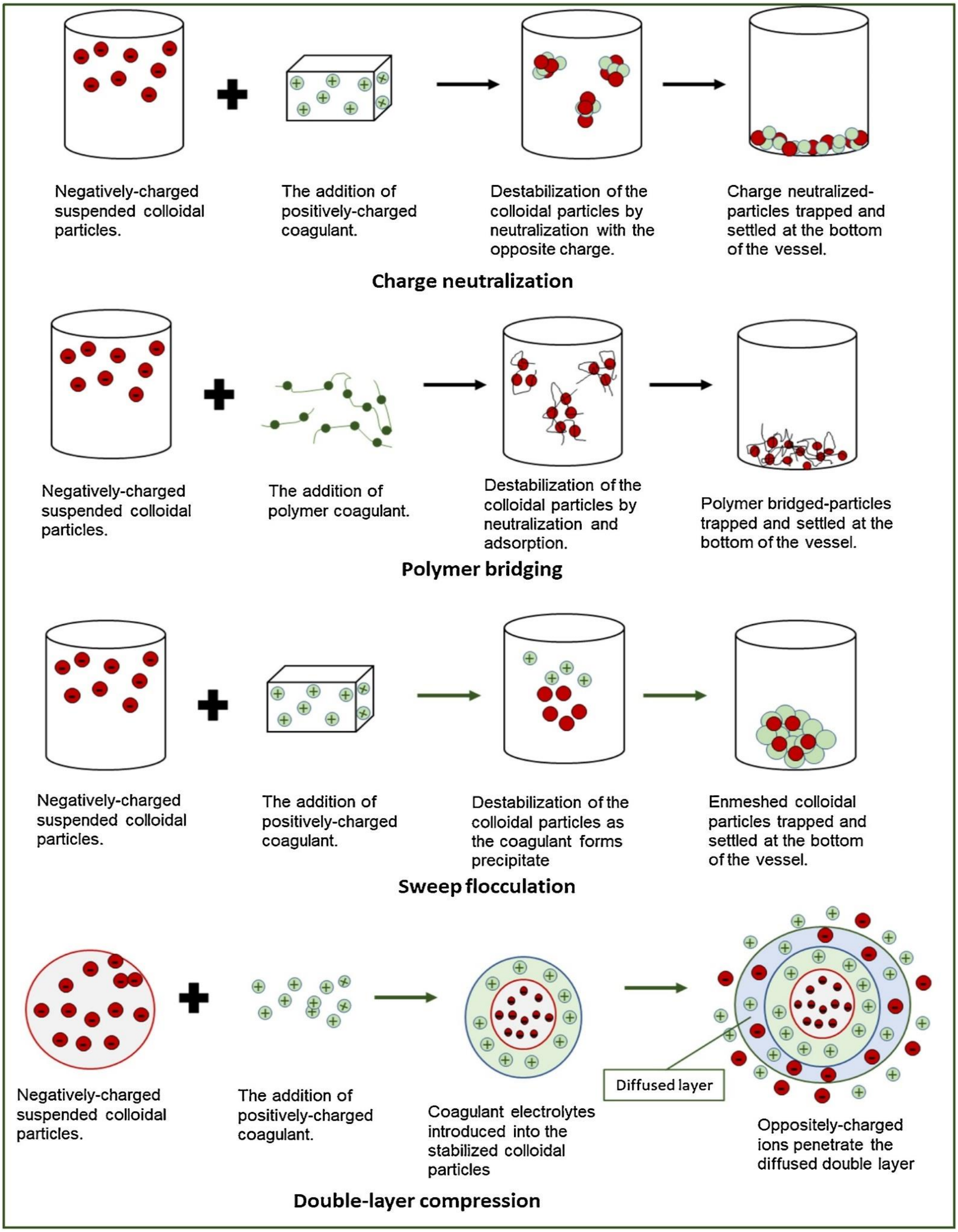

Fig. 1 Charge naturalization, polymer bridging, sweep flocculation, and double-layer compression are shown in the coagulation mechanisms diagram. Reproduced with the permission from [28], Copyright 2021 Elsevier Ltd.

Table 2. Limit of coagulant doses for untreated water.

Type of metals	Waste-water Source	Initial concentration in (mg/L)	Types of Coagulants	Dosage in (mg/L)	pH Values	Removal efficiency	Reference
As	Simulated ground-water	0.28 mg/L	$Al(H_2O)_6Cl_3$	6 mg/L	4–9	Below 0.01 mg/L	73
As	Simulated water	0.125–6.25 mmol/L	Fe-based WTR	100 mg	6	122.6 mmol/kg	74
CH_3Hg	Drainage canal (Twitchell)	1.20 pmol/L	$FeCl_3(H_2O)_x$	1.05 mmol/L	3.5	75%	75
Mn	Simulated water	1 mg/L	$Al(OH)_3$	0.2 g/240 mL	6.5	To 0.08 mg/L	76
Pb	Simulated water	5–100 mg/L	$Fe(OH)_2$	4 g/L	5.5	0.579 mmol/g	77
Pb	Tap water	17 mg/L	Alum	100 mg/L	6.5–7	To 1.3 mg/L	78
Pb	Simulated wastewater	0.002 M	$Fe_2(SO_4)_3H_2On$	0.1;0.14;0.2 mol/L	9–10	To 0.25 mg/L[c]	79
Cd	Simulated water	5–100 mg/L	$Fe(OH)_2$	4 g/L	5.5	0.187 mmol/g	77
Cd	River water	0.3 mg/L	$Fe_2(SO_4)_3H_2On$	–	7.2	20% (90%)	80
Cd	Simulated wastewater	0.002 M	$Fe_2(SO_4)_3H_2On$	0.1;0.14;0.2 mol/L	9–10	Below 0.03 mg/L[c]	79
Cd	Simulated water	10 mg/L	$FeCl_3(H_2O)_x$	0.7 g/L	7	90%	81
Cd	Tap water	15 mg/L	Alum	100 mg/L	6.5–7	To 0.2 mg/L	78
Cd	Simulated wastewater	0.002 M	$Fe_2(SO_4)_3H_2On$	0.1;0.14;0.2 mol/L	9–1	To 0.569 mg/L[c]	79
Cu	Tap water	15 mg/L	Alum	100 mg/L	6.5–7	Tp 1.7 mg/L	78
Zn	Simulated water	5–100 mg/L	$Fe(OH)_2$	4 g/L	5.5	0.612 mmol/g	77
Zn	Tap water	17 mg/L	Alum	100 mg/L	6.5–7	To 11 mg/L	78
Sb	Reservoir water with adding Sb(III)	6 μg/L	Polyaluminum chloride	5.4 mg/L	5–10	10%	82
Sb	Reservoir water with adding Sb(III)	6 μg/L	$FeCl_3(H_2O)_x$	20 mg/L	5	90%	82
Ni	Tap water	16 mg/L	Alum	100 mg/L	6.5–7	Null	78
Ni	Simulated wastewater	0.002 M	$Fe_2(SO_4)_3H_2On$	0.1;0.14;0.2 mol/L	9–10	To 0.389 mg/L[c]	79
Co	Tap water	12 mg/L	Alum	100 mg/L	6.5–7	Null	78

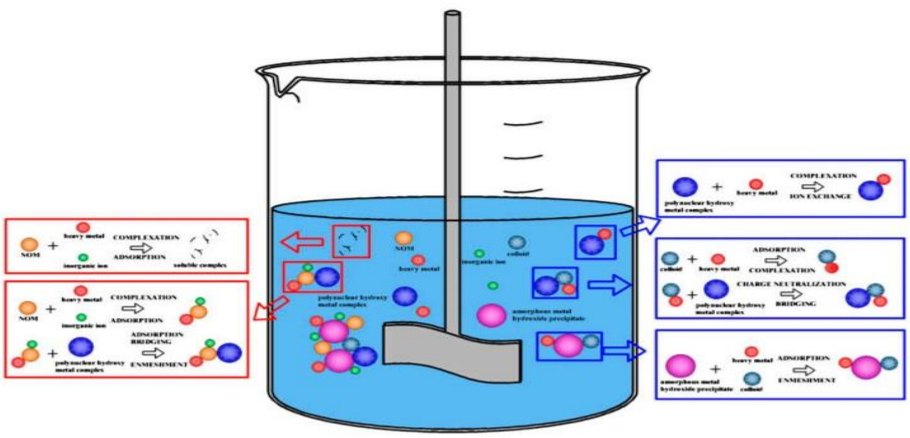

Fig. 2 The mechanism of removal of heavy metals in the coagulation process. Reproduced with the permission from [29], Copyright 2022 Elsevier B.V.

Table 3. Literature review of the Chitosan study.

Coagulation medium	Extraction Types	Experimental Setup	Removal efficiency	Coagulation Medium	References
Anionic dye solution	DD 87%, MW 105 g/mol	Jar test	Dye removal 99%	Charge neutralization, Bridging	41
Aquaculture wastewater	DD 90%, MW (105, 104, 103)	Biological filter, Jar test	Bacteria 99.9%, COD 62.8% SS 62.6%,	Charge neutralization, Bridging	42
Bentonite solution	DD 95%, MW varying	Jar test	TR 99%, TR 93%	Eletrostatic patch, Bridging, Charge neutralization	43
Biodiesel wastewater	DD 93%, MW 105 g/mol	Batch test	COD 88%, TSS 77%	Charge neutralization	44
Brewery wastewater	DD N/A, MW N/A	Jar test	COD 50%, TR95%	Bridging, Charge neutralization	45
Clay suspension	DD 85.84%, MW N/A	Jar test	TR 61.9% - low initial turbidity	Charge neutralization, Bridging	46
Diary wastewater	DD N/A, MW N/A	Jar test, Filtration	COD 55%, TR 97%	Bridging	47
Domestic wastewater	DD 85-98%	Jar test	COD 90.39%, SS 39%	N/A	48
Drinking water	DD 85%, MW N/A	Jar test, Filtration	DOC 20.5%, TR 99%	N/A	49
Fluorite solution	DD 85%, MW N/A	Batch test	Fluoride 5%	N/A	50
Heavy metal solution	DD 85%, MW N/A	Batch test	Cu(II) 9.6%, Pb(II) 58.6%	Adsorption	51
Heavy metal solutions	DD 85-90%, MW 105 g/mol	Jar test	Fe(II) 94.1%, Zn(II) 50.3% Hg(II) 97.5%, Pb(II) 91.0%	Charge neutralization	52
Inc containing wastewater	DD 89.5%, MW 104 g/mol	Jar test	COD 84%, Color 99%	Charge neutralization	53
Industrial wastewater	DD 75%, MW N/A	Batch test	Ag(II) 80-95%	Charge neutralization	54
Kaolin suspension	DD N/A, MW N/A	Jar test	TR 95%	N/A	55
Organic suspension	DD 95%, MW N/A	Jar test	TR 90%	Charge neutralization, Bridging	56
Palm oil mill effluent	DD 85%, MW N/A	Jar test	SS 95%, Palm oil 99%	Charge neutralization, Bridging	57
Rice mill wastewater	DD N/A, MW N/A	Batch test, Centrifugation, Filtration	COD >95%, TSS >95%	Charge neutralization	58
Sea water	DD N/A, MW 104	Jar test	TR 97.5%	Charge neutralization, Bridging	59
Surface water	DD N/A, MW N/A	Jar test, Filtration	TR 96.6%, Bacteria 87.5%	Charge neutralization, Adsorption	60

4. Treatment of Contaminated Water by using microorganisms

Bioremediation is an emerging technology that is widely employed to remove and reduce metal and soil contamination from polluted water. The cost-effective and eco-friendly nature of bioremediation by using microorganisms has an excellent future perspective. Toxic species present in wastewater can be modified by using a variety of microorganisms such as bacteria, fungi, algae, and yeasts.[21] The uptake of toxic chemicals, selection of microbial species, and the polluted site are essential for the success of bioremediation.[22,72] The main objective of the bioremediation technique is to treat plastics and xenobiotics by altering the characteristics of microorganisms which reduces the toxicity of water as compared to the earlier polluted state. The remediation technique by using bacteria such as Pseudomonas,

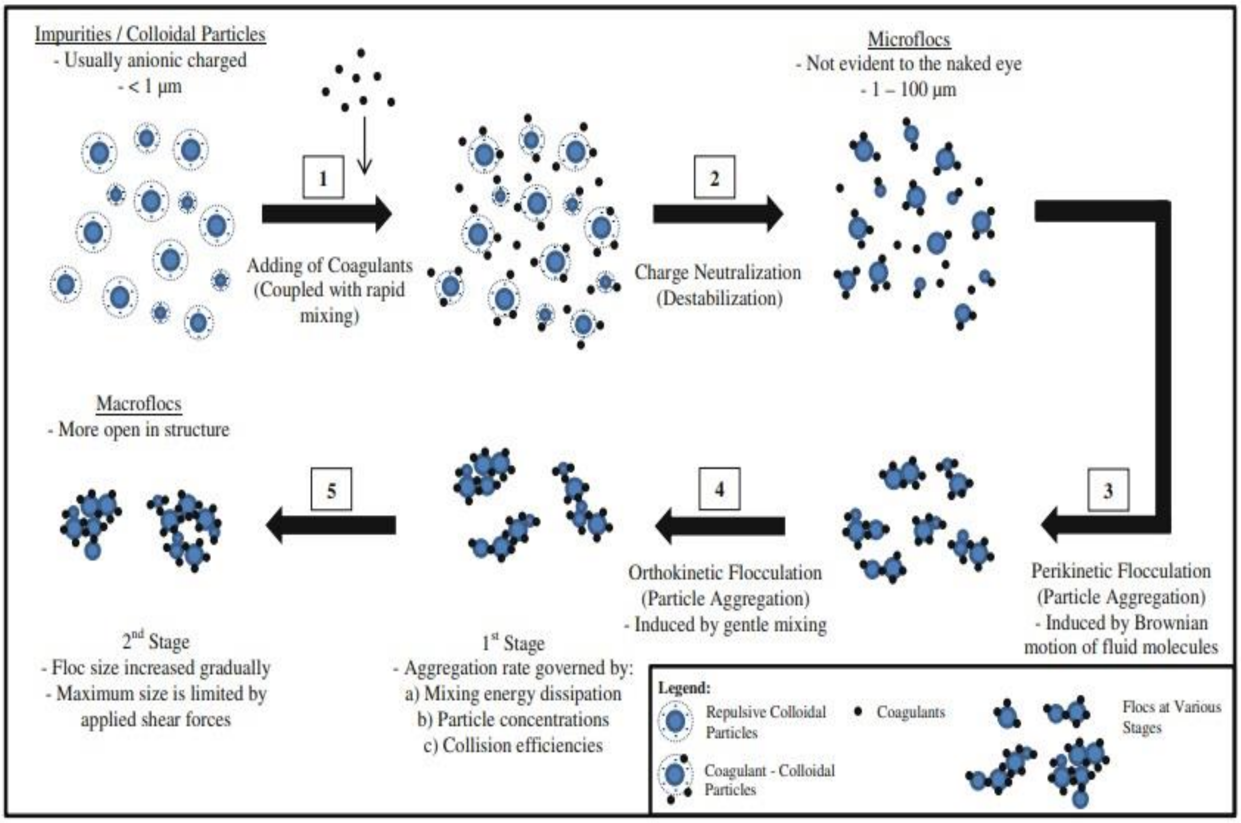

Fig. 3 Flocculation mechanism of the colloidal particles by charge neutralization coagulation in water.

B. subtilis, and endophytes has been used in treating wastewater.[23] The process of bioremediation is carried out in two ways, in situ bioremediation which occurs at a particular polluted site, and Ex situ bioremediation in which this process is carried out in an open site away from the original place. The bioremediation technique mandates the requirement of microorganisms that occur naturally and degrades the harmful pollutants to utilize them as their food. The environment which supports microbial activity results in the success of this process. Apply the natural coagulant doses for treatment water, as shown in Table 4.

5. Effect of contaminated water on plants and animals

Contaminants present in water can hinder plant growth by affecting nutrient uptake, photosynthesis, and overall metabolism. Heavy metals, pesticides, and industrial pollutants can accumulate in plant tissues and disrupt their physiological processes.[83,84] High levels of salts, such as chloride and sodium, in contaminated water, can lead to osmotic stress in plants, causing wilting and even death of plant tissues. Certain contaminants can interfere with the reproductive capacity of plants, affecting flower formation, pollen viability, and seed development.[85] Animals that consume contaminated water may experience various health issues. Chemical contaminants like heavy metals, pesticides, and industrial chemicals can accumulate in animal tissues, leading to toxicity, organ damage, and compromised immune systems.[86] Disruption of Reproduction: Contaminated water can negatively impact animal reproductive systems, affecting fertility, hatching success, and survival rates of offspring. Animals that live in or rely on contaminated water sources may bioaccumulate pollutants over time, which can result in higher concentrations of toxins in their bodies.[87] This bioaccumulation can affect predators higher up the food chain. High levels of pollutants in water can lead to a decrease in microbial diversity and alter the composition of microbial communities. Certain microorganisms may be more sensitive to specific contaminants, resulting in shifts in population dynamics.[88] Contaminants in water can inhibit the metabolic processes of microorganisms, affecting their growth, reproduction, and enzymatic activities. This can disrupt essential ecosystem functions performed by microorganisms, such as nutrient cycling and decomposition. Changes in microbial populations and their functions can have cascading effects on other organisms and ecosystem processes. For example, a decrease in beneficial microorganisms that promote plant growth can impact the overall health and productivity of ecosystems. It's important to note that the specific effects of contaminated water on plants, animals, and microorganisms can vary depending on the type and concentration of contaminants, exposure duration, and the resilience of the affected organisms. Additionally, the impacts can be influenced by factors such as the sensitivity of different species, life stages, and the overall health and resilience of ecosystems.[89-100]

Table 4. Apply the natural coagulant doses for untreated water.

Natural coagulants	Waste-water Sources	Dosages	pH Values	Parameters	Removal Efficiencies	References
Hibiscus sabdariffa (Roselle seed extract)	Glove manufacturing wastewater	60 mg/L	10 ≤	Turbidity, COD	87%, 43%	61
Moringa oleifera (Drumstick Tree)	Laundry wastewater	120 mg/L	5.7	Turbidity, COD	84%	62
Opuntia ficus indica (Cactus species)	Textile wastewater	40 mg/L	7.25	COD, Color, Turbidity	89%, 99%, 87%	63
Corchorus Olitorius L. (Jute mallow)	Agricultural wastewater	3 mg/ L	0	Total Organic compounds, BOD, COD, Cl^-	100%, 95%, 88%, 90%	64
Bamboo (Bambusa vulgaris)	Electroplating industry wastewater	1500 mg/L	5.5	Sulphate TDS Ni	93 % 97 % 99 %	65
Moringa oleifera (Drumstick Tree)	sewage, gray water			COD, BOD	61%, 65%	66
Moringa oleifera (Drumstick Tree)	Raw surface water	150 mg/L	7	Algal removal	65%	67
Moringa oleifera (Drumstick Tree)	surface water	150 mg/L	7.5	Turbidity	97%	68
Opuntia dillenii (Cactus species)	Highly turbid lake water	1000 mg/L		Color, Suspended solids	15%, 89%	69
Banana pith	Polluted river water	100 mg/L	4	Nitrates, Cu, Cr, Fe, Zn, Pb, Mn,	89%, 100%, 100%, 92%, 81%, 100%, 60%	70,71

6. Conclusion

The use of coagulants for contaminated water treatment offers a practical and efficient solution for improving water quality. By effectively removing suspended particles, pathogens, and organic matter, coagulation contributes to the provision of safe and clean water for various purposes, benefiting both human health and the environment, industrial processes, and agricultural use. Furthermore, while coagulants effectively remove many contaminants, they can also introduce by-products into the treated water, such as residual aluminum or iron. Thus, proper monitoring and control measures should be implemented to ensure that the concentrations of these by-products remain within acceptable limits. Continued research and development in this field are essential to refine coagulation processes, minimize by-product formation, and address emerging water quality challenges, ultimately advancing the goal of sustainable water management.

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

References

[1] D. J. Jayasanka, Y. Murakami, N. Araki, N. Maharjan, Effectiveness of natural coagulants in water and wastewater treatment, *Global Journal of Environmental Science Management*, 2012, **8**, 101-116, doi: 10.22034/gjesm.2022.01.08.

[2] P. J. Lucas, C. Cabral, J. M. J. Colford, Dissemination of drinking water contamination data to consumers: a systematic review of impact on consumer behaviors, *PLoS One*, 2011, **6**, e21098, doi: 10.1371/journal.pone.0021098.

[3] M. Ahmed, L. Alam, C. Mohamed, M. Mokhtar, G. Ta, Health risk of polonium 210 ingestion via drinking water: an experience of Malaysia, *International Journal of Environmental Research and Public Health*, 2018, **15**, 2056, doi: 10.3390/ijerph15102056.

[4] M. K. Hasan, A. Shahriar, K. U. Jim, Water pollution in Bangladesh and its impact on public health, *Heliyon*, 2019, **5**, e02145, doi: 10.1016/j.heliyon. 2019.e02145.

[5] S. Sharma, A. Bhattacharya, Drinking water contamination and treatment techniques, *Applied Water Science*, 2017, **7**, 1043-1067, doi: 10.1007/s13201-016-0455-7.
[6] J. Ahmed, A. Thakur, A. Goyal, Industrial wastewater and its toxic effects, In *Biological Treatment of Industrial Wastewater*, *The Royal Society of Chemistry*, 2021, 1-14, doi: 10.1039/9781839165399-00001.
[7] T. Kazi, A. Virupakshi, Treatment of tannery wastewater using natural coagulants, *International Journal of Innovative Research in Science, Engineering and Technology*, 2013, **2**, 4061-4068.
[8] V. Napacho, S. V. Manyele, Quality assessment of drinking water in Temeke District (part II): characterization of chemical parameters, *African Journal of Environmental Science and Technology*, 2010, **4**, 775-789.
[9] M. L. Jodi, U. A. Birnin-Yauri, Y. Yahaya, M. A. Sokoto, The use of some plants in water purification, *Research Journal of Chemistry and Materials Science*, 2012, **1**, 71-75.
[10] S. Nimesha, C. Hewawasam, D. J. Jayasanka, Y. Murakami, N. Araki, N. Maharjan, Effectiveness of natural coagulants in water and wastewater treatment, *Global Journal Environmental Science Management*, 2022, **8**, 101-116.
[11] M. H. Isa, L. P. Wong, N. M. Mubarak, Editorial: advances in removal of toxic substances from wastewater, *Frontiers in Environmental Science*, 2023, **11**, 1165882, doi: 10.3389/fenvs.2023.1165882.
[12] M. Z. Gusiatin, S. Pasieczna-Patkowska, M. Bálintová, M. Kuśmierz, Treatment of wastewater from soil washing with soluble humic substances using biochars and activated carbon, *Energies*, 2023, **16**, 4311, doi: 10.3390/en16114311.
[13] P. Aragonés-Beltrán, J. A. Mendoza-Roca, A. Bes-Piá, M. García-Melón, E. Parra-Ruiz, Application of multicriteria decision analysis to jar-test results for chemicals selection in the physical–chemical treatment of textile wastewater, *Journal of Hazardous Materials*, 2009, **164**, 288-295, doi: 10.1016/j.jhazmat.2008.08.046.
[14] D. Weydts, D. De Smet, M. Vanneste, Processes for reducing the environmental impact of fabric finishing, *Sustainable Apparel*, Amsterdam: Elsevier, 2015, 35-48, doi: 10.1016/b978-1-78242-339-3.00002-9.
[15] J.-Q. Jiang, The role of coagulation in water treatment, *Current Opinion in Chemical Engineering*, 2015, **8**, 36-44, doi: 10.1016/j.coche.2015.01.008.
[16] G. S. Simate, S. E. Iyuke, S. Ndlovu, M. Heydenrych, L. F. Walubita, Human health effects of residual carbon nanotubes and traditional water treatment chemicals in drinking water, *Environment International*, 2012, **39**, 38-49, doi: 10.1016/j.envint.2011.09.006.
[17] G. Obey, M. Adelaide, R. Ramaraj, Biochar derived from non-customized matamba fruit shell as an adsorbent for wastewater treatment, *Journal of Bioresources and Bioproducts*, 2022, **7**, 109-115, doi: 10.1016/j.jobab.2021.12.001.
[18] J. Duan, J. Gregory, Influence of soluble silica on coagulation by aluminium sulphate, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 1996, **107**, 309-319, doi: 10.1016/0927-7757(95)03369-6.
[19] M. A. Aboulhassan, S. Souabi, A. Yaacoubi, M. Baudu, Coagulation efficacy of a tannin coagulant agent compared to metal salts for paint manufacturing wastewater treatment, *Desalination and Water Treatment*, 2016, **57**, 19199-19205, doi: 10.1080/19443994.2015.1101016.
[20] Z. Su, X. Li, Y. Yang, Y. Fan, Probing the application of a zirconium coagulant in a coagulation–ultrafiltration process: observations on organics removal and membrane fouling, *RSC Advances*, 2017, **7**, 42329-42338, doi: 10.1039/C7RA08038G.
[21] P. Sharma, H. M. N. Iqbal, R. Chandra, Evaluation of pollution parameters and toxic elements in wastewater of pulp and paper industries in India: a case study, *Case Studies in Chemical and Environmental Engineering*, 2022, **5**, 100163, doi: 10.1016/j.cscee.2021.100163.
[22] Z. Wang, Y. Liao, X. Li, C. Shuang, Y. Pan, Y. Li, A. Li, Effect of ammonia on acute toxicity and disinfection byproducts formation during chlorination of secondary wastewater effluents, *Science of The Total Environment*., 2022, **826**, 153916, doi: 10.1016/j.scitotenv.2022.153916.
[23] I. Haq, A. S. Kalamdhad, Enhanced biodegradation of toxic pollutants from paper industry wastewater using *Pseudomonas* sp. immobilized in composite biocarriers and its toxicity evaluation, *Bioresource Technology Reports*, 2023, **24**, 101674, doi: 10.1016/j.biteb.2023.101674.
[24] I. Haq, A. S. Kalamdhad, Phytotoxicity and cyto-genotoxicity evaluation of organic and inorganic pollutants containing petroleum refinery wastewater using plant bioassay, *Environmental Technology & Innovation*, 2021, **23**, 101651, doi: 10.1016/j.eti.2021.101651.
[25] A. K. Singh, A. Kumar, M. Bilal, R. Chandra, Organometallic pollutants of paper mill wastewater and their toxicity assessment on Stinging catfish and sludge worm, *Environmental Technology & Innovation*, 2021, **24**, 101831, doi: 10.1016/j.eti.2021.101831.
[26] S. Zahmatkesh, M. Hajiaghaei-Keshteli, A. Bokhari, S. Sundaramurthy, B. Panneerselvam, Y. Rezakhani, Wastewater treatment with nanomaterials for the future: a state-of-the-art review, *Environmental Research*, 2023, **216**, 114652, doi: 10.1016/j.envres.2022.114652.
[27] A. Abdelfattah, S. S. Ali, H. Ramadan, E. I. El-Aswar, R. Eltawab, S.-H. Ho, T. Elsamahy, S. Li, M. M. El-Sheekh, M. Schagerl, M. Kornaros, J. Sun, Microalgae-based wastewater treatment: mechanisms, challenges, recent advances, and future prospects, *Environmental Science and Ecotechnology*, 2023, **13**, 100205, doi: 10.1016/j.ese.2022.100205.
[28] A. A. Owodunni, S. Ismail, Revolutionary technique for sustainable plant-based green coagulants in industrial wastewater treatment—a review, *Journal of Water Process Engineering*, 2021, **42**, 102096, doi: 10.1016/j.jwpe.2021.102096.
[29] X. Li, H. Yang, J. Pan, T. Liu, X. Cao, H. Ma, X. Wang, Y.-F. Wang, Y. Wang, S. Lu, J. Tian, L. Gao, X. Zheng, Variation of the toxicity caused by key contaminants in industrial wastewater along the treatment train of Fenton-activated sludge-advanced oxidation processes, *Science of the Total Environment*,

2023, **858**, 159856, doi: 10.1016/j.scitotenv.2022.159856.

[30] R. Kumar, S. Singh, R. Kumar, P. Sharma, Groundwater quality characterization for safe drinking water supply in sheikhpura district of Bihar, India: a geospatial approach, *Frontiers in Water*, 2022, **4**, 848018, doi: 10.3389/frwa.2022.848018.

[31] H. E. Al-Hazmi, A. Mohammadi, A. Hejna, J. Majtacz, A. Esmaeili, S. Habibzadeh, M. R. Saeb, M. Badawi, E. C. Lima, J. Mąkinia, Wastewater reuse in agriculture: prospects and challenges, *Environmental Research*, 2023, **236**, 116711, doi: 10.1016/j.envres.2023.116711.

[32] G. Sakram, S. Kuntamalla, G. Machender, R. Dhakate, A. Narsimha, Multivariate statistical approach for the assessment of fluoride and nitrate concentration in groundwater from Zaheerabad area, Telangana State, India, *Sustainable Water Resources Management*, 2019, **5**, 785-796, doi: 10.1007/s40899-018-0258-0.

[33] P. K. Sahoo, H. S. Virk, M. A. Powell, R. Kumar, J. K. Pattanaik, G. N. Salomão, S. Mittal, L. Chouhan, Y. K. Nandabalan, R. P. Tiwari, Meta-analysis of uranium contamination in groundwater of the alluvial Plains of Punjab, northwest India: status, health risk, and hydrogeochemical processes, *Science of the Total Environment*, 2022, **807**, 151753, doi: 10.1016/j.scitotenv.2021.151753.

[34] A. Kumar, M. V. Singh, P. Wasnik, D. Sridhar, Z. Guo, Toxicity of Chemical Substances in Groundwater of Jhunjhunu District of Rajasthan, India: A Physicochemical Analysis, *ES General*, 2023, **1,** 857, doi: https://dx.doi.org/10.30919/esg857.

[35] D. Saha, S. Marwaha, A. Mukherjee, Groundwater resources and sustainable management issues in India. Saha D, Marwaha S, Mukherjee A, Clean and Sustainable Groundwater in India. Singapore: Springer, 2018, 1-11, doi: 10.1007/978-981-10-4552-3_1.

[36] E. A. Adams, J. Stoler, Y. Adams, Water insecurity and urban poverty in the Global South: implications for health and human biology, *American Journal of Human Biology*, 2020, **32**, e23368, doi: 10.1002/ajhb.23368.

[37] S. Aher, K. Deshmukh, Identifying the impact of intensive agriculture practices on groundwater quality using GIS and multi-tracer techniques around Sangamner city, Maharashtra, India, *Geocarto International*, 2021, **36**, 1136-1160, doi: 10.1080/10106049.2019.1633422.

[38] A. C. Amanambu, Geogenic Contamination: Hydrogeochemical processes and relationships in Shallow Aquifers of Ibadan, South-West Nigeria, *Bulletin of Geography Physical Geography Series*, 2015, **9**, 5-20, doi: 10.1515/bgeo-2015-0011.

[39] L. Belkhiri, T. S. Narany, Using multivariate statistical analysis, geostatistical techniques and structural equation modeling to identify spatial variability of groundwater quality, *Water Resources Management*, 2015, **29**, 2073-2089, doi: 10.1007/s11269-015-0929-7.

[40] D. Banerjee, Mukherjee, Abhijit S. Acharyya, D. Chatterjee, C. Mahanta, D. Saha, S. Kumar, M. Singh, A. Sarkar, S. Sengupta, C. Dubey, D. Shukla, J. N. Raju, A. Singhvi, Contemporary groundwater pollution studies in India: a review, *Proceedings of the Indian National Science Academy*, 2012, **78**, 333-342.

[41] A. Szyguła, E. Guibal, M. A. Palacín, M. Ruiz, A. M. Sastre, Removal of an anionic dye (Acid Blue 92) by coagulation–flocculation using chitosan, *Journal of Environmental Management*, 2009, **90**, 2979-2986, doi: 10.1016/j.jenvman.2009.04.002.

[42] Y.-C. Chung, Y.-H. Li, C.-C. Chen, Pollutant removal from aquaculture wastewater using the biopolymer chitosan at different molecular weights, *Journal of Environmental Science and Health, Part A*, 2005, **40**, 1775-1790, doi: 10.1081/ese-200068058.

[43] A. Soros, J. E. Amburgey, C. E. Stauber, M. D. Sobsey, L. M. Casanova, Turbidity reduction in drinking water by coagulation-flocculation with chitosan polymers, *Journal of Water Health*, 2019, **17**, 204-218, doi: 10.2166/wh.2019.114.

[44] W. Pitakpoolsil, M. Hunsom, Adsorption of pollutants from biodiesel wastewater using chitosan flakes, *Journal of the Taiwan Institute of Chemical Engineers*, 2013, **44**, 963-971, doi: 10.1016/j.jtice.2013.02.009.

[45] W. P. Cheng, F. H. Chi, R. F. Yu, Y. C. Lee, Using chitosan as a coagulant in recovery of organic matters from the mash and lauter wastewater of brewery, *Journal of Polymers and the Environment*, 2005, **13**, 383-388, doi: 10.1007/s10924-005-5533-0.

[46] M. V. Jadhav, Y. S. Mahajan, Investigation of the performance of chitosan as a coagulant for flocculation of local clay suspensions of different turbidities, *KSCE Journal of Civil Engineering*, 2013, **17**, 328-334, doi: 10.1007/s12205-013-2021-2.

[47] F. H. Chi, W. P. Cheng, Use of chitosan as coagulant to treat wastewater from milk processing plant, *Journal of Polymers and the Environment*, 2006, **14**, 411-417, doi: 10.1007/s10924-006-0027-2.

[48] D. Zeng, J. Wu, J. F. Kennedy, Application of a chitosan flocculant to water treatment, *Carbohydrate Polymers*, 2008, **71**, 135-139, doi: 10.1016/j.carbpol.2007.07.039.

[49] R. Fabris, C. W. K. Chow, M. Drikas, Evaluation of chitosan as a natural coagulant for drinking water treatment, *Water Science & Technology*, 2010, **61**, 2119-2128, doi: 10.2166/wst.2010.833.

[50] S. P. Kamble, S. Jagtap, N. K. Labhsetwar, D. Thakare, S. Godfrey, S. Devotta, S. S. Rayalu, Defluoridation of drinking water using chitin, chitosan and lanthanum-modified chitosan, *Chemical Engineering Journal*, 2007, **129**, 173-180, doi: 10.1016/j.cej.2006.10.032.

[51] A. Morillas-España, T. Lafarga, A. Sánchez-Zurano, F. G. Acién-Fernández, C. González-López, Microalgae based wastewater treatment coupled to the production of high value agricultural products: current needs and challenges, *Chemosphere*, 2022, **291**, 132968, doi: 10.1016/j.chemosphere.2021.132968.

[52] A. Gamage, F. Shahidi, Use of chitosan for the removal of metal ion contaminants and proteins from water, *Food Chemistry*, 2007, **104**, 989-996, doi: 10.1016/j.foodchem.2007.01.004.

[53] J. Roussy, M. Van Vooren, E. Guibal, Influence of chitosan characteristics on coagulation and flocculation of organic suspensions, *Journal of Applied Polymer Science*, 2005, **98**, 2070-2079, doi: 10.1002/app.22411.
[54] C. L. Lasko, M. P. Hurst, An investigation into the use of chitosan for the removal of soluble silver from industrial wastewater, *Environmental Science & Technology*, 1999, **33**, 3622-3626, doi: 10.1021/es980443r.
[55] R. Divakaran, V. N. Sivasankara Pillai, Flocculation of kaolinite suspensions in water by chitosan, *Water Research*, 2001, **35**, 3904-3908, doi: 10.1016/S0043-1354(01)00131-2.
[56] J. Roussy, P. Chastellan, M. Van Vooren, E. Guibal, Treatment of ink-containing wastewater by coagulation/flocculation using biopolymers, *Water SA*, 2007, **31**, 369-376, doi: 10.4314/wsa.v31i3.5208.
[57] A. L. Ahmad, S. Sumathi, B. H. Hameed, Coagulation of residue oil and suspended solid in palm oil mill effluent by chitosan, alum and PAC, *Chemical Engineering Journal*, 2006, **118**, 99-105, doi: 10.1016/j.cej.2006.02.001.
[58] K. Thirugnanasambandham, V. Sivakumar, J. Prakash Maran, Application of chitosan as an adsorbent to treat rice mill wastewater—Mechanism, modelling and optimization, *Carbohydrate Polymers*, 2013, **97**, 451-457, doi: 10.1016/j.carbpol.2013.05.012.
[59] H. Altaher, The use of chitosan as a coagulant in the pre-treatment of turbid sea water, *Journal of Hazardous Materials*, 2012, **233-234**, 97-102, doi: 10.1016/j.jhazmat.2012.06.061.
[60] M. Mandloi, S. Chaudhari, G. K. Folkard, Evaluation of natural coagulants for direct filtration, *Environmental Technology*, 2004, **25**, 481-489, doi: 10.1080/09593332508618457.
[61] X. Huang, B. Gao, Y. Wang, Q. Yue, Q. Li, Y. Zhang, Coagulation performance and flocs properties of a new composite coagulant: Polytitanium–silicate–sulfate, *Chemical Engineering Journal*, 2014, **245**, 173-179, doi: 10.1016/j.cej.2014.02.018.
[62] Y. X. Zhao, B. Y. Gao, G. Z. Zhang, S. Phuntsho, H. K. Shon, Coagulation by titanium tetrachloride for fulvic acid removal: factors influencing coagulation efficiency and floc characteristics, *Desalination*, 2014, **335**, 70-77, doi: 10.1016/j.desal.2013.12.016.
[63] F. Bouatay, F. Mhenni, Use of the Cactus Cladodes Mucilage (Opuntia Ficus Indica) As an Eco-Friendly Flocculants: Process Development and Optimization using Statistical Analysis, *International Journal of Environmental Research*, 2014, **8**, 1295-1308. 10.22059/IJER.2014.822.
[64] H. Altaher, E. Tarek, R. Abubeah, An agricultural waste as a novel coagulant aid to treat high turbid water containing humic acids, *Global NEST Journal*, 2016, **18**, 279-290, doi: 10.30955/gnj.001559.
[65] D. Sivakumar, J. Nouri, T. Modhini, K. Deepalakshmi, Nickel removal from electroplating industry wastewater: A bamboo activated carbon, *Global Journal of Environmental Science Management*, 2018, **4**, 325-338, doi: 10.22034/gjesm.2018.03.006.
[66] W. M. Desta, M. E. Bote, Wastewater treatment using a natural coagulant (*Moringa oleifera* seeds): optimization through response surface methodology, *Heliyon*, 2021, **7**, e08451, doi: 10.1016/j.heliyon.2021.e08451.
[67] Y. Wu, X. Fang, X.-T. Yang, C.-Y. Guan, X.-R. Sun, H.-Y. Wu, A. Hu, L.-F. Lin, Q.-Q. Xiao, Comparative study on the removal of organic pollutants by magnetic composite and pre-magnetized zero-valent iron activated persulfate, *Chemosphere*, 2022, **286**, 131722, doi: 10.1016/j.chemosphere.2021.131722.
[68] M. Pritchard, T. Craven, T. Mkandawire, A. S. Edmondson, J. G. O'Neill, A comparison between *Moringa oleifera* and chemical coagulants in the purification of drinking water–An alternative sustainable solution for developing countries, *Physics and Chemistry of the Earth, Parts A/B/C*, 2010, **35**, 798-805, doi: 10.1016/j.pce.2010.07.014.
[69] Y. A. E. I. Nougbodé, C. P. Agbangnan, A. Y. Koudoro, C. A. Dèdjiho, M. P. Aïna, D. Mama, D. C. K. Sohounhloué, Evaluation of the *Opuntia dillenii* as natural coagulant in water clarification: case of treatment of highly turbid surface water, *Journal of Water Resource and Protection*, 2013, **5**, 1242-1246, doi: 10.4236/jwarp.2013.512133.
[70] B. Kakoi, J. W. Kaluli, P. Ndiba, G. Thiong'o, Banana pith as a natural coagulant for polluted river water, *Ecological Engineering*, 2016, **95**, 699-705, doi: 10.1016/j.ecoleng.2016.07.001.
[71] A. R. Karbassi, M. Heidari, An investigation on role of salinity, pH and DO on heavy metals, elimination throughout estuarial mixture, *Global Journal of Environmental Science Management*, 2015, **1**, 41-46, doi: 10.7508/gjesm.2015.01.004.
[72] M. Alazaiza, A. Albahnasawi, G. Ali, M. Bashir, D. Nassani, T. Al Maskari, S. Amr, M. Abujazar, Application of natural coagulants for pharmaceutical removal from water and wastewater: a review, *Water*, 2022, **14**, 140, doi: 10.3390/w14020140.
[73] C. Hu, H. Liu, G. Chen, J. Qu, Effect of aluminum speciation on arsenic removal during coagulation process, *Separation and Purification Technology*, 2012, **86**, 35-40, doi: 10.1016/j.seppur.2011.10.017.
[74] A. G. Caporale, P. Punamiya, M. Pigna, A. Violante, D. Sarkar, Effect of particle size of drinking-water treatment residuals on the sorption of arsenic in the presence of competing ions, *Journal of Hazardous Materials*, 2013, **260**, 644-651, doi: 10.1016/j.jhazmat.2013.06.023.
[75] Y. K. Henneberry, T. E. C. Kraus, J. A. Fleck, D. P. Krabbenhoft, P. M. Bachand, W. R. Horwath, Removal of inorganic mercury and methylmercury from surface waters following coagulation of dissolved organic matter with metal-based salts, *Science of The Total Environment*, 2011, **409**, 631-637, doi: 10.1016/j.scitotenv.2010.10.030.
[76] W. Wang, X. Zhang, H. Wang, X. Wang, L. Zhou, R. Liu, Y. Liang, Laboratory study on the adsorption of Mn(2+) on suspended and deposited amorphous Al(OH)(3) in drinking water distribution systems, *Water Resources*, 2012, **46**, 4063-4070, doi: 10.1016/j.watres.2012.05.017.
[77] Y. W. Chiang, K. Ghyselbrecht, R. M. Santos, J. A. Martens, R. Swennen, V. Cappuyns, B. Meesschaert, Adsorption of multi-heavy metals onto water treatment residuals: Sorption capacities and applications, *Chemical Engineering Journal*, 2012, **200-202**,

405-415, doi: 10.1016/j.cej.2012.06.070.
[78] R. Nilsson, Removal of metals by chemical treatment of municipal waste water, *Water Research*, 1971, **5**, 51-60, doi: 10.1016/0043-1354(71)90185-0.
[79] Y.-J. Tu, C.-K. Chang, C.-F. You, S.-L. Wang, Treatment of complex heavy metal wastewater using a multi-staged ferrite process, *Journal of Hazardous Materials*, 2012, **209-210**, 379-384, doi: 10.1016/j.jhazmat.2012.01.050.
[80] D. Purkayastha, U. Mishra, S. Biswas, A comprehensive review on Cd(II) removal from aqueous solution, *Journal of Water Process Engineering*, 2014, **2**, 105-128, doi: 10.1016/j.jwpe.2014.05.009.
[81] S. Golbaz, A. J. Jafari, M. Rafiee, R. R. Kalantary, Separate and simultaneous removal of phenol, chromium, and cyanide from aqueous solution by coagulation/precipitation: mechanisms and theory, *Chemical Engineering Journal*, 2014, **253**, 251-257, doi: 10.1016/j.cej.2014.05.074.
[82] M. Kang, T. Kamei, Y. Magara, Comparing polyaluminum chloride and ferric chloride for antimony removal, *Water Research*, 2003, **37**, 4171-4179, doi: 10.1016/S0043-1354(03)00351-8.
[83] S. M. Rodrigues, B. Henriques, A. T. Reis, A. C. Duarte, E. Pereira, P. F. A. M. Römkens, Hg transfer from contaminated soils to plants and animals, *Environmental Chemistry Letters*, 2012, **10**, 61-67, doi: 10.1007/s10311-011-0329-z.
[84] E. K. Mahmoud, A. M. Ghoneim, Effect of polluted water on soil and plant contamination by heavy metals in El-Mahla El-Kobra, Egypt, *Solid Earth*, 2016, **7**, 703-711, doi: 10.5194/se-7-703-2016.
[85] R. Eisler, S. N. Wiemeyer, Cyanide hazards to plants and animals from gold mining and related water issues, *Reviews of Environmental Contamination and Toxicology,* 2004, **183**, 21-54, doi: 10.1007/978-1-4419-9100-3_2.
[86] R. Eisler, Arsenic hazards to humans, plants, and animals from gold mining, *Reviews of Environmental Contamination and Toxicology*, 2004, **180**, 133-165, doi: 10.1007/0-387-21729-0_3.
[87] B. A. Manny, D. Kenaga, The Detroit River: effects of contaminants and human activities on aquatic plants and animals and their habitats. Munawar M, Edsall T, Environmental assessment and habitat evaluation of the upper great lakes connecting channels, Dordrecht: Springer, 1991: 269-279.10.1007/978-94-011-3144-5_16.
[88] P. E. Stackelberg, E. T. Furlong, M. T. Meyer, S. D. Zaugg, A. K. Henderson, D. B. Reissman, Persistence of pharmaceutical compounds and other organic wastewater contaminants in a conventional drinking-water-treatment plant, *Science of The Total Environment*, 2004, **329**, 99-113, doi: 10.1016/j.scitotenv.2004.03.015.
[89] Q. Wang, Y. Cui, Y. Dong, Phytoremediation of polluted waters potentials and prospects of wetland plants, *Acta Biotechnologica*, 2002, **22**, 199-208, doi: 10.1002/1521-3846(200205)22: 1/2199: AID-ABIO199>3.0.CO;2-T.
[90] W. Li, Y. Shi, L. Gao, J. Liu, Y. Cai, Occurrence of antibiotics in water, sediments, aquatic plants, and animals from Baiyangdian Lake in North China, *Chemosphere*, 2012, **89**, 1307-1315, doi: 10.1016/j.chemosphere.2012.05.079.
[91] E. Ranieri, P. Gikas, Effects of plants for reduction and removal of hexavalent chromium from a contaminated soil, *Water, Air, & Soil Pollution*, 2014, **225**, 1981, doi: 10.1007/s11270-014-1981-2.
[92] L. Knobeloch, B. Salna, A. Hogan, J. Postle, H. Anderson, Blue babies and nitrate-contaminated well water, *Environmental Health Perspectives*, 2000, **108**, 675-678, doi: 10.1289/ehp.00108675.
[93] M. V. Singh, Waste and virgin high-density poly(ethylene) into renewable hydrocarbons fuel by pyrolysis-catalytic cracking with a $CoCO_3$ catalyst, *Journal of Analytical and Applied Pyrolysis*, 2018, **134**, 150-161, doi: 10.1016/j.jaap.2018.06.003.
[94] M. V. Singh, S. Kumar, M. Sarker, Waste HD-PE plastic, deformation into liquid hydrocarbon fuel using pyrolysis-catalytic cracking with a $CuCO_3$ catalyst, *Sustainable Energy & Fuels*, 2018, **2**, 1057-1068, doi: 10.1039/C8SE00040A.
[95] M. V. Singh, Conversions of waste tube-tyres (WTT) and waste polypropylene (WPP) into diesel fuel through catalytic pyrolysis using base $SrCO_3$, *Engineered Science*, 2021, **13**, 87-97, doi: 10.30919/es8d1158.
[96] M. V. Singh, Pyrolysis of waste polyolefins into liquid petrochemicals using metal carbonate catalyst, *Engineered Science*, 2022, **19**, 285-291, doi: 10.30919/es8d699.
[97] V. S. Man, Deformation of waste tube-tyres into liquid green hydrocarbons (LGHs) through pyrolysis using the $FeCO_3$, *Materials Today: Proceedings*, 2022, **51**, 1669-1674, doi: 10.1016/j.matpr.2020.08.689.
[98] M. V. Singh, S. Kumar, Pyrolysis of waste polyolefins and e-component to produce renewable green fuel over cadmium carbonate, *Green Materials*, 2022, **10**, 127-136, doi: 10.1680/jgrma.21.00024.
[99] M. V. Singh, A $BaCO_3$ nanomaterial for pyrolysis of sustainable waste and virgin polystyrene into green aromatic derivatives, *Chemistry Select*, 2023, **8**, e202204400, doi: 10.1002/slct.202204400.
[100] M. V. Singh, Pyrolysis processes and physiochemical properties of liquid hydrocarbon fuel from waste plastics, *Chemical Engineering & Technology*, 2023, **46**, 1411-1423, doi: 10.1002/ceat.202200519.

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