ZIBELINE INTERNATIONAL™ PUBLISHING

Water Conservation & Management (WCM)

DOI: http://doi.org/10.26480/wcm.04.2025.758.765

ISSN: 2523-5664 (Print)
ISSN: 2523-5672 (Online)
CODEN: WCMABD

CrossMark

RESEARCH ARTICLE

TREE LEAVES AS NON-FAMILIAR ADSORBENT MEDIA FOR ADDRESSING SOLUTIONS CONTAMINATED BY EUTROPHICATION ANIONS

Yasir A. J. Alhamadani[a], Saad Saber Abbas[b], Hawraa Ali Hashim[b], Younus Mohammed Abed[b], Mohammed Nsaif Abbas[c]*

[a]Directorate of Construction and Building, Ministry of Higher Education and Scientific Research, Baghdad, Iraq.
[b]Ministry of Education, General Directorate of Education, Baghdad Karkh III, Baghdad, Iraq.
[c]Materials Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
**Corresponding Author Email: mohammed.nsaif.abbas@uomustansiriyah.edu.iq*

Article History:

Received 11 September 2025
Revised 21 October 2025
Accepted 17 November 2025
Available online 16 December 2025

ABSTRACT

The current study aims to evaluate the conversion of virgin Eucalyptus leaves from domestic troublesome waste into a suitable adsorption medium for removing nitrate anions from simulated polluted aqueous solutions, using a batch-type adsorption unit and at notable range of operating parameters. Virgin Eucalyptus leaves were collected from northern Baghdad during the winter, washed, dried, then ground and sifted. The largest quantity of powder was used in the subsequent treatment step. The study investigated the effect of changing temperature, contact time, and agitation speed as operating conditions for the adsorption unit, while the contaminated solution variables varied between pH and initial nitrate ion concentration. The dosage of virgin Eucalyptus leaves powder was the key factor in determining the efficiency of the adsorptive treatment process. The results obtained from the experiments indicated that the powder of virgin Eucalyptus leaves has a good ability for recovering nitrate anions from contaminated simulated solutions. The efficiency was increased with increasing agitation speed, contact time, and adsorbent dose, while it decreased with increasing initial concentration of the target anions and temperature. The pH of the solution had a bi-behavior effect on efficiency, with removal increasing in acidic zone and decreasing in alkaline zone. The acidity function exhibited a dual behavior, increasing with rising pH values between 1-6, while in the alkaline range the percentage removal decreased dramatically. The optimal time for the adsorption process was two hours, as 6.5 g of virgin Eucalyptus leaves powder was able to remove 78% of 73 ppm concentration of the nitrate anions at room temperature, neutral-acidic pH, and moderate agitation speed. Based on the above results, the virgin Eucalyptus leaves confirm their ability to be a useful and important material in maintaining ecological balance, through the treatment of wastewater contaminated with nitrate anions, especially in agricultural areas that produce this type of pollutant as a byproduct of fertilizer use.

KEYWORDS

Adsorption, Batch-unit, Eucalyptus leaves, Eutrophication, and Nitrate anion.

1. INTRODUCTION

Pollution issue is one of the most serious environmental issues that concerns scientists and specialists around the world, due to its direct repercussions on human health and the sustainability of ecosystems, soils, and water resources, which are the basis of life, economic and social development (Abd Ali et al., 2024). Water pollution can be defined as any change in the physical, chemical, or biological properties of water that makes it unsuitable for various uses such as drinking, agriculture, industry, and aquatic life (Hashem et al., 2021). In general, this contamination results from increasing the performance of various human activities, which cause the introduction of foreign, non-native substances called "pollutants", including physical, chemical, and biological pollutants, into the aquatic environment, leading to a change in its quality (Khaleel et al., 2022). Variable properties such as salinity, color, temperature, turbidity, total suspended solids, and dissolved oxygen content of water fall under the category of physical pollution (Abbas and Abbas, 2013a). While water is classified as biologically polluted if it contains harmful microorganisms such as bacteria, algae, protozoa, viruses, parasites, and fungi (Ali and Abbas, 2020). However, the most dangerous and impactful type is chemical pollution, which results from an increase in the concentration of various chemicals, such as heavy metals, dyes, eutrophication elements, pesticides, and the like, in water sources, beyond the levels permitted regionally or internationally. (Abbas and Alalwan, 2019). One of the most important types of chemical pollution is pollution by eutrophication elements (phosphate and nitrate anions), due to its widespread and often imperceptible presence, in addition to its harmful effects on humans, other organisms, and ecosystems (Sridhar et al., 2025). Various agricultural activities, the use of nitrogen fertilizers, and animal waste contribute significantly to surface and groundwater pollution with nitrate anions in agricultural and rural areas, while industrial waste, inefficient sewage systems, and their little natural occurrence contribute to water pollution with nitrate anions in cities (Duda et al., 2023). This type of chemical pollution was particularly observation in the 1950s, in

Quick Response Code	Access this article online	
	Website: www.watconman.org	**DOI:** 10.26480/wcm.04.2025.758.765

Cite The Article: Yasir A. J. Alhamadani, Saad Saber Abbas, Hawraa Ali Hashim, Younus Mohammed Abed, Mohammed Nsaif Abbas (2025). Managing Water ScarcityThrough Policy And Institutional Reform : Tree Leaves As Non-Familiar Adsorbent Media For Addressing Solutions Contaminated By Eutrophication Anions. Water Conservation & Management, 9(4): 758-765.

the midst of the "Green agricultural revolution", which encouraged the wider use of chemical fertilizers and reduced reliance on organic types, for more development of agriculture (Navarro et al., 2025). Concurrent studies in the 1950s and 1960s played a major role in guidance the attention to this environmental issue and its future health effects, especially in developed countries in North America and Europe, where they confirmed the presence of high concentrations of nitrate anions in well water and agricultural waste in those regions of the world (Novotny, 1999). The results of these studies were not properly addressed, and due to the need to increase agricultural production to meet the growing demand for food resulting from population growth, the excessive use of nitrogen fertilizers has exacerbated this problem in many other countries of the world due to the lack of suitable infrastructure to treat the rising concentrations of nitrate anions in the polluted wastes of agricultural and industrial activities (Abbas and Abbas, 2013b). Ins spite of fertilizers is considered as a major source, practical monitoring has identified numerous other sources of nitrate anion pollution, both natural and human-caused. Naturally, the biological break down of organic substances, followed by natural sediment and acid rain, are among the most important sources. Human activities, however, constitute the largest share, with sewage and industrial wastewater discharge being the second largest source of nitrate anions polluting water, beyond the fertilizer. Nitrogen oxide emissions from power plants and vehicles, resulting from the burning of fossil fuels, also contribute to the problem (Abbas and Abbas, 2013c). Nitrate anions are considered safe for humans at certain concentrations, but their danger lies in the conditions that allow them to be converted within the body into divalent nitrite anions. These nitrites can cause severe health problems, most notably blue baby syndrome (methemoglobinemia), and are also related to certain types of cancer in adults, such as bladder, prostate, and pharyngeal cancer, as they are classified as toxic and carcinogenic substances (Cao et al., 2022). Given the negative public health effects associated with nitrate anion pollution, many international health and environmental organizations and agencies have established rigorous limits for this substance in drinking water. The World Health Organization, the European Commission, and many countries, including Iraq, have set a permissible concentration of nitrate anions in potable water at 50 ppm. However, the situation differs in the United States, where the Environmental Protection Agency (EPA) has set a much stricter limit of no more than 10 ppm for nitrates anions in drinking water, reflecting the importance of the issue and the seriousness of the potential impacts (Seyyedsalehi et al., 2023). Beyond human impact, other environmental elements are not immune to the effects of pollution from these dangerous anions. The phenomenon of eutrophication is primarily a result of increased concentrations of nitrate and phosphate anions in water bodies. This phenomenon poses additional risks to aquatic life due to the dense growth of algae, which blocks sunlight and depletes dissolved oxygen essential for various forms of aquatic life, especially fish, leading to their perdition and resulting in economic losses as well as environmental damage. Furthermore, these invasive algae provide a safe haven for predators and harmful organisms such as snakes and rodents, exacerbating existing problems and disrupting the ecological balance. As for the soil, the continuous accumulation of nitrate anions-resulting from the disposing of fertilizer residue and other agricultural and industrial byproducts-degrades soil quality, alters its properties, and renders it unsuitable for agricultural use (Navarro et al., 2025). Therefore, it has become important, indeed urgent, to address pollution with all possible means and make this issue a priority that cannot be postponed, given its negative effects on humans, the environment, and living organisms. This requires continuous work to develop and update existing methods, as well as to innovate new approaches and techniques that contribute for removing pollution in general or, at the very least, reducing the concentrations of harmful and toxic substances to permissible levels (Abbas and Abbas, 2014). Currently, there are many methods that have proven effective in treating pollutants in general, including nitrates, such as ion exchange, reverse osmosis, coagulation-flocculation, electrolysis, advanced oxidation, ozonation, filtration, evaporation, distillation, precipitation, reduction, biological treatment, and others (Abbas et al., 2019a). Although many of these methods are classified as environmentally friendly, they have several drawbacks that warrant further review. These disadvantages include the high cost, specialized equipment required, the need for large areas or preliminary treatment, high energy consumption, the generation of toxic waste requiring additional treatment, and the risk of microbial contamination due to unintentional errors or negligence. Furthermore, they require skilled labor and ongoing, expensive maintenance (Abbas et al., 2019b). In contrast, adsorption technology stands out as one of the portentous manners in treating contaminants, which calls for attention to it and its development, given its various advantages, including that it is eco-friendly, economical and inexpensive, and does not involve large areas or pre-treatments, in addition to its ability to remove different pollutants in extreme conditions, not only from polluted water, but also from air, soil, and even crude oil (Alalwan et al., 2021). According to confirmed studies, adsorption as a treatment manner has been successful in purifying contaminated media due to the properties of renowned adsorbent materials such as silica gel (Ito et al., 2024), zeolite (Khudair et al., 2024), activated carbon (Maddodi et al., 2020), alumina (Shadhan et al., 2024), and others. This behavior is attributed to the unique and distinctive properties of these adsorbents, like their high surface area, diverse functional groups, and large capacity, which have enabled them to occupy a distinguished position among other materials used. However, the use of these highly efficient adsorbents also presented economic challenges. Their manufacturing is costly, and they require continuous regeneration after each use. Furthermore, their mass constantly decreases due to contact with contaminated solutions, ultimately accumulating as toxic substances that require specialized treatment for safe disposal (Abbas et al., 2020). All these limitations have led to a decline in their use and searching for alternative materials that are both cost-effective and possess adequate treatment efficiency (Alsarayreh et al., 2025a). One of the most important alternatives available that has attracted the attention of researchers and experts is agricultural and industrial waste such as pomegranate peels (Ali et al., 2024b), orange peels (Hasan et al., 2021), watermelon rinds (Abbas and Nussrat, 2020), rice husks (Alalwan et al., 2018), tangerine peels (Gadooa et al., 2025), banana peels (Abdullah et al., 2023), pistachio peels (Ali et al., 2025), almond shell (Hameed et al., 2025), mandarin peels (Alhamd et al., 2024a), waste tea leaves (Al-Ali et al., 2023), sunflower seed husks (Abdulkareem et al., 2023), lemon peels (Al-Hermizy et al., 2022), eggshells (Ali et al., 2020a), mango peels (Abed et al., 2025a), pineapple peels (Ibrahim et al., 2025a), aluminum foil (Ghulam et al., 2020), plastic (Abed et al., 2025b), water hyacinth (Al-Hermizy et al., 2025), and tree leaves such as buckthorn (Alhamd et al., 2024b), tangerine (Mahmood et al., 2025), *Eucalyptus* (Ali et al., 2024a), and others, either by using them as adsorption media directly or by treating them acidically or alkalinely or by converting them into activated or nanomaterials to increase their efficiency and improve their properties (Ali et al., 2021). Despite the variety of pollutants, these agricultural and industrial wastes had a distinct and clear ability to be treated and removed, including biological stains (Hameed and Abbas, 2024), dyes (Alwan et al., 2021), eutrophication elements (Abbas, 2015), hardness (Ibrahim et al., 2021), heavy metals (Ali et al., 2023), inorganic toxic (Alalwan et al., 2020), metals of petroleum origin such as vanadium (Hasan et al., 2025), organic acid residues (Alsarayreh et al., 2024), pesticides (Abd ali et al., 2018), pharmaceutical waste (Ibrahim et al., 2020a), and sulfate anions (Abbas and Ibrahim, 2020). Although these residues accumulate as toxic waste most of the time after the treatment process is complete, the properties of these materials have highlighted the possibility of utilizing by converting them from harmful materials into additives to enhance the performance of concrete (Abbas et al., 2022a), rodenticides for rats (Ibrahim et al., 2020b) and rabbits (Abd Al-Latif et al., 2023), raw materials for preparing chemical substances such as acetone (Abbas et al., 2022b), catalysts (Abbas et al., 2021), nanomaterials (Alminshid et al., 2025), promoted bioethanol (Hamdi et al., 2024), or by converting them into soil fertilizer (Ibrahim et al., 2025b). Accordingly, the main purpose of the current study is to investigate the conversion of virgin *Eucalyptus* leaves from agricultural waste into an adsorbent material for recovering nitrate anions from contaminated solutions using a batch adsorption unit and to determine the optimal operating conditions for the process.

2.METHODOLOGY

2.1 Eucalyptus leaves

Virgin *Eucalyptus* leaves were collected from *Eucalyptus* trees in orchards and agricultural lands in the Al-Taji area, north of Al-Kadhimiya district, between December 1, 2024, and December 30, 2024. The collected leaves were selected for their freshness, appearance, and lack of tearing or damage, to ensure their integrity and freedom from pathogens that could affect their performance as an adsorption medium. The collected leaves were washed with excess tap water, then with water and liquid soap to ensure they were clean and free of any remaining impurities, dirt and mud, before being rinsed twice with double distilled water. The clean leaves were dried in two stages. First, they were exposed to open air in a clean place at a temperature of 25-28°C for 10 hours per day for five days. Then they were dried in an electric oven at 50°C for no more than 6 hours, or until the leaves reached a stable weight. The dried leaves were ground twice using a household grinder, and the powder was then sieved according to the method described in Figure 1 (Rajaa et al., 2023). The powder from virgin *Eucalyptus* leaves passing through a 1 mm (18 mesh) sieve was selected as it was the largest quantity, as shown in Figure 2. The powder was stored in 500 cm^3 amber jars in a dark, dry place at 4°C until use.

Figure 1a: Eucalyptus leaves

Figure 1b : Eucalyptus leaves powder

Figure 1 : Virgin Eucalyptus leaves used in the current investigation

2.2 Stock solution of nitrate anions

To prepare a stock solution with a concentration of 500 ppm nitrate anions, potassium nitrate salt was used due to its high-water solubility of up to 130 g/L. Mass of 0.83 g of potassium nitrate, supplied by Yingfengyuan Industrial Group Limited-China of 99% purity as a white powder, was dissolved in an unspecified amount of double-distilled water. The dissolution process was carried out under normal laboratory conditions at 20°C using a magnetic stirrer at 150 rpm. After dissolution, the nitrate anion solution was transferred using a clean, sterile glass funnel into a volumetric flask and diluted to 500 mL with double-distilled water. The solution was stored in a clean, dry place, and the flask was covered with two layers of aluminum foil to prevent light penetration and avoid any unintended changes.

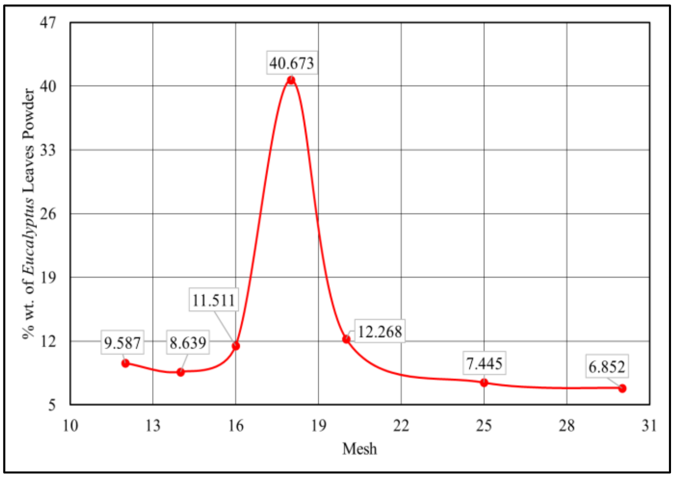

Figure 2 : Sieve analysis of *Eucalyptus* leaves used in this study

2.4 Calibration curve

Concentration of nitrate anions in the stock solution and adsorption-treated solutions were determined using a UV-Visible spectrophotometer, Shimadzu UV 1800 (Japan) through the calibration curve which has been prepared particularly for this study. After accurately determining nitrates anion in the aqueous phase once its adsorption byproduct, was calculated from noticing how much nitrate anion had remained in the aqueous solution after absorption was enough for this graph to offer, the *Eucalyptus* leaves % removal and their maximum absorptive capacity. The calibration curve was made using the procedure outlined in by measuring the absorbance of a number of standard nitrate anion solutions with known concentrations at a wavelength of 439 nm. In order to create a colorful complex, ammonium molybdate was added and then chemically reduced with hydrazine in an acidic environment. The calibration curve was created by recording and charting the matching absorbance values. Every concentration measurement was made three times to guarantee analytical accuracy, and the curve was created using the mean values. The calibration curve that was created and utilized to determine the nitrate anion concentrations in this study is displayed in Figure 3.

2.5 Adsorption Experiments

To avoid interference with other elements, ions, and any other substances may be presented in real polluted water, the ability of virgin *Eucalyptus* leaves powder to adsorb nitrate anions was tested using simulated solutions at specific concentrations of the pollutant. The test solutions were prepared by diluting the stock solution to the specified concentration using double-distilled water, while the pH of the contaminated solution was adjusted using 0.1 N concentration solutions of 37% hydrochloric acid and high-purity white flakes sodium hydroxide, supplied by “Wuhan Newradar Trade Company Limited” and “Fengchen Group”, respectively. The agitation speed and temperature of the water bath shaker were set before the required dose of virgin *Eucalyptus* leaves powder was added. The experimental flasks, wrapped in tightly secured aluminum foil, were loaded into the apparatus, and the experiment continued until the end of the required time period. The samples were carefully extracted from the water bath shaker device and the solution was filtered using Whitmann 41® filter paper to remove the *Eucalyptus* leaves powder.

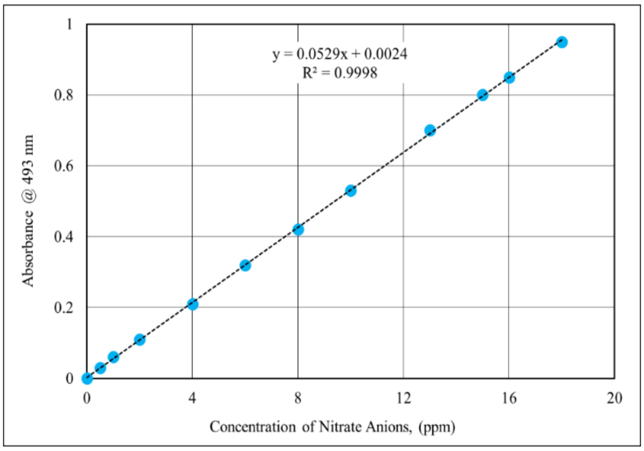

Figure 3 : UV-Vis. calibration curve of nitrate anion used in this study

The residual concentration of nitrate anions was examined using a UV-Vis. spectrophotometer and a calibration curve, while the treatment efficiency and adsorption capacity were determined using equations (1) and (2) (Alsarayreh et al., 2025b) respectively:

$$\%R = \frac{C_1 - C_2}{C_1} \times 100 \quad (1)$$

$$q = \frac{V}{m}(C_1 - C_2) \quad (2)$$

Where: Where: C_1 and C_2: The initial and final concentrations of nitrate anions in the solution before and after adsorption, ppm, respectively; $\%R$: Percentage removal of nitrate anion using *Eucalyptus* leaves powder (dimensionless); V: Volume of solution = 100 cm^3, and m: Mass of *Eucalyptus* leaves powder used in each experiment. q: Adsorption capacity measured as ratio of the milligrams of nitrate anions adsorbed per gram of *Eucalyptus* leaves powder (mg/g).

3. Results And Discussion

This part will discuss the experimental results obtained from changing the various operational variables within the studied ranges. The findings will be interpreted in light of the hypotheses and other documented references that support the results of this investigation.

3.1 Effect of pH varying on the removal of nitrate anion

The effect of pH change on the removal efficiency of nitrate anions using virgin *Eucalyptus* leaves powder was studied within a range of 1–9, while the other designing variables were kept constant at 1 g, 180 min, 250 rpm, 1 ppm, and 25 °C for adsorbent dose, contact time, agitation speed, initial concentration of nitrate anion in the contaminated solution, and temperature, respectively. The results of studying of this variable, shown in Figure 4, indicate that the relationship between treatment efficiency and the change in pH of the contaminated solution is a direct relationship in the range between 1 and 6, where the treatment efficiency starts to increase from 3.3% to 23%, respectively. This behavior can be explained by the interaction of several simultaneous mechanisms affecting both the state of the pollutant and the surface chemistry of the adsorbent. At very low pH, hydrogen ions (H^+) are abundant and compete strongly for functional groups at active sites on the adsorption surface, reducing the binding of nitrate anions and thus decreasing removal efficiency (Alhamd et al., 2024a). However, as pH rises, competition decreases and the surface charge of virgin *Eucalyptus* leaves changes, increasing the uptake of target anions until an equilibrium is reached at pH 6, where effective binding sites are available without saturation or inhibition (Alminshid et al., 2021). A rapid decrease is likely related to a change in the chemical species of the pollutant to a form less readily retained at the surface, or the pollutant becoming associated with hydroxides or other ions, forming soluble or stable compounds that reduce its adsorption potential (Abbas et al., 2019a).

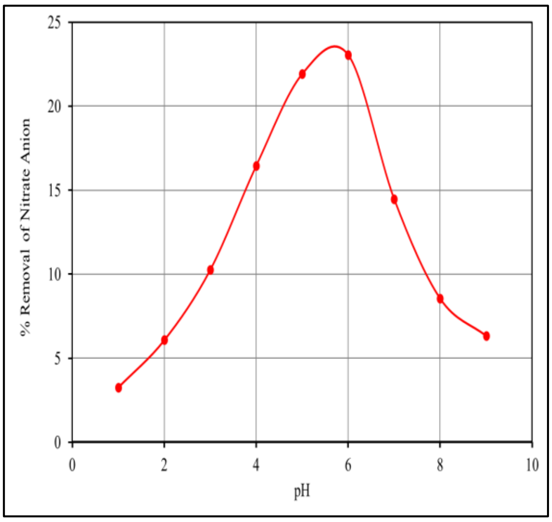

Figure 4: Effect of pH on the nitrate anions removal efficiency

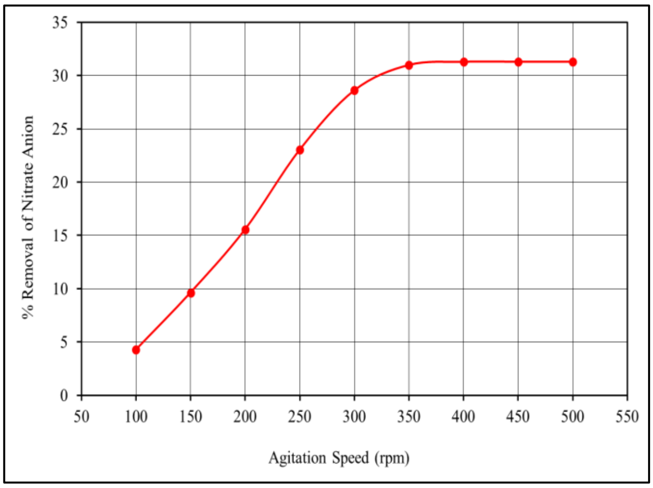

Figure 5 : Effect of agitation speed on the nitrate anions removal efficiency

3.2 Effect of agitation speed varying on the removal of nitrate anion

The effect of agitation speed change on the removal efficiency of nitrate anions using virgin *Eucalyptus* leaves powder was studied within a range of 100–500 rpm, while the other designing variables were kept constant at 1 g, 180 min, 6, 1 ppm, and 25 °C for adsorbent dose, contact time, acidity of polluted solution, initial concentration of nitrate anion in the contaminated solution, and temperature, respectively. The results of studying of this variable, shown in Figure 5, indicate that increasing the agitation speed initially led to a gradual increase in removal efficiency from 4% at 100 rpm to 31% at 350 rpm, as the mixing between the solid (virgin *Eucalyptus* leaf powder) and liquid (solution contaminated with nitrate anions) phases increased, which improved mass transfer and accelerated the arrival of the target anions to the active surface of the adsorbent (Ibrahim et al., 2021). However, the efficiency of treatment abide constant at agitation speeds above 350 rpm, and no significant increase occurred in its maximum value. This behavior can be explained by the fact that increasing the agitation speed within the lower range reduces the resistance of the boundary layer surrounding the virgin *Eucalyptus* leaves, thus increasing the rate of outward diffusion and enhancing adsorption (Al-Ali et al., 2023). Furthermore, exceeding 350 rpm leads the system to a state of dynamic equilibrium where no further improvement occurs, as mass transfer is no longer the determining factor in the process (Al-Hermizy et al., 2025). Consequently, the removal efficiency stabilizes at a constant value representing the maximum possible efficiency under the experimental conditions studied.

3.3 Effect of initial concentration varying on the removal of nitrate anion

The effect of initial concentration change on the removal efficiency of nitrate anions using virgin *Eucalyptus* leaves powder was studied within a range of 1–75 ppm, while the other designing variables were kept constant at 1 g, 180 min, 6, 350 rpm, and 25 °C for adsorbent dose, contact time, acidity of polluted solution, agitation speed of the contaminated solution, and temperature, respectively. The results of studying of this variable, shown in Figure 6, indicate that the removal efficiency gradually decreases with increasing initial concentration of the contaminating nitrate anions. This behavior is attributed to several interrelated factors. At low concentrations, the available active sites on the surface of the adsorbent are abundant compared to the number of nitrate anions in the contaminating solution, allowing for the adsorption of a large proportion and achieving high removal efficiency (Hasan et al., 2025). However, increasing the initial concentration leads to an increase in the number of nitrate anions competing for the same number of active sites without a corresponding increase in the number of active sites, resulting in gradual surface saturation and a decrease in processing efficiency (Mahmood et al., 2025). Furthermore, at high concentrations, the driving force for mass transfer decreases due to the reduced concentration difference between the liquid phase and the adsorbent surface, thus limiting the adsorption rate (Ali et al., 2025). Moreover, increased solution viscosity at high concentrations may hinder intraparticle diffusion and reduce the efficient delivery of anions to internal active sites (Abed et al., 2025b). The formation of surface layers of adsorbed ions can also obstruct the remaining sites and prevent complete reaction, thus demonstrating the inverse relationship between initial pollutant concentration and removal efficiency (Gadooa et al., 2025).

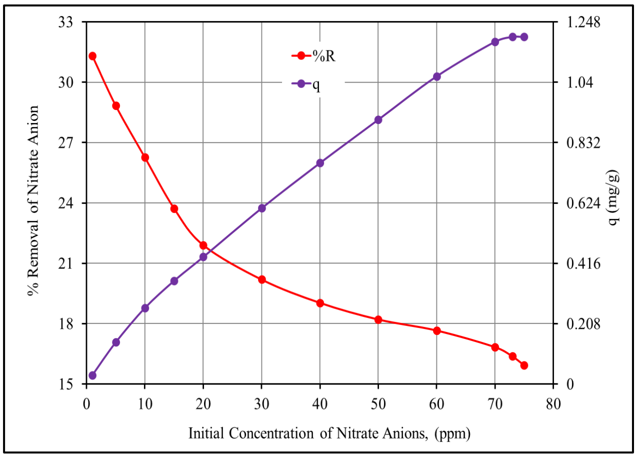

Figure 6: Effect of initial concentration on the nitrate anions removal efficiency

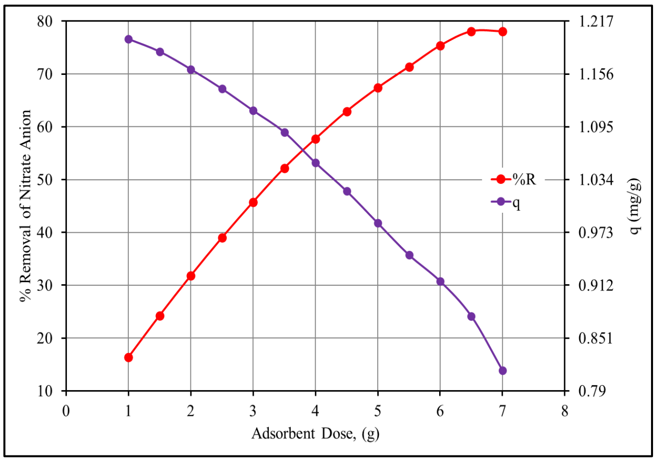

Figure 7: Effect of adsorbent dose on the nitrate anions removal efficiency

3.4 Effect of adsorbent dosage varying on the removal of nitrate anion

The effect of adsorbent dose change on the removal efficiency of nitrate anions using virgin *Eucalyptus* leaves powder was studied within a range of 1–7 g, while the other designing variables were kept constant at 73 ppm, 180 min, 6, 350 rpm, and 25 °C for initial concentration of nitrate anion in the contaminated solution, contact time, acidity of polluted solution, and temperature, respectively. The results of studying this variable, shown in Figure 7, indicate that the processing efficiency gradually increases with increasing the adsorbent dose, rising from 16.4% at 1 g to 78% at 6.5 g, then stabilizing at approximately the same level despite increasing the dose to 7 g. This behavior is attributed to the fact that increasing the mass of virgin *Eucalyptus* leaves provides a greater number of active sites capable of trapping nitrate anions from the contaminating solution, thus increasing the surface area available for adsorption and improving the likelihood of the target anions reaching the functional groups responsible for adsorption process, and consequently increasing the removal efficiency (Hameed and Abbas, 2024). However, the stability of efficiency at high doses may be due to the saturation of most active sites with nitrate anions, thus reaching an equilibrium state between the pollutant dispersed in the solution and the surface of virgin *Eucalyptus* leaves (Hameed et al., 2025). Additionally, agglomeration of the adsorbent molecules may occur at high concentrations, reducing the effective surface area and limiting further adsorption efficiency (Hasan et al., 2025). This phenomenon can also be explained by the decreasing relative concentration of the pollutant compared to the amount of adsorbent, so that there are not enough available ions to fill all the active sites, which leads to a relative stability in removal efficiency at higher doses, which reflects the system reaching saturation or maximum effectiveness of the adsorption process under the operating conditions used (Ibrahim et al., 2025b).

3.5 Effect of contact time varying on the removal of nitrate anion

The effect of contact time change on the removal efficiency of nitrate anions using virgin *Eucalyptus* leaves powder was studied within a range of 10–180 minutes, while the other designing variables were kept constant at 6.5 g, 73 ppm, 6, 350 rpm, and 25 °C for adsorbent dose, initial concentration of nitrate anion, acidity of polluted solution, agitation speed of the contaminated solution, and temperature, respectively. The results of studying of this variable, shown in Figure 8, indicate that the removal efficiency gradually increases with increasing contact time from 6% at 10 minutes until it reaches a steady state at 78% after 120 minutes, reflecting typical behavior of adsorption processes that depend on the interaction between the pollutant and the active sites on the surface of the adsorbent material. The remarkable stability in efficiency after 120 minutes indicates that the system has reached a state of equilibrium, where the adsorption rate is balanced with the separation rate, and therefore there is no significant change in the removal rate despite the increasing the contact time (Alhamd et al., 2024b). The relative stability in the rate of increase after two hours can be explained by surface saturation or the weakness of residual attractive forces compared to the thermal kinetic energy of the adsorbed molecules (Alsarayreh et al., 2025b). Therefore, the optimal contact time for this process is approximately 120 minutes, after which no further improvement in performance is achieved. This indicates that the removal process is governed by a dynamic equilibrium between adsorption and desorption, within the limits of the structural properties of virgin *Eucalyptus* leaves and the nature of the nitrate anions dispersed in the contaminated solution.

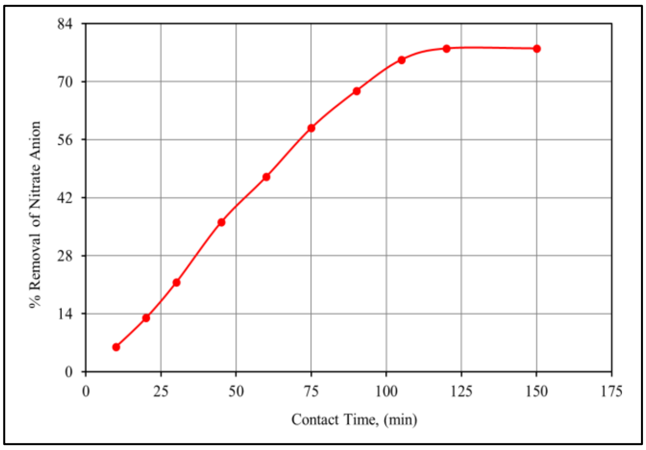

Figure 8: Effect of contact time on the nitrate anions removal efficiency

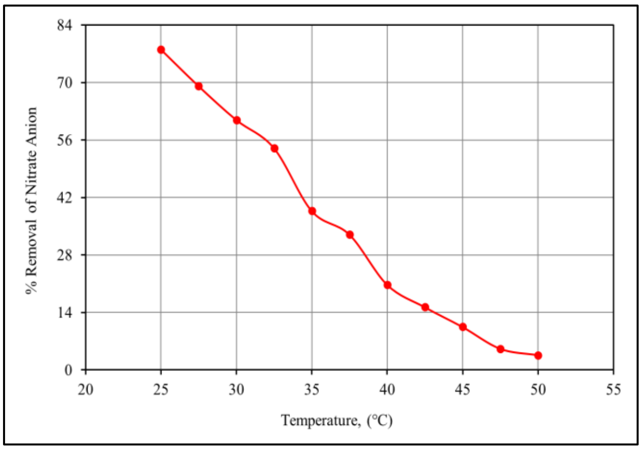

Figure 9: Effect of temperature on the nitrate anions removal efficiency

3.6 Effect of temperature varying on the removal of nitrate anion

The effect of temperature on the removal efficiency of nitrate anions using virgin *Eucalyptus* leaves powder was studied within a range of 25–50 °C, while the other designing variables were kept constant at 6.5 g, 73 ppm, 6, 350 rpm, and 120 minutes for adsorbent dose, initial concentration of nitrate anion, acidity of polluted solution, agitation speed of the contaminated solution, and contact time, respectively. The results of studying of this variable, shown in Figure 9, indicate that the removal efficiency gradually decreases with increasing temperature from 25 to 50 °C, demonstrating that the adsorption process is exothermic in nature. At low temperatures, the bonding forces between nitrate anions in the contaminated solution and the surface of *Eucalyptus* leaves are stronger, as the lower kinetic energy of the target anions allows them a greater opportunity to bind to the active sites (Abbas et al., 2019a). At higher temperatures, the reverse direction of the adsorption process is favored due to the weakening attraction between the nitrate anions dispersed in the contaminating solution and the surface of virgin eucalyptus leaves (Ali et al., 2024a). These combined behaviors explain the marked decrease in removal efficiency with increasing temperature, confirming that the adsorption process in this system is governed by heat-sensitive physical and chemical mechanisms exhibiting an exothermic character (Alwan et al., 2021).

4. Conclusions

The leaves of trees, including *Eucalyptus* trees, fall in orchards, gardens, and even streets of cities, causing significant pollution of water and soil. This makes it a direct cause of blocked drains and sewers, blocking sunlight from aquatic life in waterbodies, polluting large areas of land with agricultural waste, and providing a suitable environment for the breeding of rodents and harmful organs such as snakes, if their quantities are large as a result of accumulation. However, the results of the current study show that virgin *Eucalyptus* leaves are a solution, not an issue, as they represent a viable and economical option through the application of the zero-residue level concept according to the environmental sustainability approach. The data obtained demonstrated that *Eucalyptus* leaves powder passing through an 18-mesh sieve is a highly efficient, readily available, and inexpensive adsorption medium for recovering nitrate anions from contaminated solutions. Sixty-five g of these virgin leaves powder can treat one liter of water contaminated with nitrate anions at a concentration more than seven times the limit set by the US Environmental Protection Agency (EPA) at room temperature, a speed of 350 rpm, and a neutral pH for two hours of treatment in a batch adsorption unit. These results indicate that virgin *Eucalyptus* leaves are a promising material and open the door to studying their direct use, without any additional treatment, as an adsorption medium for various pollutants such as heavy metals and dyes.

References

Abbas, F. S., Abdulkareem, W. S., and Abbas, M. N., 2022a. Strength Development of Plain Concrete Slabs by the Sustainability Potential of Lead-Loaded Rice Husk (LLRH). Journal of Applied Engineering Science, 20(1), Pp. 160–167. https://doi:10.5937/jaes0-32253

Abbas, M. N., 2015. Phosphorus Removal from Wastewater Using Rice Husk and Subsequent Utilization of the Waste Residue. Desalination and Water Treatment, 55(4), Pp. 970–977. https://doi.org/10.1080/19443994.2014.922494

Abbas, M. N., and Abbas F. S., 2014. Application of Rice Husk to Remove Humic Acid from Aqueous Solutions and Profiting from Waste Leftover. WSEAS Transactions on Biology and Biomedicine, 11(9), Pp. 62–69.

Abbas, M. N., and Abbas, F. S., 2013a. Iraqi Rice Husk Potency to Eliminate Toxic Metals from Aqueous Solutions and Utilization from Process Residues. Advances in Environmental Biology, 7(2), Pp. 308–319.

Abbas, M. N., and Abbas, F. S., 2013b. The Predisposition of Iraqi Rice Husk to Remove Heavy Metals from Aqueous Solutions and Capitalized from Waste Residue. Research Journal of Applied Sciences, Engineering and Technology, 6(22), Pp. 4237–4246.

Abbas, M. N., and Abbas, F. S., 2013c. The Feasibility of Rice Husk to Remove Minerals from Water by Adsorption and Avail from Wastes. Research Journal of Applied Sciences, WSEAS Transactions on Environment and Development, 9(4), Pp. 301–313.

Abbas, M. N., and Alalwan, H. A., 2019. Catalytic Oxidative and Adsorptive Desulfurization of Heavy Naphtha Fraction. Korean Journal of Chemical Engineering, 12(2), Pp. 283–288. http://doi.org/10.9713/kcer.2019.57.2.283

Abbas, M. N., and Ibrahim, S. A., 2020. Catalytic and thermal desulfurization of light naphtha fraction. Journal of King Saud University - Engineering Sciences, 32(4), Pp. 229–235. https://doi.org/10.1016/j.jksues.2019.08.001

Abbas, M. N., and Nussrat, T. H., 2020. A Statistical Analysis of Experimental Data for the Adsorption Process of Cadmium by Watermelon Rinds In a Continuous Packed Bed Column. International Journal of Innovation, Creativity and Change, 13(3), Pp. 124–138.

Abbas, M. N., Ali, S. T., and Abbas, R. S., 2020. Rice Husks as a Biosorbent Agent for Pb+2 Ions from Contaminated Aqueous Solutions: A Review. Biochemical and Cellular Archives, 20(1), Pp. 1813–1820. https://doi.org/10.35124/bca.2020.20.1.1813

Abbas, M. N., Al-Madhhachi, A. T., and Esmael S. A., 2019a. Quantifying Soil Erodibility Parameters due to Wastewater Chemicals. International Journal of Hydrology Science and Technology, 9(5), Pp. 550–568. http://doi.org/10.1504/IJHST.2019.10016884

Abbas, M. N., Al-Tameemi, I. M., Hasan, M. B., and Al-Madhhachi, A. T., 2021. Chemical Removal of Cobalt and Lithium in Contaminated Soils using Promoted White Eggshells with Different Catalysts. South African Journal of Chemical Engineering, 35, Pp. 23–32. https://doi.org/10.1016/j.sajce.2020.11.002

Abbas, M. N., Ibrahim, S. A., Abbas, Z. N., and Ibrahim T. A., 2022b. Eggshells as a Sustainable Source for Acetone Production. Journal of King Saud University - Engineering Sciences, 34(6), Pp. 381–387. https://doi.org/10.1016/j.jksues.2021.01.005

Abbas, M. N., Al-Hermizy, S. M. M., Abudi, Z. N., and Ibrahim, T. A., 2019b. Phenol Biosorption from Polluted Aqueous Solutions by Ulva lactuca Alga using Batch Mode Unit. Journal of Ecological Engineering, 20(6), Pp. 225–235. https://doi.org/10.12911/22998993/109460

Abd ali, I. K., Ibrahim, T. A., Farhan, A. D., and Abbas M. N., 2018. Study Of the Effect of Pesticide 2,4-D on the Histological Structure of the Lungs in the Albino Mice (Mus musculus). Journal of Pharmaceutical Sciences and Research, 10(6), Pp. 1418–1421.

Abd Ali, I. K., Salman, S. D., Ibrahim, T. A., Abbas, M. N., 2024. Study of the Teratogenic Effects of Antimony on Liver in the Adult Rabbit (Oryctolagus cuniculus). Advancements in Life Sciences, 11(2), Pp. 462–469. http://dx.doi.org/10.62940/als.v11i2.2773

Abd Al-Latif, F. S., Ibrahim, T. A., and Abbas, M. N., 2023. Revealing Potential Histological Changes of Deltamethrin Exposure on Testicular Tissue in Albino Rabbits (Oryctolagus cuniculus). Advancements in Life Sciences, 10(4), Pp. 619–626. http://dx.doi.org/10.62940/als.v10i4.2323

Abdulkareem, W. S., Aljumaily, H. S. M., Mushatat, H. A., and Abbas M. N., 2023. Management of Agro-Waste by Using as an Additive to Concrete and Its Role in Reducing Cost Production: Impact of Compressive Strength as a Case Study. International Journal on "Technical and Physical Problems of Engineering" (IJTPE), 15(1), Pp. 62–67.

Abdullah, W. R., Alhamadani, Y. A. J., Abass, I. K., and Abbas, M. N., 2023. Study of Chemical and Physical Parameters Affected on Purification of Water from Inorganic Contaminants. Periodicals of Engineering and Natural Sciences, 11(2), Pp. 166–175. http://dx.doi.org/10.21533/pen.v11i2.3508

Abed, Y. M., Allawi, F., Ali, S. M., Alhamd, S. J., Ibrahim, T. A., and Abbas, M. N., 2025. Implementing a Sustainability Approach by Converting Plastic Bottle Waste from a Mischievous Substance to a Beneficial Material by Means of Zero Residue Level Concept. Karbala International Journal of Modern Science (KIJOMS), 11(3), Pp. 396-411. https://doi.org/10.33640/2405-609X.3413

Abed, Y. M., Salman, A. A., Alhamd, S. J., Abbas, M. N., Al-Obaidi, M. A., and Challoob, S. H., 2025. Effective Removal of Stannous Ions from Aqueous Solutions Using Mango Peels: Adsorption Performance And

Mechanistic Visions. International Journal of Environmental Analytical Chemistry. https://doi.org/10.1080/03067319.2025.2519870

Al-Ali, S. I. S., Abudi, Z. N., and Abbas, M. N., 2023. Modelling and Simulation for the use of Natural Waste to Purified Contaminated Heavy Metals. Journal of the Nigerian Society of Physical Sciences, 5(1), Article No. 1143. https://doi.org/10.46481/jnsps.2023.1143

Alalwan, H. A., Abbas, M. N., and Alminshid, A. H., 2020. Uptake of Cyanide Compounds from Aqueous Solutions by Lemon Peel with Utilising the Residue Absorbents as Rodenticide. Indian Chemical Engineer, 62(1), Pp. 40–51. https://doi.org/10.1080/00194506.2019.1623091

Alalwan, H. A., Abbas, M. N., Abudi, Z. N., and Alminshid, A. H., 2018. Adsorption of thallium ion (Tl+3) from Aqueous Solutions by Rice Husk in a Fixed-Bed Column: Experiment and Prediction of Breakthrough Curves. Environmental Technology and Innovation, 12, Pp. 1–13. https://doi.org/10.1016/j.eti.2018.07.001

Alalwan, H. A., Mohammed, M. M., Sultan, A. J., Abbas, M. N., Ibrahim, T. A., Aljaafari, H. A. S., and Alminshid, A. A., 2021. Adsorption of Methyl Green Stain from Aqueous Solutions using Non-Conventional Adsorbent Media: Isothermal Kinetic and Thermodynamic Studies. Bioresource Technology Reports, 14, 100680. https://doi.org/ 10.1016/j.biteb.2021.100680

Alhamd, S. J., Abbas, M. N., Al-Fatlawy, H. J. J., Ibrahim, T. A., and Abbas, Z. N., 2024b. Removal of Phenol from Oilfield Produced Water using Non-Conventional Adsorbent Medium by an Eco-Friendly Approach. Karbala International Journal of Modern Science (KIJOMS), 10(2), Pp. 191–210. https://doi.org/10.33640/2405-609X.3350

Alhamd, S. J., Abbas, M. N., Manteghian, M., Ibrahim, T. A., Jarmondi, K. D. S., 2024a. Treatment of Oil Refinery Wastewater Polluted by Heavy Metal Ions via Adsorption Technique using Non-Valuable Media: Cadmium Ions and Buckthorn Leaves as a Study Case. Karbala International Journal of Modern Science (KIJOMS), 10(1), Pp. 1–18. https://doi.org/10.33640/2405-609X.3334

Al-Hermizy, S. M. M., Al-Ali, S. I. S., Abdulwahab, I. A., and Abbas, M. N., 2022. Elimination of Zinc Ions (Zn+2) from Synthetic Wastewater Using Lemon Peels. Asian Journal of Water, Environment and Pollution, 19(5), Pp. 79–85. https://doi.org/10.3233/AJW220073

Al-Hermizy, S. M. M., Awadh, H. A., and Abbas, M. N., 2025. Biosorption Technique Using Water Hyacinth Plant as an Effective and Sustainable Approach for Treating Oil Refinery Waste: Vanadium Element as a Case Study, Journal of Ecological Engineering, 26(6), Pp. 251–272. https://doi.org/10.12911/22998993/202658

Ali, G. A. A., and Abbas, M.N., 2020. Atomic Spectroscopy Technique Employed to Detect the Heavy Metals from Iraqi Waterbodies Using Natural Bio-Filter (Eichhornia crassipes) Thera Dejla as a Case Study. Systematic Reviews in Pharmacy, 11(9), Pp. 264–271. https://doi.org/10.31838/srp.2020.9.43

Ali, G. A. A., Ibrahim, S. A., and Abbas, M. N., 2021. Catalytic Adsorptive of Nickel Metal from Iraqi Crude Oil using Non-Conventional Catalysts. Innovative Infrastructure Solutions, 6(7), Pp. 1–9. https://doi.org/ 10.1007/s41062-020-00368-x

Ali, S. A. K., Abudi, Z. N., Abbas, M. N., Alsaffar, M. A., and Ibrahim T. A., 2024. Synthesis of Nano-silica Particles using Eucalyptus globulus Leaf Extract and Their Innovative Application as an Adsorbent for Malachite Green Dye, Russian Journal of Applied Chemistry, 97(1), Pp. 2–14. https://doi.org/10.1134/S1070427224010099

Ali, S. A. K., AL-Kaabi, Z., Kasim, M. N., Abbas, M. N., and Ibrahim, T. A., 2023. Remediation of Antimony from Aqueous Solutions by Adsorption Technique: Isothermal, Kinetic and Thermodynamic Studies. Indian Journal of Environmental Protection, 43(14), Pp. 1316–1325, (Conference 2023). https://www.e-ijep.co.in/43-14-1316-1325/

Ali, S. A. K., Almhana, N. M., Hussein, A. A., and Abbas M. N., 2020a. Purification of Aqueous Solutions from Toxic Metals using Laboratory Batch Mode Adsorption Unit Antimony (V) Ions as a Case Study. Journal of Green Engineering (JGE), 10(11), Pp. 10662–10680.

Ali, S. M., Saeed, B. M., Alwitry, Z. A., Abbas, M. N., 2025. Employment of Non-Conventional Material in Purification of Contaminated Aqueous Solutions. Water Conservation and Management (WCM), 9(4), Pp. 495–506. http://doi.org/10.26480/wcm.04.2025.495.506

Ali, S. T., Qadir, H. T., Moufak, S. K., Al-Badri, M. A. M., and Abbas, M. N., 2020b. A Statistical Study to Determine the Factors of Vitamin D Deficiency in Men: the City of Baghdad as a Model. Indian Journal of Forensic Medicine and Toxicology, 14, 1, Pp. 691–696. https://doi.org/10.37506/ijfmt.v14i1.132

Ali, S. T., Shahadha, R. W., Abdulkareem, W. S., and Abbas M. N., 2024. Available Low Cost Agro-Waste as an Efficient Medium to Eliminate Heavy Metal Contamination using Sustainable Approach Achieving Zero Residue Level, Journal of Ecological Engineering, 25(10), Pp. 160–175. https://doi.org/10.12911/22998993/191945

Alminshid, A. H., and Abbas, M. N., Alalwan, H. A., Sultan, A. J., and Kadhome, M. A., 2021. Aldol Condensation Reaction of Acetone on Mgo Nanoparticles Surface: An In-Situ Drift Investigation. Molecular Catalysis, 501, 111333. https://doi.org/10. 1016/j.mcat. 2020. 111 333

Alminshid, A. H., Alalwan, H. A., Mohammed, M. M., and Abbas, M. N., 2025. Spectroscopic Study of Methane Reaction Mechanism on Mgo Nanoparticles. Ionic, Pp. 13–29. https://doi.org/10.1080/ 001945 06.2025.2459833

Alsarayreh, A. A., Al-zoubi, H. Q., and Abbas, M. N., 2025b. Sustainable Nickel Removal from Water by using Waste Tea Leaves For Eco-Friendly Water Treatment. Indian Chemical Engineer. https://doi. org/10.1080/00194506.2025.2459833

Alsarayreh, A. A., Ibrahim, S. A., Alhamd S. J., Ibrahim T. A., and Abbas M. N., 2024. Removal of Selenium Ions from Contaminated Aqueous Solutions by Adsorption using Lemon Peels as a Non-Conventional Medium. Karbala International Journal of Modern Science (KIJOMS), 10(4), Pp. 511–531. https://doi.org/10.33640/2405-609X.3375

Alsarayreh, A. A., Nsaif, R. Z., Nsaif, M. M., Nsaif, Z. M., and Abbas, M. N., 2025a. Nickel Remediation by Adsorption Technique Achieving the Concept of Zero Residue Level. The Jordan Journal of Civil Engineering (JJCE), 19(1), Pp. 13–29. https://doi.org/10.14525/JJCE.v19i1.02

Alwan, E. K., Hammoudi, A. M., Abd, I. K., Abd Alaa, M. O., and Abbas, M. N., 2021. Synthesis of Cobalt Iron Oxide Doped by Chromium Using Sol-Gel Method and Application to Remove Malachite Green Dye. NeuroQuantology, 19(8), Pp. 32-41 http://doi:10.14704/nq. 2021.19.8.NQ21110

Cao, M., Hu, A., Gad, M., Adyari, B., Qin, D., Zhang, L., Sun, Q., and Yu, C. P., 2022. Domestic Wastewater Causes Nitrate Pollution in an Agricultural Watershed, China. The Science of the total environment, 823, 153680. https://doi.org/10.1016/j.scitotenv.2022.153680

Duda, R., Zdechlik, R., and Kania, J., 2023. Groundwater Nitrate Pollution Risk Assessment Based on the Potential Impact of Land Use, Nitrogen Balance, And Vulnerability. Environmental science and pollution research international, 30(58), Pp. 122508–122523. https://doi.org/10.1007/s11356-023-30850-9

Gadooa, Z. A., Alsarayreh, A. A., and Abbas M. N., 2025. Adsorption of Thallium using Tangerine Peels and Exploitation from the Waste in an Eco-Friendly Manner. Ecological Engineering and Environmental Technoloy, 26(2), Pp. 131–152. https://doi.org/10.12912/27197050/196880

Ghulam, N. A., Abbas, M. N., and Sachit D. E., 2020. Preparation Of Synthetic Alumina from Aluminium Foil Waste and Investigation of Its Performance in the Removal Of RG-19 Dye from Its Aqueous Solution. Indian Chemical Engineer, 62(3), Pp. 301–313. https://doi.org/10.1080/00194506.2019.1677512

Hamdi, G. M., Abbas, M. N., Ali, S. A. K., 2024. Bioethanol Production from Agricultural Waste: A Review. Journal of Engineering and Sustainable Development (JESD), 28(2), Pp. 233–252. https://doi.org/10.31272/ jeasd.28.2.7

Hameed, W. A., and Abbas, M. N., 2024. Dyes Adsorption from Contaminated Aqueous Solution Using SiO2 Nanoparticles Prepared from Extracted Tree Leaves. Journal of Ecological Engineering, 25(7), Pp. 41–57. https://doi.org/10.12911/22998993/187921

Hammed, A. S., Alsarayreh, A. A., and Abbas, M. N., 2025. Applying of Zero

Residue Level Concept in Integrated Management of Toxic and Solid Wastes as a Sustainable Approach. Ecological Engineering and Environmental Technology, 25(1), Pp. 353–378. https://doi.org/10.12912/27197050/196409

Hasan, M. B., Al-Tameemi, I. M., and Abbas, M. N., 2021. Orange Peels as a Sustainable Material for Treating Water Polluted with Antimony. Journal of Ecological Engineering, 22(2,) Pp. 25-35. https://doi.org/10.12911/22998993/130632

Hasan, M. B., Ibrahim, S. A., Rahmah, N. M., Ibrahim, T. A., Alminshid, A. H., and Abbas, M. N., 2025. Vanadium Remediation from Polluted Wastewater Using a Novel Non-Conventional Adsorbent. Results in Engineering (RINENG), 27, Article no. 105665. https://doi.org/10.1016/j. rineng.2025.105665

Hashem, N. S., Ali, G. A. A., Jameel, H. T., Khurshid, A. N., and Abbas M. N., 2021. Heavy Metals Evaluation by Atomic Spectroscopy for Different Parts of Water Hyacinth (Eichhornia Crassipes) Plants: Banks of Tigris River and Al-Zuhairat Village Sites. Biochemical and Cellular Archives, 21(2), Pp. 3813-3819. https://connectjournals.com/03896.2021.21.3813

Ibrahim, S. A., Alhamd, S. J. K., Ali, S. M., Abbas, M. N., Ibrahim, T. A., and Alsarayreh A. A., 2025a. Remediation of Aqueous Solutions Contaminated by Benzidine Toxic Dye using Non-Conventional Adsorbent: Morphological and Modelling Studies, Al-Qadisiyah Journal for Engineering Sciences (QJES), 18(2), Pp. 66-78. https://doi.org/10.30772/qjes.2024.149956.1244

Ibrahim, S. A., Alsarayreh, A. A., Khaled, T. T., Abbas, M. N., 2025b. Buckthorn Leaves as an Efficient Material for Simultaneously Multi Eco-Friendly Purposes. Journal of Engineering and Sustainable Development (JESD), 29(4), Pp. 539-549. https://doi.org/ 10.31272/jeasd.3033

Ibrahim, S. A., Hasan, M. B., Al-Tameemi, I. M., Ibrahim T.A., and Abbas M. N., 2021. Optimization of Adsorption Unit Parameter of Hardness Remediation from Wastewater using Low-Cost Media. Innovative Infrastructure Solutions, 6(4), Article number: 200. https://doi.org/10.1007/s41062-021-00564-3

Ibrahim, T. A., Mahdi, H. S., Abbas, R. S., and Abbas, M. N., 2020a. Study the Effect of Ribavirin Drug on the histological structure of the testes in Albino mice (Mus musculus). Journal of Global Pharma Technology, 12(02 Suppl.), Pp. 142-146. http://www.jgpt.co.in/index.php/jgpt/article/ view/3233

Ibrahim, T. A., Mohammed, A. M., Abd ali, I. K., Abbas M.N., and Hussien S. A., 2020b. Teratogenic Effect of Carbamazepine Drug on the Histological Structure of Testes in the Albino Mouse (Mus musculus). Indian Journal of Forensic Medicine and Toxicology, 14(4), Pp. 1829-1834. https://doi.org/10.37506/ijfmt.v14i4.11809

Ito, K., Noguchi, M., Horioka, Y., Ohshita, J., and Hirokawa, T., 2024. Separation of Iodate, Bromide, Nitrite, Nitrate, and Iodide in Seawater by Ion Chromatography using 1-Aminoundecyl Group Chemically Bonded Silica Columns. Analytical sciences: the international journal of the Japan Society for Analytical Chemistry, 40(11), Pp. 2027–2032. https://doi.org/10.1007/s44211-024-00639-y

Khaleel, L. R., Al-Hermizy, S. M., and Abbas, M. N. 2022. Statistical Indicators for Evaluating the Effect of Heavy Metals on Samaraa Drug Industry Water Exposed to the Sun and Freezing. Tropical Journal of Natural Product Research, 6(12), Pp. 1969-1974. http://www.doi.org/ 10.26538/tjnpr/ v6i12.12

Khudair, S. Y., Alsarayreh, A. A., and Abbas, M. N. 2024. Adsorption of Vanadium from Iraqi Crude Oil on Nano Zeolite and Alum Sludge. Journal of Engineering and Sustainable Development (JESD), 28(6), Pp. 762-769. https://doi.org/10.31272/jeasd.28.6.9

Maddodi, S. A., Alalwan, H. A., Alminshid, A. H., Abbas, M. N. 2020. Isotherm and Computational Fluid Dynamics Analysis of Nickel Ion Adsorption from Aqueous Solution using Activated Carbon. South African Journal of Chemical Engineering, 32, Pp. 5-12. https://doi.org/ 10.1016/j.sajce.2020.01.002

Mahmood, R. S., Abbas, M. N., Abudi, Z. N., and Alsarayreh, A. A. 2025. Harnessing the Green Method to Synthesize Cobalt Oxide Nanoparticles and Testing Its Performance in Treating the Hidden Pollution of Fluoride from Aqueous Solutions. Water Conservation and Management (WCM), 9(3), Pp. 508–519. https://doi.org/10.26480/wcm.03.2025.508.519

Navarro, B. B., Machado, M. J., and Figueira, A., 2025. Nitrogen Use Efficiency in Agriculture: Integrating Biotechnology, Microbiology, and Novel Delivery Systems for Sustainable Agriculture. Plants (Basel, Switzerland), 14(19), 2974. https://doi.org/10. 3390/plants14192974

Novotny, V. 1999. Diffuse Pollution from Agriculture — A worldwide outlook. Water Science and Technology, 39(3), Pp. 1-13. https://doi.org/10.1016/S0273-1223(99)00027-X

Rajaa, N., Kadhim, F. J., Abbas, M. N., and Banyhussan, Q. S., 2023. The Improvement of Concrete Strength Through the Addition of Sustainable Materials (agro-waste loaded with copper ions). 3rd International Conference for Civil Engineering Science (ICCES 2023), IOP Conf. Series: Earth and Environmental Science, 1232, 012038, 9 Pages. http://doi.org/10.1088/1755-1315/1232/1/012038

Seyyedsalehi, M. S., Mohebbi, E., Tourang, F., Sasanfar, B., Boffetta, P., and Zendehdel, K., 2023. Association of Dietary Nitrate, Nitrite, and N-Nitroso Compounds Intake and Gastrointestinal Cancers: A Systematic Review and Meta-Analysis. Toxics, 11(2), 190. https://doi.org/10.3390/ toxics11020190

Shadhan, Z. J., Alhamd, S., and Abbas, M. N., 2024. Recovery of Vanadium Element from Wastewater of Petroleum Refineries using Effective Adsorbent: Mathematical Approach via Isothermal, Kinetics and Thermodynamic Simulation. Al-Qadisiyah Journal for Engineering Sciences (QJES), 17(3), Pp. 211-219. https://doi.org/10.30772/qjes.2024.145441.1069

Sridhar, C. N., Subramani, T., Kumar, G. R. S., and Soundaranayaki, K., 2025. Nitrate Pollution Index and Age Wise Health Risk Appraisal for the Pambar River Basin in South India. Environmental geochemistry and health, 47(6), 198. https://doi.org/10.1007/s10653-025-02512-x