SIMULTANEOUS REMOVAL OF NITRATE AND PHOSPHATE FROM KITCHEN WASTEWATER USING GROUNDNUT HUSK BIOCHAR

A. B. DUWIEJUAH, N. A. AHMED & Y. AMADU

A. B. D. & N. A. A.: Department of Biotechnology and Molecular Biology, Faculty of Biosciences, University for Development Studies, Tamale, Ghana; Y. A.: Department of Horticulture, Faculty of Agriculture, Food and Consumer Sciences, University for Development Studies, Tamale, Ghana

Correspondence author's email address: aduwiejuah@uds.edu.gh

ABSTRACT

Biochar as a green, economically efficient, and ecological adsorbent shows a great potential in tackling water pollutants by its widely availability feedstock, low-cost and favourable surface characteristics. Eutrophication of water bodies is caused due to large amounts of phosphorus and nitrogen elements which are usually discharged into the environment. In this study, groundnut husk biochar was used to remove nitrate and phosphate from kitchen wastewater at different dosages. Wastewater of 100 mL was added to each of the groundnut husk biochar in a conical flask and agitated at 150 rpm for 60 minutes. Adsorption efficiency of groundnut husk biochar for nitrate ranged from 98.03% to 98.18% and phosphate ranged from 99.92% to 99.95%. Nitrate and phosphate showed a maximum adsorption capacity of 9.78×10^{-4} mg/g and 4.64mg/g $\times 10^{-3}$. The adsorption processes for nitrate and phosphate are better described by heterogeneous interactions than by the uniform monolayer hypothesis, which is simplified by the Langmuir model. This study showed a very high adsorption efficiency of groundnut husk biochar. This indicates that low-cost groundnut husk biochar adsorbents can be used for removal of nitrate and phosphate from wastewater. Similar adsorptive experiments can be carried out using different agricultural waste to produce biochar as this can contribute to environmental safety and cleanliness.

Keywords: Adsorption efficacy, groundnut husk biochar, Langmuir isotherm, kitchen wastewater, phosphate

Introduction

Wastewater from chemical industries such as textile tanneries, agrochemical ceramic and paint effluent, landfills is the attention of the environmental protection agencies all over the world (Hossain *et al.,* 2022). Wastewater encompasses pollutants that are obstinate and can change into an irrepressible form which are detrimental to the environment and human health (Adeola *et al.*, 2021). One of the most serious issues with water pollution is eutrophication (Lugo-Arias *et al.,* 2025) which is caused due to large amounts of phosphorus and nitrogen elements which are usually discharged into the environment. Nitrogen (N) and phosphorus (P) are vital nutrients that are necessary for the structure, metabolism, and general functioning of living things (Haddouk *et al.,* 2026). A major source of nutrient loading in water bodies is household sewage, which is frequently high in these nutrients. High levels of these nutrients in drinking water can also be harmful to human health, such as in groundwater sources, where nitrates may be found as a result of the widespread usage of chemical fertilisers (Bahrami & Amiri, 2022). Industrial effluents, agricultural runoff, and municipal wastewater discharge these nutrients into rivers, lakes, and reservoirs, resulting in accelerated algal and cyanobacterial development, which causes dangerous algal blooms and ecosystem imbalance (Kamel & Ahmed, 2026). Nitrate concentrations higher than 10 mg/L are linked to respiratory tract illnesses, infantile cyanosis syndrome (blue baby syndrome), and cancer, whilst phosphate levels above 0.5 mg/L can result in osteoporosis and urine damage (Lugo-Arias *et al.,* 2024).

The excessive use of chemical fertilisers and pesticides in agricultural areas also hastens nutrient runoff into nearby waterways (Haddouk *et al.,* 2026). Furthermore, the build-up of nutrients is exacerbated by the addition of aquaculture feed inputs and livestock manure. All of these human activities, taken together, exacerbate water eutrophication, which results in ecosystem collapse, biodiversity loss, algal blooms, fish death, and major economic consequences (Yin *et al.,* 2017; Akinnawo, 2023). As a result, effective, cost-effective, and environmentally responsible methods for removing N and P are essential to reduce nutrient contamination and safeguard the aquatic environment.

Traditional treatment methods of wastewater such as activated sludge, reserve osmosis is not efficient in nutrients removal and are very expensive to treat wastewater in our developing country. However, these technologies have some drawbacks, including inadequacy in pollutants removal at low concentrations and converting contaminants completely into less toxic byproducts or biodegradable, chemical consumption and high energy, process complexity, and high operation costs and maintenance among others (Yang *et al.,* 2018). These challenges limit their usage particularly at low resources sittings in developing countries. The usage of adsorption technology is very effective and attractive since it does not produce sludge and has high efficiency (Yang *et al.,* 2018).
Adsorption is one of the simplest, least time-consuming and cheapest treatment methods of wastewater that scientists have explored and researched (Crini *et al.,* 2019). The employment of waste-derived or natural adsorbents is particularly appealing since these materials are frequently plentiful, renewable, and low cost, which aids in the aims of circular economy and resource recovery (Haddouk *et al.,* 2026). Agriculture waste is a significant source of resources for harmful metal removal using adsorption techniques (Dai *et al.,* 2018). Biochar has become a very efficient adsorbent due to its accessible surface area, porous structure, and adaptable surface chemistry, which allows it to retain N and P nutrients (Trivedi *et al.,* 2025). Additionally, its capacity to retrieve nutrients in plant-available forms makes it possible to reuse nutrient-rich biochar beneficially as a soil amendment or fertiliser, promoting nutrient recycling and circular economy concepts. Groundnut husk biochar can be used as biomass-based adsorption materials for the treatment of wastewater.

Groundnut shells are widely used food processing and human consumption. About 260,000 tonnes of groundnut shells waste is annually produced worldwide (Verma *et al.*, 2012). The husk of groundnut is often disposed of without converting it into any other significant material. This poses environmental problems as it adds up to agricultural waste, resulting in challenges with waste management (Figueroa *et al.,* 2020). These groundnut husks therefore serve as a rich source of resource that can be used for the production of adsorbent for the removal of nitrate and phosphate from wastewater and the environment at large due to its unique properties. As a result, an effective and practical solution that meets both commercial and environmental requirements should be advertised and implemented on a big scale. Nonetheless, further research is required to combine readily accessible and low-cost materials in treatment processes, which might lower total costs of treatment whilst increasing effectiveness for harmful metal removal. Hence, the use of residues from agriculture as green and economical adsorbents for removing nitrate and phosphate from wastewaters are required. The objective was to determine groundnut shell biochar removal rate of nitrate and phosphate from kitchen wastewater.

Experimental

Groundnut husk collection and biochar preparation

The groundnut husk was collected from various groundnut grind mills in Tamale. Other materials and foreign biomass were to remove from the groundnut shell husks. Biochar was made from groundnut shell husks at the University for Development Studies (UDS), Nyankpala Campus's Agricultural Sub-Sector Improvement Programme (AgSsIP) Laboratory. Groundnut husks were kept in the muffle furnace and charred at 500 ± 5 °C for 30 min to obtain 503.5 g groundnut husk biochar. Biochar was then crushed and sieved.

Sample collection

Kitchen wastewater was collected from five (5) private hostels in Nyankpala into polypropylene bottles and transported to the UDS, Spanish laboratory. All sample equipment (hand gloves, ice chest, marker, and polypropylene bottles) were thoroughly cleaned before use. Hand gloves protect the skin on the hands and prevent direct contact with kitchen wastewater, which contains toxic metals and other microscopic species. To minimise leakage of samples, the ice chest was utilised to in storing the samples of kitchen wastewater.

Adsorption experiment

The adsorption experiment was conducted in the UDS Spanish laboratory. A gram of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 g groundnut husk biochar each was weighted and transferred into a well-labeled conical flask. And 100 mL of the kitchen wastewater with initial concentration of nitrate (0.39 mg/L) and phosphate (2.02 mg/L) was transferred into the conical flask containing the biochar. The mixture was then placed onto a rotatory orbital shaker and stirred at 150 rpm for 60 minutes (contact time). The pH (4.17) and temperature (25 °C) were measured using a pH meter. After 60 minutes, the samples were removed from the orbital shaker and then filtered into plastic bottles via glass funnels using Whatman's qualitative filter paper (125 mm Ø) into a 35 mL. The filtered samples (elutes) were transported to the University of Ghana Ecological Laboratory for analysis.

Calculations for adsorption efficiency nitrate and phosphate using groundnut husk biochar

For each of the nutrient uptake and the adsorbent concentration all at equilibrium was calculated using the symbol Qe (Dada *et al.,* 2012). Hence, calculating the adsorption efficiency can be denoted mathematically as:

$$Q_e = \frac{C_i - C_f}{M} \times V \qquad [1]$$

To determine, the percentage adsorption (R (%), it's also represented as:

$$R(\%) = \frac{C_i - C_f}{C_i} \times 100 \qquad [2]$$

Where Q_e is the adsorption capacity, C_f and C_i is the final and initial concentration of toxic metals after adsorption, respectively M is the amount of biochar, and V is the solution volume.

Adsorption isotherms

The isotherm models used in computing have represented mathematically based on below assumptions by researchers. A researched work by Zhang *et al.* (2020) reported that, elimination of a gas molecule onto a comparable solid surface was best use of the Langmuir isotherms model. Mainly, Langmuir isotherm is used in the adsorption of atoms onto a uniform surface, this could be a crystal of materials (solid) with adsorptive properties (Massoudinejad *et al.,* 2019). This can be exemplified mathematically in a linear equation. Below is the equation formular provided:

$$\frac{C_e}{Q_m} = \frac{1}{K_L\, Q_{max}} + \frac{C_e}{Q_{max}} \qquad [3]$$

Where C_e is the adsorbate at equilibrium concentration (mg/g), Q_{max} (mg/g) is the adsorbed molecules amount on the adsorbent surface at any time and K_L is the Langmuir constant (L/mg) (Dada *et al.,* 2012).

R_L can also be employed as separation factor. It is a constant. R_L can be denoted as:

$$R_L = \frac{1}{1 + K_L C_o} \qquad [4]$$

Where C_o is the adsorbate initial concentration and K_L is the Langmuir constant (L/g).

When the $R_L > 1$ indicates it could be non-conducive adsorption, $R_L = 1$ indicates linear, $R_L = 0$ is irreversible and $0 < R_L < 1$ is favourable (Dada *et al.,* 2012).

The mathematical of the Freundlich isotherm is:

$$Q_e = K_F C_e^{1/n} \qquad [5]$$

where $\frac{1}{n}$ is the intensity of the adsorption and K_F is the adsorption capacity (L mg^{-1}). The $\frac{1}{n}$ shows how energy is relatively distributed and how heterogeneous the adsorption sites simoare (Dada *et al.,* 2012). If $\frac{1}{n} < 1$ means normal adsorption, $\frac{1}{n} > 1$ indicates that there is co-operative adsorption, n = 1 means there are two-phase partition that does not depend on concentration has occurred (Dada *et al.,* 2012).

Results and discussion

Adsorption efficiency of nitrate and phosphate by groundnut husk biochar in kitchen wastewater

Adsorption efficiency of groundnut husk biochar for nitrate and phosphate was ≥ 98.03% and ≥ 99.92%, respectively as presented in table 1. This illustrates a very high adsorption efficiency of groundnut husk biochar. Biochars have a much pore volume and larger surface area than their source raw material, making them superior adsorbents to the raw materials (Ahmad *et al.,* 2014). Depending on the type of biochar, contaminants can be removed through a variety of mechanisms including electrostatic interactions, complexation, precipitation, and physical sorption (Inyang *et al.,* 2016). The most non-polar ions in soil structure such as NO_3^-, NH_4^+ and PO_4^{3-} are thought to be absorbed by biochar through surface adsorption (Dai *et al.,* 2020).

TABLE 1
Adsorption of nitrate and phosphate by groundnut husk biochar in kitchen wastewater

Metals	Dosage (g)	Initial concentration (mg/L)	Percentage (%)
Nitrate	0.5	0.39	98.18
	1.0	0.39	98.15
	1.5	0.39	98.18
	2.0	0.39	98.15
	2.5	0.39	98.13
	3.0	0.39	98.15
	3.5	0.39	98.03
Phosphate	0.5	2.02	99.95
	1.0	2.02	99.95
	1.5	2.02	99.93
	2.0	2.02	99.92
	2.5	2.02	99.93
	3.0	2.02	99.92
	3.5	2.02	99.93

In comparison, the production of biochar is less expensive and requires less energy (Zheng *et al.,* 2010). The functional groups on a biochar influence its physicochemical properties and adsorption capacity (Deng *et al.,* 2017). The biochar porous structure, large specific surface area, and surface functional groups are important characteristics that promise high contaminant removal efficiencies (Yao *et al.,* 2016). Rice husk ash was also investigated for phosphate removal and demonstrated up to 89% (a maximum removal) using a 2 g/L dose for 120 minutes at a pH of 6 (Mor *et al.,* 2016). The biochar is applied to the slurry to effectively remove nitrate and it was discovered that adsorption of N is higher at concentrations of 500 mg/L (89%) and 250 mg/L (81%), than at higher concentrations of 1250 mg/L (80%) and 1000 mg/L (76%) (Kizito *et al.,* 2015). The removal of phosphorus from wastewater is accomplished by treating calcium-rich biochar in an aqueous solution. The initial phosphorous concentration rate in the solution differs linearly with calcium-rich biochar (Dai *et al.,* 2020).

This current study results for nutrient removal effectiveness are in line with patterns seen in the literature for biochar systems using different doses. At 20 g/L, the elimination of NH_4^+ reached 80%, which is equivalent to biochars, which usually have NH_4^+ adsorption capabilities of less than 20 mg/g (Zhang et al., 2020). The trends showed that higher biochar dosages increase total removal efficiency whilst decreasing unit adsorption capacity. At 20 g/L, the 70.8% removal of PO_4^{3-} is greater than 38.1% reported by Cui et al. (2016). The NO_3^- removal was 74% at 20 g/L, which is significantly higher than the majority of unmodified biochars, which typically have extremely poor NO_3^- sorption (Zhang et al., 2020).

Langmuir and Freundlich adsorption isotherms

The nitrate maximum adsorption capacity was 9.78×10^{-4} mg/g and an adsorption equilibrium (K_L) of 3.04×10^{-2} L/mg (Table 2). R_L for nitrate in the study was 0.38 and a correlation coefficient (R^2) of 0.25 (Figure 1). For phosphate, an adsorption equilibrium (K_L) of 0.94 L/mg and the maximum adsorption capacity was 4.64×10^{-3} mg/g (Table 2). R_L for phosphate in the study was 1.04 and a correlation coefficient (R^2) of 0.46 (Figure 2). Nitrate and phosphate showed a maximum adsorption capacity of 9.78×10^{-4} mg/g and 4.64×10^{-3} which was lower as compared to 0.78 mg/g and 3.40 mg/g, respectively, as reported by Sayadi *et al.* (2020). This present study had K_L of 3.04×10^{-2} L/mg and 0.94 for nitrate and phosphate respectively, as compared to 0.04 L/mg and 18.22 L/mg reported by Sayadi *et al.* (2020). The R_L for nitrate was 0.38 which suggest the shape of the isotherm for adsorption by groundnut husk shell was favourable since when $0 < R_L < 1$ (Ayawei *et al.*, 2017).

The Freundlich isotherm provides an expression for describing heterogeneous adsorbent surfaces and the exponentially scattered active sites and energies on them (Ayawei *et al.,* 2017). The K_F recorded for the adsorption process was 102.90 L/g and 203.75 L/g for nitrate and phosphate, respectively (Table 2). The $^1/_n$ documented for nitrate and phosphate was 0.20 and 0.001, respectively, this shows that, the normal adsorption $^1/_n$ is less than 1 (Ayawei *et al,* 2017). The N values for nitrate and phosphate was 5 and 1000, respectively. The R^2 for nitrate and phosphate shows that the data does not fit well with both Langmuir and Freundlich adsorption isotherm. However, the K_F suggest the better fit of the Freundlich model implying that nutrient adsorption onto groundnut husk biochar takes place on a heterogeneous surface with an uneven distribution of active sites, and that multilayer adsorption is probably involved. This implies that the adsorption processes for nitrate and phosphate are better described by heterogeneous interactions than by the uniform monolayer hypothesis, which is simplified by the Langmuir model.

TABLE 2

Modelling of the results of groundnut shell biochar

Ion	Langmuir parameter				Freundlich parameter			
Metal	Q_{max} (mg/g)	K_L (L/g)	R_L	R^2	$^1/_n$	N	K_F (mg/g)	R_2
NO_3^-	9.78×10^{-4}	3.04×10^{-2}	0.38	0.25	0.20	5.00	102.90	0.25
PO_4^{3-}	4.64×10^{-3}	0.94	1.04	0.46	0.001	1000	203.75	0.47

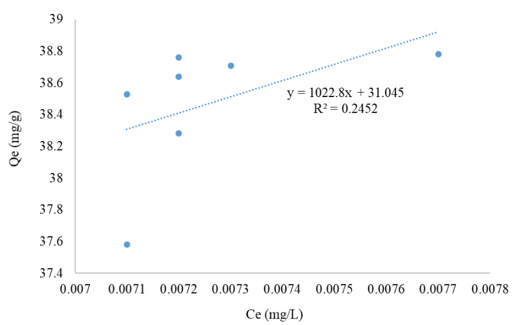

Fig. 1: Langmuir isotherm for nitrate in kitchen wastewater by groundnut husk biochar

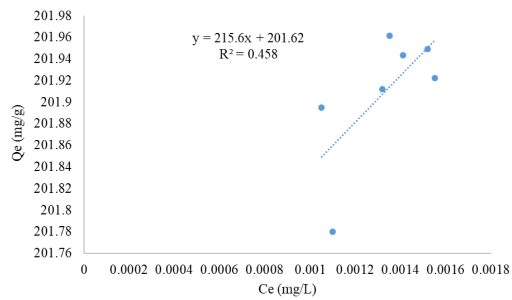

Fig. 2: Langmuir isotherm for phosphate in kitchen wastewater by groundnut husk biochar

pH is above 7 owing to increased competition with hydroxide ions, whereas the removal is low when the pH is below 7 due to the oxides instability at lower pH (Katal *et al.,* 2012). This study result is comparable to adsorptive nitrate removal at pH 7 using red mud and lower removal at advanced pH values (Katal *et al.,* 2012). A study by Manhooei *et al.* (2019) reported an optimum removal efficiency of nitrate of 86.5% was obtained at pH 7, room temperature, an initial concentration of 20 mg/L, and a 3 g/L dose within 10 minutes. The adsorption of nitrate was found to be affected by anions (Manhooei *et al.*, 2019).

Conclusion

The removal efficiency of nitrate and phosphate from kitchen wastewater by groundnut husk biochar adsorbents was very effective. The adsorption processes for nitrate and phosphate are better described by heterogeneous interactions than by the uniform monolayer hypothesis, which is simplified by the Langmuir model. Similar adsorptive experiments can be carried out using different agricultural waste to produce biochar as this can contribute to environmental safety and cleanliness.

Acknowledgement

Our profound gratitude goes to Mr. Prince Owusu and Mr. Justin Kan-Uge for their supporting making this a success.

Conflict of Interest

There is no conflict of interest among the authors of this research article.

References

ADEOLA, A. O., DE LANGE, J. & FORBES, P. B. (2021) Adsorption of antiretroviral drugs, efavirenz and nevirapine from aqueous solution by graphene wool: Kinetic, equilibrium, thermodynamic and computational studies. *Applied Surface Science Advances* **6**, 100157.

AHMAD, M., RAJAPAKSHA, A. U., LIM, J. E., ZHANG, M., BOLAN, N., MOHAN, D. & OK, Y. S. (2014) Biochar as a sorbent for contaminant management in soil and water: a review. *Chemosphere* **99**, 19 - 33.

AKINNAWO, S. O. (2023). Eutrophication: Causes, consequences, physical, chemical and biological techniques for mitigation strategies. *Environ. Chall.* **12**, 100733.

AYAWEI, N., EBELEGI, A. N. & WANKASI, D. (2017) Modelling and interpretation of adsorption isotherms. *Journal of chemistry* 2017.

BAHRAMI, M. & AMIRI, M. J. (2022). Nitrate removal from contaminated waters using modified rice husk ash by hexadecyltrimethylam monium bromide surfactant. *React Kinet Mech Catal.,* 135, 459 - 478. https:// doi. org/ 10. 1007/ s11144- 021- 02149-8

CRINI, E., LINCHTFOUSE, L. D. & WILSON. (2019) *Conventional and non -conventional adsorbents for wastewater treatment.*

CUI, X., HAO, H., ZHANG, C., HE, Z. & YANG, X. (2016). Capacity and mechanisms of ammonium and cadmium sorption on different wetland-plant derived biochars. *Sci. Total Environ.,* **539**, 566 – 575.

DADA, A. O., OLALEKAN, A. P., OLATUNYA, A. M. & DADA, O. J. I. J. C. (2012) Langmuir, Freundlich, Temkin and Dubinin–Radushkevich isotherms studies of equilibrium sorption of Zn^{2+} unto phosphoric acid modified rice husk. *IOSR Journal of applied chemistry* **3** (1), 38 - 45.

DAI, Q., SUN, W., WANG, L., LU, M., LIU, J., LI, S. & SUN, Y. (2018) *Utilization of agricultural waste as adsorbent for the removal of contaminants*.

DAI, Y., WANG, W., LU, L., YAN, L. & YU, D. (2020) Utilization of biochar for the removal of nitrogen and phosphorus. *J. Clean. Prod.* 257. doi:10.1016/j.jclepro.2020.120573.

DENG, Y., ZHANG, T. & WANG, Q. (2017) Biochar adsorption treatment for typical pollutants removal in livestock wastewater: a review. *Engineering applications of biochar* **71**.

FIGUEROA, K. H. N., GARCÍA, N. V. M. & VEGA, R. C. (2020) Cocoa by-products. *Food Wastes and By-products: Nutraceutical and Health Potential*, 373 - 411.

HADDOUK, A., TRABELSI, I., TIZAOUI, C., & WAHAB, M. A. (2026). Efficient removal of phosphate, nitrate, and ammonia from wastewater using unmodified woodchip biochar. *Water,* **18** (2), 211.

HOSSAIN, S., ANIK, A. H., KHAN, R., AHMED, F. T., SIDDIQUE, M., BAKAR, A. & ALAM, M. (2022) Public health vulnerability due to the exposure of dissolved metal (oid)s in tap water from a Mega City (Dhaka, Bangladesh): source and quality appraisals. *Exposure and Health*, 1 - 20.

INYANG, M. I., GAO, B., YAO, Y., XUE, Y., ZIMMERMAN, A., MOSA, A. & CAO, X. (2016) A review of biochar as a low-cost adsorbent for aqueous heavy metal removal. *Critical Reviews in Environmental Science and Technology* **46** (4), 406 - 433.

KAMEL, A. F. & AHMED, S. H. (2026). Simultaneous removal of nutrients from water using advanced sustainable technologies: A comprehensive systematic review (2005-2024). *Al-Rafidain Journal of Engineering Sciences*, 713 - 734.

KATAL, R., BAEI, M. S., RAHMATI, H. T. & ESFANDIAN, H. (2012) Kinetic, isotherm and thermodynamic study of nitrate adsorption from aqueous solution using modifed rice husk. *J Ind Eng Chem* **18**, 295–302.

KIZITO, S., WU, S., KIRUI, W.K., LEI, M., LU, Q., BAH, H. & DONG, R. (2015) Evaluation of slow pyrolyzed wood and rice husks biochar for adsorption of ammonium nitrogen from piggery manure anaerobic digestate slurry. *Sci. Total Environ.* **505***,* 102–112 ISSN 0048-9697.

LUGO-ARIAS, J., GONZÁLEZ-ÁLVAREZ, J., MATURANA, A., VILLA-PAREJO, J., & BARRAZA-HERAS, C. (2025). Removal of nitrate and phosphate from aqueous solutions using bioadsorbents derived from agro-industrial wastes of rice husk and corn stalk. *Biomass Conversion and Biorefinery*, **15** (12), 19453 - 19475.

LUGO-ARIAS, J., VARGAS, S. B., MATURANA, A., GONZÁLEZ-ÁLVAREZ, J., LUGO-ARIAS, E., & RICO, H. (2024). Nutrient removal from aqueous solutions using biosorbents derived from rice and corn husk residues: a systematic review from the environmental management perspective. *Water*, **16** (11), 1543.

MANHOOEI, L., MEHDINEJADIANI, B. & AMININASAB, S. M. (2019) Cellulose nanocrystal modified with 3-chloro propyl trimethoxysilane: a new bio-adsorbent for nitrate removal from water. *Water Environ. J.* **34***,* 50 - 60.

MASSOUDINEJAD, M., RASOULZADEH, H. & GHADERPOORI, M. (2019) Magnetic chitosan nanocomposite: fabrication, properties, and optimization for adsorptive removal of crystal violet from aqueous solutions. *Carbohydrate polymers* **206**, 844 - 853.

MICHÁLEKOVÁ-RICHVEISOVÁ, B., FRIŠTÁK, V., PIPÍŠKA, M., ˇ DURIŠKA, L., MORENO-JIMENEZ, E. & SOJA, G. (2017). Iron-impregnated biochars as effective phosphate sorption materials. *Environ. Sci. Pollut. Res. Int.,* **24**, 463 – 475.

MOR, S., CHHODEN, K. & RAVINDRA, K. (2016) Application of agro-waste rice husk ash for the removal of phosphate from the wastewater. *J. Clean. Prod.* **129***,* 673 - 680.

SAYADI, M., FARASATI, M., G MAHMOODLU, M. & ROSTAMI, C. F. (2020) Removal of nitrate, ammonium, and phosphate from water using conocarpus and paulownia plant biochar. *Iranian Journal of Chemistry and Chemical Engineering (IJCCE)* **39** (4), 205 - 222.

TRIVEDI, Y., SHARMA, M., MISHRA, R. K., SHARMA, A., JOSHI, J., GUPTA, A. B., ACHINTYA, B., SHAH, K. & VUPPALADADIYAMD, A. K. (2025). Biochar potential for pollutant removal during wastewater treatment: A comprehensive review of separation mechanisms, technological integration, and process analysis. *Desalination*, **600**, 118509.

VERMA, A. K., DASH, R. R. & BHUNIA, P. (2012) A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters. *Journal of Environmental Management* 93 (1), 154 - 168.

YANG, Q., WANG, X., LUO, W., SUN, J., XU, Q., CHEN, F. & ZENG, G. (2018) Effectiveness and mechanisms of phosphate adsorption on iron-modified biochars derived from waste activated sludge. *Bioresource Technology* **247**, 537 - 544.

YAO, C., PAN, Y., LU, H., WU, P., MENG, Y., CAO, X. & XUE, S. (2016) Utilization of recovered nitrogen from hydrothermal carbonization process by *Arthrospira platensis*. *Bioresource Technology* **212**, 26 - 34.

YIN, Q., ZHANG, B., WANG, R. & ZHAO, Z. (2017). Biochar as an adsorbent for inorganic nitrogen and phosphorus removal from water: A review. *Environ. Sci. Pollut. Res.,* **24**, 26297 – 26309.

ZHANG, M., SONG, G., GELARDI, D. L., HUANG, L., KHAN, E., MAŠEK, O., PARIKH, S. J. & OK, Y. S. (2020). Evaluating biochar and its modifications for the removal of ammonium, nitrate, and phosphate in water. *Water Res*. **186**, 116303.

ZHANG, Y., WANG, Y., ZHANG, H., LI, Y., ZHANG, Z. & ZHANG, W. (2020) Recycling spent lithium-ion battery as adsorbents to remove aqueous heavy metals: Adsorption kinetics, isotherms, and regeneration assessment. *Resources, Conservation and Recycling* **156**, 104688.

ZHENG, W., GUO, M., CHOW, T., BENNETT, D. N. & RAJAGOPALAN, N. (2010) Sorption properties of greenwaste biochar for two triazine pesticides. *J. Hazard. Mater.* **181**, 121 - 126.

Received 16 May. 24; revised 25 May 26.