Plant-based coagulants for water treatment

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Abstract. The use of coagulants that are derived from natural material has significantly increased over the last decades due to the safety and cost-effectiveness use of such coagulants. Therefore, the current study aims to use a plant-based coagulant namely Moringa Oleifera seeds to remove the water turbidity. During the experimental work, samples of water of 250 nephelometric turbidity units (NTU) were mixed with various amounts of Moringa Oleifera seeds in the laboratory at room temperature (20 ± 1 °C) for 90 minutes. Every 10 minutes, 5.0 ml samples were collected using a plastic container and filtered to be checked using a spectrophotometer for the removal of turbidity. Besides, the impact of mixing time, dose of Moringa Oleifera, and pH on the removal of the turbidity was investigated. The outcome showed that the turbidity of the treated water decreases with the increase in the dosage of Moringa Oleifera and the mixing time. However, it was noticed that the removal efficiency of the turbidity decreases when the pH value is more than 7. The removal of the water turbidity of 92% was achieved using 8 g/l of Moringa Oleifera for 80 minutes.

1. Introduction
Many nations around the world suffer from serious potable water scarcity for many reasons including the lack of resources and financial support [1-3]. Besides, the growing population and industrial sectors have led to the discharge of growing pollution loads to freshwater bodies and making the purification process increasingly expensive [4, 5]. Researchers, [6, 7], have reported that about 1.2 billion person does not have access to freshwater, and more than 6 million individual dies due to polluted water-related diseases each year. Other scholars [8-11] confirms that millions of cubic meters of polluted water are yearly discharged into the water bodies (surface or groundwater bodies) due to industrial growth. For instance, Abdulhadi et al. [12] stated that the textile industry daily consumes large quantities of freshwater and discharges the majority of this water as extremely contaminated to water bodies. On average, the textile industry consumes about 0.2 cubic meters of freshwater to produce 1.0 kg of fabric. The petroleum industry is the main producer of highly polluted wastewater nearly about 1.6 times of the produced oil. Researchers reported that more than 33.6 million barrels of heavily polluted water are disposed to water bodies to produce only 84 million barrels of oil. It is expected that the demand for oil industry products will more than 100 million barrel per day which will lead to generating huge quantities of heavily polluted water with various contaminants including dyes, phenols, and nutrients [13-16].
Turbidity is one of the most common water pollutants due to soil erosion, runoff, or the presence of elevated numbers of microorganisms [17-20]. It significantly spoils the water appearance, negatively affects fish production, damages the water quality, and could cause several diseases such as nausea [21-24]. Thus, 1.0 nephelometric turbidity unit (NTU) is set by the world health organization as the maximum turbidity level for drinking purposes. To achieve this limitation, many biological, chemical, and physical methods were employed to minimize the turbidity of the water. Biological approaches employ microorganisms to remove the pollutants from water. Such approaches are effective in the removal of organic components of the water turbidity, nonetheless, their efficiency is less in the removal of inorganic matter-related turbidity. Therefore, researchers normally couple the biological methods with other treatment methods to remove the turbidity. For instance, the granular activated carbon method and the moving-bed biofilm method are combined to remove turbidity from the leachate of landfills, where about 90% of the turbidity and 70% of the colours were removed from the leachate samples [25-29]. The combination of the aerated filter method and an anoxic filter bed was found efficient to decrease the turbidity to about 94% of the turbidity from the textile industry wastewater [12, 30]. Researchers showed that the biological methods are efficient in removing turbidity from water. However, such methods face several limitations including treatment duration, space requirements, and pollution loads [31-33]. Physical methods such as sand filter and screening remove pollutants from water without changing the chemical composition of pollutants [34-37]. For example, a crumb rubber filter was used to remove turbidity from the water where about 47.8% of the turbidity was removed using a grain size of 2 to 4 mm, and discharge of 24.4 m$^3$/h. The literature indicated that slow sand filters could remove turbidity from water by a percentage of more than 85%. On the other hand, some researchers coupled poly-aluminum-chloride coagulation with rapid sand filtration to remove turbidity and achieved 80.0% removal of the turbidity. However, physical methods either have low cost and removal efficiency or have high cost and good removal efficiency [38-40]. Chemical methods employ chemical additives to group the fine particles in large flocs in which are removed by sedimentation or floatation [39, 41]. For example, a number of researchers, [17, 19, 39] used many coagulants (such as poly-aluminum chloride and poly-titanium chloride) to minimize the turbidity from 7.0 NTU to 1.2 NTU. A 5 mg/l of poly-aluminum ferric chloride is used to remove 86% of colour and 100% of turbidity at a pH of 7.5. Polymeric zinc-iron-phosphate is also used to reduce the turbidity from about 9 NTU to less than 1.0 NTU in 15 minutes [42-44]. However, the industrial coagulants could cause negative effects on humans and the environment such as Alzheimer's disease and some types of cancer. Thus, researchers currently focus on the use of natural coagulants such as cactus opuntia and watermelon seeds to remove turbidity from water [12, 17, 45]. The need for cost-effective coagulants for water treatment because the poor countries are subjected to a significant increase in water demand nowadays because of global warming [46-48], which also increases water pollution in those countries [49-51]. Additionally, the coagulation process is favourable nowadays because the sludge of water and wastewater treatments could be used as a cementitious material [52-55], or in other construction materials [56, 57].

*Moringa oleifera* seeds (MOSs), Fig. 1, are Moringaceae tree seeds, which have been successfully used as a natural coagulant to remove pollutants from water, such as heavy metals [17]. Researchers stated that MOSs are extensively used in water treatment due to their fullness with acids that have great coagulant and anti-microbial properties. For instance, the MOSs were used to remove heavy metals such as lead and copper from wastewater where a removal efficiency of more than 70% was achieved [17]. The MOSs was also used as a powder to remove organic contaminants where about 65% of the organic content was removed after 180 minutes of treatment. Other scholars used the seeds to eliminate biological pollutants from water and achieved 40% removal efficiency after 1.5-hour contact time. Accordingly, efficient, and safe water treatment methods are required to meet the future demand for potable water. Currently, the researcher’s attention is the use of natural to remove pollutants from water and wastewater. Thus, the current research is designed to use the MOSs as a natural coagulant to eliminate the turbidity of the water.
2. Methodology

2.1. Materials
The Department of Civil Engineering, Liverpool John Moores University provided the seeds. According to Alenazi, et al., [17], the seeds have to be dried for 48 hours at an oven temperature of 40° and crashed and sieved at mesh 0.42 mm to be used in experiments. Following this, after drying the seeds, the exterior of the seeds was removed by hand, while the interior was ground using a food processor. The resultant was passed through a 0.42 mm mesh sieve and kept in a vessel to be employed in the turbidity removal trials.

2.2. Solution
Alenazi, et al., [17] stated artificial turbid water can be prepared by mixing 5 liters of deionized water and 50 grams of kaolin at 20 revolutions per minute for 60 minutes. The turbid water used in this study was prepared according to Alenazi, et al., [17] method and kept for one day to hydrate the kaolin. The turbidity of the prepared synthetic water was 250 NTU.

2.3. Batch experiments
The turbidity removal efficiency of the MOSs was examined by conducting batch tests on the prepared synthetic water samples. As recommended by Alenazi, et al., [17], the tests were conducted by adding a dose of MOSs powder to 1 liter of the prepared turbid water of 250 NTU and mixed for a maximum of 90 minutes at a speed of 40 revaluations per minute. The impacts of the mixing time, the pH level, and the dose of the MOSs powder were examined by applying several mixing times ranged from 10 to 90 minutes, pH level varied between 4 and 9, and MOSs doses varied between 4 to 12 g/l. The pH level was controlled using HCL and NaOH and measured using Hannah portable pH meter. The turbidity removal efficiency was calculated by collecting 5 ml samples every 10 minutes. Whatman filter paper number 5 was used to filter the samples for the turbidity elimination test and the removal of the turbidity was calculated using the spectrophotometer and the calibration curve. According to Hashim et al., [58], the following equation can be used to calculate the removal efficiency.

\[
\text{Turbidity removal efficiency (\%) } = \frac{A_1 - A_2}{A_1} \times 100
\]

Where \(A_1\) represents the primary turbidity level of 250 NTU, while \(A_2\) represents the closing level of the turbidity.

3. Results and discussion

3.1. Influence of the pH
The turbidity removal efficiency can be affected by the concentration of the hydrogen ions (pH level) of the water as it impacts the concentration of ions in the water and cationic acids in the MOSs powder. The influence of pH on the removal efficiency of turbidity has been investigated by treating 1000 ml of water samples using 250 NTU initial turbidity level for 30 minutes at pH values ranged from 4 to 9. Figure 1 provides a graphic presentation on the impact of pH on the removal efficiency of the water turbidity. When the water becomes alkaline (the pH more than 7), the removal efficiency decreases with the increase in water pH level due to the presence of hydroxyl ions. It can be also seen that the best removal efficiency of turbidity was stable at the middle pH level range between 4 and 7. This performance in turbidity removal at the middle pH level is attributed to the existence of hydrogen ions which increased the absorption ability of MOSs powder. Accordingly, a pH level of 7 has been selected to identify the impact of the MOSs dose and contact time.
3.2. The influence of the MOSs dose
The dosage of MOSs strangely influences the removal of the turbidity of the water as it makes the most of the surface area available for turbidity adsorption. Accordingly, the impacts of the MOSs on the elimination of turbidity from the water were considered by treating the same sample size (1000 ml) of water for the same duration (30 minutes) and the decided pH level of 7. The initial turbidity was selected to be 250 NTU and the doses of MOSs were 4, 6, 8, 10, and 12 g/l at every 5 minutes. Figure 2 highlighted that the increase in the MOSs dose rises the removal of the turbidity of the water. This confirms that the more the MOSs powder dose the more the available space to adsorb turbidity which significantly enhances the removal efficiency. After 8 g/l dose of MOSs, the removal efficiency stabled on 75% removal; accordingly, a dose of 8 g/l of the MOSs has been used to examines the impact of mixing time on the removal efficiency of the turbidity of the water.

![Figure 1. Impact of pH on the removal of water turbidity.](image1)

3.3. The influence of the mixing time
Time plays a vital role in any water treatment activity such as adsorption. The time allows longer contact between the pollutants of the water and the adsorbent. Thus, the influence of treatment duration on the removal of turbidity has been analyzed by treating samples that have a sample size of 1000 ml, initial turbidity of 250 NTU, the pH level of 7 for 90 minutes using a MOSs dose of 8 g/l. The outcome showed in Figure 3 highlighted that the removal of turbidity has steeply increased to reach about 90% after 50 minutes of contact time. Accordingly, a dose of 8 g/l of the MOSs was able to remove 92% of the turbidity of water with a pH level of 7 after 90 minutes.

![Figure 2. The impact of MOSs dose on the removal efficiency of the turbidity of the water.](image2)
3.4. **Evaluating the performance of the MOSs as a coagulant**

Scholars such as [17], and [39] applied various types of chemical coagulants to remove the turbidity from the water. According to [17], the removal efficiency of the turbidity from water and wastewater using chemical coagulants ranged between 86 and 100%. Accordingly, the MOSs powder (a natural coagulant) adopted in this research achieved a comparable outcome of 92% removal efficiency for the turbidity of the water. Therefore, it can be said that the negative impacts of chemical coagulants can be minimized by using eco-friendly natural coagulants such as MOSs.

### 4. Conclusions

The current study investigated the use of natural coagulants namely *Moringa oleifera* seeds for the removal of the turbidity from water. According to the outcome of this experimental study, it can be said that the *Moringa oleifera* seeds can be considered as an acceptable substitute to the chemical coagulants for the removal of the turbidity pollution from water as it was able to remove 92% of the turbidity. A higher dose of MOSs and longer contact time provide better removal of the turbidity pollution from water. Additionally, the removal efficiency of the MOSs is influenced by the pH value of the treated water, which can be improved by maintaining the pH level below 7. The MOSs can be considered as an eco-friendly coagulant as the chemical management for the MOSs is not required and have no impact on human health.

### References

[1] Mohammed A-H, Hussein A H, Yeboah D, Al Khaddar R, Abdulhadi B, Shubbar A A and Hashim K S 2020 Electrochemical removal of nitrate from wastewater *IOP Conference Series: Materials Science and Engineering* 888.

[2] Khalid H S, Idowu I A, Jasim N, Phipps D, Pedrola M O, Alattabi A W and Abduredha M J M 2018 Removal of phosphate from River water using a new baffle plates electrochemical reactor *5* 1413-8.

[3] Hashim K S, Pedrola M O, Alattabi A W, Abduredha M, Alawsh R J S and Technology P 2019 Electrocoagulation as a green technology for phosphate removal from river water *210* 135-44.

[4] Abduredha M, Al Khaddar R, Jordan D, Abduridha A J E, Development and Sustainability 2020 Investigating municipal solid waste management system performance during the Arba’een event in the city of Kerbala, Iraq *22* 1431-54.

[5] Idowu I A, Atherton W, Rafid A, Alo B I and Andy S 2019 An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences *Waste Management* *87* 761-71.
[6] Ali E N, Muyibi S A, Salleh H M, Alam M Z and Salleh M R 2010 Production of natural coagulant from Moringa oleifera seed for application in treatment of low turbidity water Journal of Water Resource and Protection 2 259.

[7] Abdulredha M, Rafid A, Jordan D and Hashim K 2017 The development of a waste management system in Kerbala during major pilgrimage events: determination of solid waste composition 196 779-84.

[8] Abdulredha M, Rafid A, Jordan D and Alattabi A 2017 Facing up to waste: how can hotel managers in Kerbala, Iraq, help the city deal with its waste problem? 196 771-8.

[9] Alattabi A W, Harris C, Alzeyadi A and Abdulredha M J P e 2017 Online Monitoring of a sequencing batch reactor treating domestic wastewater 196 800-7.

[10] Abdullahi B, Muradov M and Rafid R 2021 Continuous-flow electrocoagulation (EC) process for iron removal from water: Experimental, statistical and economic study Science of The Total Environment 756 1-16.

[11] Khalid H S, Andy A, Rafid M R, Patryk K and Al-Shamma’a A 2021 Water purification from metal ions in the presence of organic matter using electromagnetic radiation-assisted treatment Journal of Cleaner Production 280

[12] Abdullahi B A, Andy A and Rafid R A 2019 Influence of current density and electrodes spacing on reactive red 120 dye removal from dyed water using electrocoagulation/electrofloation (EC/EF) process First International Conference on Civil and Environmental Engineering Technologies (ICCEET) 584.

[13] Emamjomeh M M, Mousazadeh M, Mokhtari N, Jamali H A, Makkiabadi M, Naghdali Z and Ghanbari R 2020 Simultaneous removal of phenol and linear alkylbenzene sulfonate from automotive service station wastewater: Optimization of coupled electrochemical and physical processes Separation Science and Technology 55 3184-94.

[14] Al-Marri S, AlQuzweeni S S, AlKizwini R S, Zubaidi S L and Al-Khafaji Z S 2020 Ultrasonic-Electrocoagulation method for nitrate removal from water IOP Conference Series: Materials Science and Engineering 888.

[15] Alyafei A, AlKizwini R S, Yeboah D, Gkantou M, Al Khaddar R, Al-Faluji D and Zubaidi S L 2020 Treatment of effluents of construction industry using a combined filtration-electrocoagulation method IOP Conference Series: Materials Science and Engineering 888.

[16] Aqeeq K, Mubarak H A, Amoako-Attah J, Abdul-Rahaim L A, Al Khaddar R, Abdellatif M, Al-Janabi A and Hashim K S 2020 Electrochemical removal of brilliant green dye from wastewater IOP Conference Series: Materials Science and Engineering 888.

[17] Alenazi M, Hassan A A, Muradov M and Abdulhadi B 2020 Turbidity removal using natural coagulants derived from the seeds of strychnos potatorum: statistical and experimental approach IOP Conference Series: Materials Science and Engineering 888.

[18] Ali S A, Jafer H, Abdulredha M, Al-Khafaji Z S, Nasr M S, Al Masoodi Z and Sadique M J J o B E 2020 Properties of cement mortar incorporated high volume fraction of GGBFS and CKD from 1 day to 550 days 101327.

[19] Alenezi A K, Hasan H A, Amoako-Attah J, Gkantou M, Muradov M and Abdulhadi B 2020 Zeolite-assisted electrocoagulation for remediation of phosphate from calcium-phosphate solution IOP Conference Series: Materials Science and Engineering 888.

[20] Abdulla G, Kareem M M, Hashim K S, Muradov M, Mubarak H A, Abdellatif M and Abdulhadi B 2020 Removal of iron from wastewater using a hybrid filter IOP Conference Series: Materials Science and Engineering 888.

[21] Alhendal M, Nasir M J, Amoako-Attah J, Al-Faluji D, Muradov M and Abdulhadi B 2020 Cost-effective hybrid filter for remediation of water from fluoride IOP Conference Series: Materials Science and Engineering 888.

[22] Alattabi A W, Harris C and Alzeyadi A 2017 Treatment of Residential Complexes’ Wastewater using Environmentally Friendly Technology Procedia Engineering 196 792-9.
[24] Alattabi A W, Harris C B, Ortoneda-Pedrola M and Phipps D 2017 Improving sludge settleability by introducing an innovative, two-stage settling sequencing batch reactor Journal of Water Process Engineering 20 207-16.

[25] Safaa K H, Ali S S M, AlRifaie J K, Idowu I and Gkantou M 2020 Escherichia coli inactivation using a hybrid ultrasonic–electrocoagulation reactor Chemosphere 247 125868-75.

[26] AlKhaddar R, Al-Jumeily D, Alwash R and Aljefery M H 2020 Electrocoagulation as an eco-friendly River water treatment method. In Advances in Water Resources Engineering and Management (Berline: Springer).

[27] Hassan Alnaimi I J I, Abdulkalaal Al-Janabi, Michaela Gkantou, Salah L. Zubaidi, Patryk K, Magomed Muradov 2020 Ultrasonic-electrochemical treatment for effluents of concrete plants Ultrasonic-electrochemical treatment for effluents of concrete plants IOP Conference Series: Materials Science and Engineering 888.

[28] Andy A, Ortoneda Pedrola M and Phipps D 2017 Defluoridation of drinking water using a new flow column-electrocoagulation reactor (FCER) - Experimental, statistical, and economic approach Journal of Environmental Management 197 80-8.

[29] Khalid H S, Idowu I A, Jasim N, Phipps D, Patrick P, Pedrola M O, Alattabi A W and Abdulredha M 2018 Removal of phosphate from River water using a new baffle plates electrochemical reactor MethodsX 5 1413-8.

[30] Majdi H S, Shubbar A, Nasr M S, Al-Khafaji Z S, Jafer H, Abdulredha M, Al Masoodi Z, Sadique M and Hashim K J D i B 2020 Experimental data on compressive strength and ultrasonic pulse velocity properties of sustainable mortar made with high content of GGBFS and CKD combinations

[31] Hussein A H, Zubaidi S L, Kraid L and Alwash R 2019 Effect of initial pH value on the removal of reactive black dye from water by electrocoagulation (EC) method 2nd International Scientific Conference

[32] Kot P, Alwash R, Al-Jumeily D and Aljefery M 2020 Energy efficient electrocoagulation using baffle-plates electrodes for efficient Escherichia Coli removal from Wastewater Journal of Water Process Engineering 33 101079-86.

[33] Zanki A K, Mohammad F H, Muradov M, Kareem M M and Abdulhadi B 2020 Removal of organic matter from water using ultrasonic-assisted electrocoagulation method IOP Conference Series: Materials Science and Engineering 888.

[34] Mohammad A, Abdulridha A, Shubbar A and Jordan D 2020 Estimating municipal solid waste generation from service processions during the Ashura religious event IOP Conference Series: Materials Science and Engineering 671.

[35] Zubaidi S L, Al-Bugharbee H, Muhsen Y R, Al-Jumeily D and Aljaaf A J 2019 The Prediction of Municipal Water Demand in Iraq: A Case Study of Baghdad Governorate 12th International Conference on Developments in eSystems Engineering (DeSE)

[36] Salah Z L, Abdellatif M and Muhsin Y R 2019 Using LARS–WG model for prediction of temperature in Columbia City, USA IOP Conference Series: Materials Science and Engineering 584.

[37] Kadhim A, Sadique M, Al-Mufli R and Hashim K 2020 Long-term performance of novel high-calcium one-part alkali-activated cement developed from thermally activated lime kiln dust Journal of Building Engineering 32 1-17.

[38] Muhammad A, Rafid A, Jordan D and Abdulridha A 2018 Benchmarking of the Current Solid Waste Management System in Karbala, Iraq, Using Wasteware Benchmark Indicators World Environmental and Water Resources Congress 2018: Groundwater, Sustainability, and Hydro-Climate/Climate Change

[39] Al-Saati N H, Hussein T K, Abbas M H, Al-Saati Z N, Sadique M, Aljefery M H and Carnacina I 2019 Statistical modelling of turbidity removal applied to non-toxic natural coagulants in water treatment: a case study Desalination and Water Treatment 150 406-12.

[40] Omran I I, Al-Saati N H, Al-Saati Z N, Patryk K, Khaddar R A, Al-Jumeily D, Shaw A, Ruddock F and Aljefery M 2019 Assessment of heavy metal pollution in the Great Al-Mussaib irrigation channel Desalination and Water Treatment 168 165-74.
[41] Zubaidi S L, Al-Bugharbee H, Muhsin Y R, Hashim K and Rafid R 2020 Forecasting of monthly stochastic signal of urban water demand: Baghdad as a case study IOP Conference Series: Materials Science and Engineering 888.

[42] Abdulredha M, Jordan D, Patryk K and Abdulridha A 2018 Estimating solid waste generation by hospitality industry during major festivals: A quantification model based on multiple regression 77 388-400.

[43] Safaa H K, Al-Saati N H, Alquzweeni S S, Kraidi L, Hussein A H, Alkhaddar R, Shaw A and Alwash R 2019 Decolourisation of dye solutions by electrocoagulation: an investigation of the effect of operational parameters First International Conference on Civil and Environmental Engineering Technologies (ICCEET) 584.

[44] Al-Jumeily D, Alkaddar R, Al-Tufail M and Lunn J 2019 Sustainable and Environmental Friendly Ancient Reed Houses (Inspired by the Past to Motivate the Future) 11th International Conference on Developments in eSystems Engineering (DeSE)

[45] Hashim K S, Al-Saati N H, Hussein A H and Al-Saati Z N 2018 An investigation into the level of heavy metals leaching from canal-dreged sediment: a case study metals leaching from dreged sediment First International Conference on Materials Engineering & Science

[46] Lafata Z S, Al-Bugharbee H, Ortega Martorell S, Gharghan S, Olier I, Hashim K, Al-Bdairi N and Kot P 2020 A Novel Methodology for Prediction Urban Water Demand by Wavelet Denoising and Adaptive Neuro-Fuzzy Inference System Approach Water 12 1-17.

[47] Zubaidi S L, Abdulkareem I H, Al-Bugharbee H, Ridha H M, Gharghan S K, Al-Qaim F F, Muradov M and Alkhaddar R 2020 Hybridised Artificial Neural Network model with Slime Mould Algorithm: A novel methodology for prediction urban stochastic water demand Water 12 1-18.

[48] Salah S L, Ethaib S, Al-Bdairi N S S, Al-Bugharbee H and Gharghan S K 2020 A novel methodology to predict monthly municipal water demand based on weather variables scenario Journal of King Saud University-Engineering Sciences 32 1-18.

[49] Lafata Z S, Ortega-Martorell S, Al-Bugharbee H, Olier I, Gharghan S K and Al-Khaddar R 2020 Urban Water Demand Prediction for a City that Suffers from Climate Change and Population Growth: Gauteng Province case study Water 12 1-18.

[50] Ortega-Martorell S, Alkhaddar R M, Abdellatif I M, Gharghan S K, Ahmed M S and Hashim K 2020 A Method for Predicting Long-Term Municipal Water Demands Under Climate Change Water Resources Management 34 1265-79.

[51] Grmasha R A, Al-sareji O J, Salman J M and Jasim I A 2020 Polycyclic Aromatic Hydrocarbons (PAHs) in Urban Street Dust Within Three Land-Uses of Babylon Governorate, Iraq: Distribution, Sources, and Health Risk Assessment Journal of King Saud University - Engineering Sciences 33, 1-15

[52] Kadhim A, Sadique M, Al-Mufli R and Hashim K 2020 Developing One-Part Alkali-Activated metakaolin/natural pozzolan Binders using Lime Waste as activation Agent Advances in Cement Research 32 1-38.

[53] Shubbar A A, Sadique M, Nasr M S, Al-Khafaji Z S and Hashim K S 2020 The impact of grinding time on properties of cement mortar incorporated high volume waste paper sludge ash Karbala International Journal of Modern Science 6 1-23.

[54] Ali A S, Sadique M, Shanbara H K and Hashim K 2020 The Development of a New Low Carbon Binder for Construction as an Alternative to Cement. In Advances in Sustainable Construction Materials and Geotechnical Engineering (Berlin: Springer).

[55] Ewadh H M, Muhsin A A, Zubaidi S L, Kot P, Muradov M, Aljefery M and Al-Khaddar R 2020 Phosphate removal from water using bottom ash: Adsorption performance, coexisting anions and modelling studies Water Science and Technology 83 1-17.

[56] Jafer H, Dulaiami A, Atherton W and Sadique M 2018 The development of a low carbon binder produced from the ternary blending of cement, ground granulated blast furnace slag and high calcium fly ash: An experimental and statistical approach Construction and Building Materials 187 1051-60.
[57] Abdulhussain S A, Al-Shaer A, AlKizwini R S, Hawesah H A and Sadique M 2019 Investigating the influence of cement replacement by high volume of GGBS and PFA on the mechanical performance of cement mortar First International Conference on Civil and Environmental Engineering Technologies (ICCEET) 584.

[58] Shaw A, Al Khaddar R, Pedrola M O and Phipps D 2017 Energy efficient electrocoagulation using a new flow column reactor to remove nitrate from drinking water - Experimental, statistical, and economic approach Journal of Environmental Management 196 224-33.