


River water turbidity removal using new natural coagulant aids: case study of Euphrates River, Iraq

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ABSTRACT

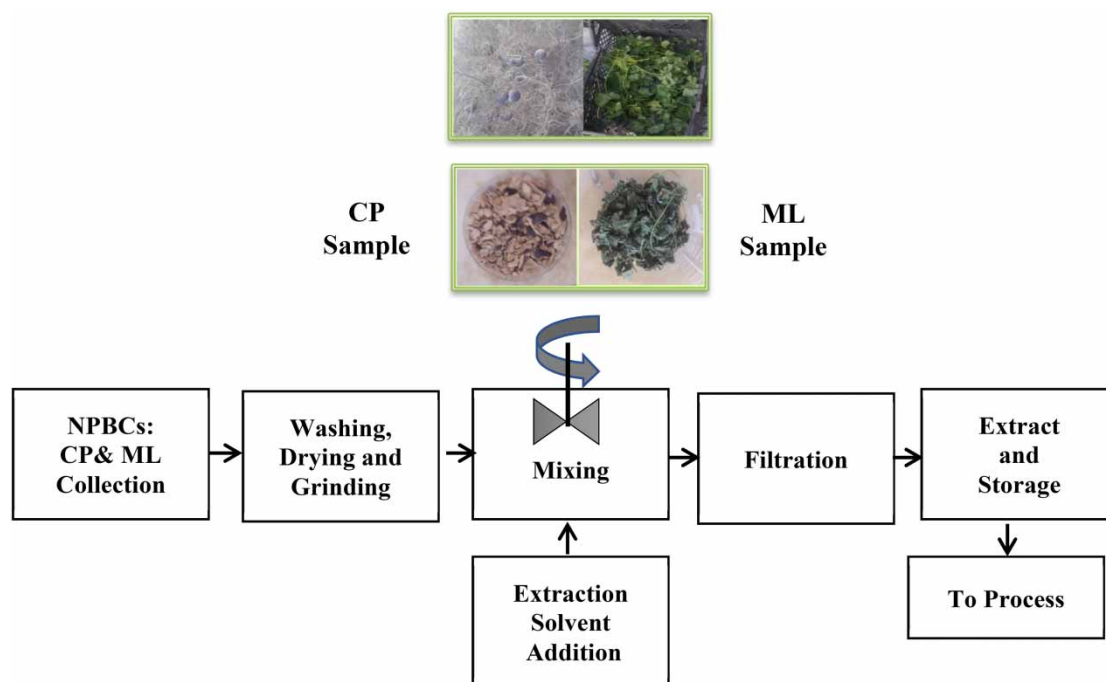
For turbidity removal, most drinking water treatment plants are using coagulants due to the presence of suspended and colloidal materials at the coagulation and flocculation units. Aluminium and sulphates salts are the widely used coagulants, such as aluminium sulphate (Alum) and ferric chloride. However, several researches have linked Alzheimer's disease to the use of aluminium sulphate. Hence, scholars have conducted several researches on the possibility to reduce the amount of aluminium sulphate by using natural material/plants base as coagulant aids. In this study, Mallow's Leaves Extracts (MLE) and Carob's Pods Extracts (CPE) were used as an alternative coagulant aid. Couples of coagulation tests were implemented to find the optimal dosage of aluminium sulphates used as coagulants. The results displayed that the maximum turbidity removal efficiency by adding 100% of each coagulant, i.e. alum, MLE and CPE, were 61.16, 51.175 and 37.12%, respectively. In addition, the minimum residual turbidity and maximum turbidity removal efficiency were 4.56 NTU and 97.72% by adding 22.5 alum and 7.5 MLE presenting 30 mg/L dosing. Further, the minimum residual turbidity and maximum turbidity removal efficiency were 15.4 NTU and 92.3% by adding 22.5 alum and 7.5 CPE presenting 30 mg/L dosing.

Key words: coagulant aids, coagulation, turbidity, water quality, water treatment

HIGHLIGHTS

- Mallow's Leaves Extracts (MLE) and Carob's Pods Extracts (CPE) were used as an alternative coagulant aid.
- Couples of coagulation tests were implemented to find the optimal dosage of aluminium sulphates used as coagulants.
- The results revealed that MLE and CPE have considerable flocculation properties.
- The minimum residual turbidity was 15.4 NTU by adding 22.5 alum and 7.5 CPE presenting 30 mg/L dosing.

GRAPHICAL ABSTRACT



1. INTRODUCTION

In rural areas or underdeveloped countries, inadequate water treatment systems and limited availability of chemicals products exist. Hence, the best possible alternative is to use as easy and comparatively cost-effective point-of-use (POU) technology such as coagulation (Sobsey *et al.* 2008). In the treatment process of drinking water and wastewater, coagulation is an important operation (Ansari *et al.* 2018a; Yaseen *et al.* 2019). It is applied to remove dissolved chemical and turbidity by the addition of synthetic chemical-based coagulants and the most common coagulants include ferric chloride (FeCl_3), alum (AlCl_3), and polyaluminium chloride (PAC) (Vijayaraghavan *et al.* 2011).

Since high quality of drinking water is required, coagulation and flocculation processes are significantly applied for both fresh water and wastewater treatment plants (Al Doury & Al Samerrai 2019; Bhagat *et al.* 2020). In addition, it is widely used in fresh water and wastewater treatment due to its simplicity and cost-effectiveness (Tzoupanos & Zouboulis 2008; Ibrahim 2019). Figure 1 shows the advantages of natural plant-based coagulants (NPBCs) over chemical coagulants (Choy *et al.* 2014). The importance of using NPBCs are reported recently due to their advantages as they represent environmental-friendly materials, healthier and safer than alum decrease the sludge treatment and management cost, etc. (Jayalakshmi *et al.* 2017). In addition, NPBCs work as adsorbent of many chemical compounds when applied as coagulant aids and thus they are applied in wastewater treatment research (Iqbal *et al.* 2019).

As a matter of fact, using extra alum doses in drinking water treatment plants could have a negative impact on human health in addition to the high processing cost of alum coagulant doses (Muthuraman & Sasikala 2014). The scarcity of water resources has become the main problem in many countries of the world (Wan Mohtar *et al.* 2019). Therefore, other sources of surface water including streams, lakes and ponds have been supplied to residential areas and used as drinking water after treatment (Kakoi *et al.* 2016). Application of chemical coagulants (e.g. alum) materials are significantly used in fresh water and wastewater treatment to obtain high quality of water, which is considered a significant factor for the stability of the ecosystem. However, increasing pollutants in fresh water and wastewater more than the standard levels led to the use of natural coagulants (Chhipi-Shrestha *et al.* 2020). Since natural coagulants are considered as environmentally-friendly, an abundant source with low price, and rapidly biodegradable compared to inorganic based coagulants, they became more desirable and are widely used in water treatment (Kumar 2020; Mehr & Akdegirmen 2021). The composition of fresh water and wastewater could highly contain turbidity, total suspended solid (TSS), and chemical oxygen demand (COD), coming from

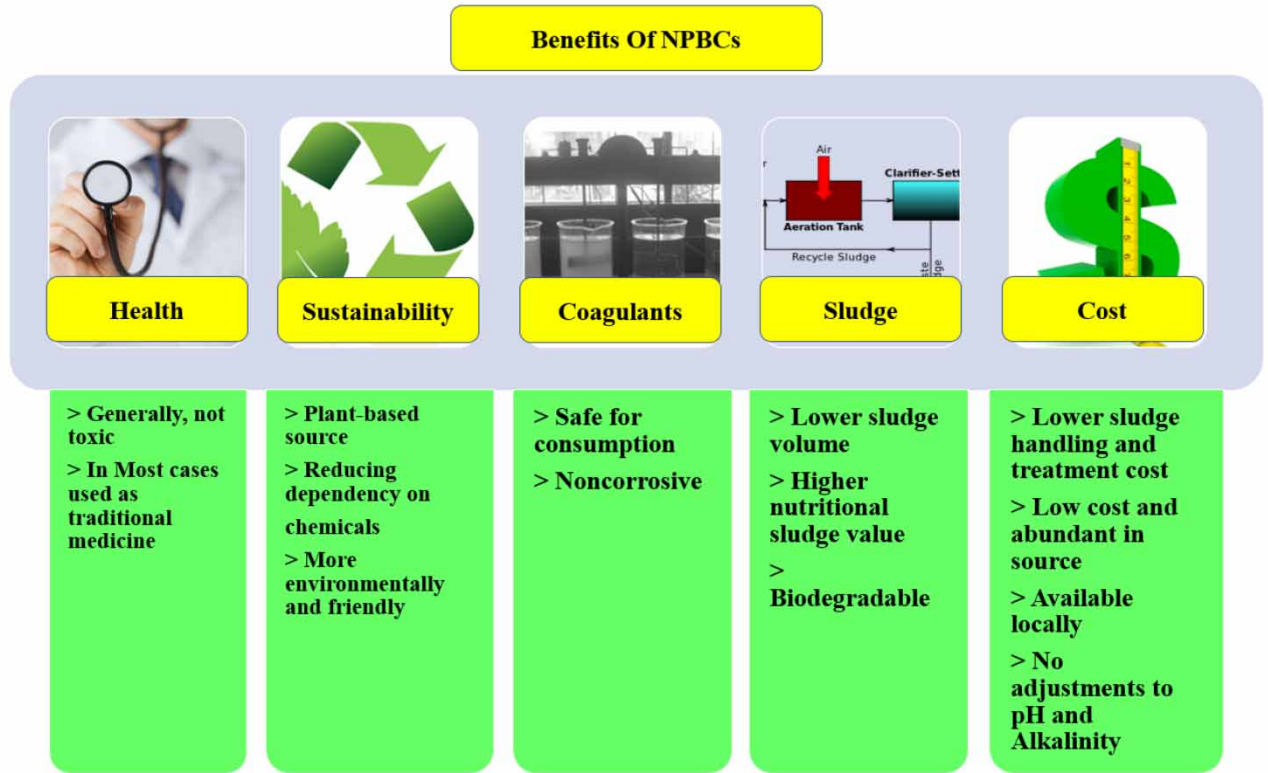


Figure 1 | Advantages of natural plant-based coagulants (NPBCs) over chemical coagulants.

both domestic and surface runoff sources (Alavi *et al.* 2021). Turbidity is represented by suspended and colloidal material that can be preliminarily removed through conventional fresh water and wastewater treatment methods using coagulation/flocculation processes (Gippel 1995). There are different types of coagulants and flocculants including inorganic and organic materials, which were commonly used in conventional wastewater treatment processes (Al-Doury & Alwan 2019; Shihab & Ahmad 2020). Globally, organic coagulants consist of aluminium that is commercially available and is the most substantially used major coagulant in treatment processes for fresh water and wastewater. However, excessive use of this traditional coagulant material has increased processing cost and resulted in different diseases for humans (Lee *et al.* 2014).

Many water treatments plants (WTPs) in various countries around the world began relying on natural coagulants rather than industrial coagulants to remove or reduce contaminants such as turbidity, colour, suspended solids, etc. The main reason behind using these natural coagulants instead of chemical coagulants is that they are widely available at a low cost and can be considered more healthy and efficient materials in comparison with others in water treatment. Therefore, many researchers started to investigate the use of these natural materials in water treatment and studied their impact on turbidity removal. In this study, the motivation and focus is to use different types of plants which widely available in the west and middle part of Iraq as a natural coagulant for turbidity removal from raw water.

2. RELATED RESEARCH

Since there is a serious concern about the relation between aluminium residuals in the treated water and human health, most of the natural coagulants and especially those made of plant were developed to be used as an alternative for alum material (Bina *et al.* 2009; Li *et al.* 2020). Drinking water sources such as river, lakes, groundwater, etc. usually require the use of coagulation and flocculation stage to eliminate turbidity in the form of suspended and colloidal material (Asadollah *et al.* 2020). One of the major benefits of the treatment process is the capability to reduce or remove different pollutants such as colour organic compounds, bacteria, algae, and clay particles. For instance, suspended particles could clog filters or harm the disinfection process, significantly minimizing the risk of waterborne diseases (Fatoki & Ogunfowokan 2002; Ansari *et al.* 2018b). Also, adding aluminium salts could cause Alzheimer's disease and there is a concern about its residuals

in the treated water because of using an inadequate amount of alum (Bina *et al.* 2009). Therefore, iron salts are considered as one of the best choices. However, the cost of any imported chemicals can be considered as a serious problem, especially for developing countries. Consequently, recently natural coagulants from plant-based coagulant sources have been developed and widely used for treatment of fresh water and wastewater compared to chemical coagulants. This is to reduce the cost of fresh water and wastewater treatment processes and may be performed as well as chemical materials used for treatment (ELsayed *et al.* 2020; Lanan *et al.* 2020).

Many researchers have studied the efficiency of different natural coagulants. For example, Chitosan and Moringa Oleifera have been used as a coagulant in water treatment (Ravikumar & Sheeja 2012). These natural coagulants are equivalent to their chemical counterparts in terms of removal efficiency when they are used for water treatment at low-to-medium turbidity ranging from 50 to 500 NTU (Yin 2010). Jatropha was used to remove the turbidity ranging between 100 and 8000 NTU which was noticed to agglomerate faster and larger compared to using alum and the turbidity removal efficiency was 98% (Abidin *et al.* 2013). Plant leaves of Cassia Alata (LCA) were applied as a coagulant and the experiments showed that LCA can eliminate turbidity to 93.33% (Rak & Ismail 2012). Peanut seeds extract (PSE) was applied as coagulant with early turbidity of 200 NTU using only 20 mg/L of the extract. Turbidity removal efficiency of 93.2% was achieved. Patale & Pandya (2012) studied the Coccinia indica fruit extract (CIE) as coagulant to treat raw water with initial turbidity of 100 NTU. The authors reported that CIE has high turbidity removal efficiency (94% was achieved). Opuntia dillenii (ODE) is a based-plant coagulant extracted from the Cactaceae family and jar tests showed that ODE can remove 89–93% of the initial turbidity (Noughbodé *et al.* 2013). One study has used natural plants of Moringa Oleifera seed and leaves, which are widely available in the southern part of Iraq (Ghawi 2017). The natural coagulants were used in the compact unit of drinking water treatment located in Al-Diwaniyah city in Iraq to remove turbidity as well as heavy metals from raw water. The results of the previous study proved that there is no health impact by using these natural coagulants (natural plants) in water treatment. In addition, this study confirmed that removal percentages of turbidity and heavy metals from raw water were up to 99 and 98%, respectively, which met WHO's guidelines for drinking water (Kim *et al.* 2020). Also, it was concluded that Moringa Oleifera seed and leaves can be significantly used as a natural coagulant rather than other chemical coagulants used in removing turbidity and suspended solids from raw water.

Many factors led to the use of natural coagulants instead of alum-based coagulants in water treatment. For example, human health problems are highly associated with using alum-based coagulants in the drinking water treatment process because of aluminium residuals supplied to consumers (Xue *et al.* 2021). Moreover, an alum-based coagulant is expensive. Consequently, safe, cost-effective, and environmentally friendly natural coagulants are required in the turbidity removal process. Another study showed that different diseases such as Alzheimer's, carcinogenic and neurotoxic health effects are considerably linked to chemical coagulants used in water treatment (Kurniawan *et al.* 2020). A study has used Vigna mungo, Zea plants as natural coagulants to eliminate the turbidity from wastewater and recommended using these natural materials (Sasikala & Muthuraman 2017). It was reported that natural coagulants including Allium cepa peel ash, waste tea powder, Phyllanthus niruri, Vigna mungo and Zea were effectively used in turbidity removal between 70 and 97% for synthetic and surface water samples at neutral pH (Choy *et al.* 2016). Chemical coagulants are widely used in drinking water treatment. However, the excessive use of these materials has increased the costs and environmental disadvantages. On the other hand, the synthetic organic polymer and polyacrylamide-based coagulant materials including acrylamide have neurotoxic and carcinogenic effects. Thus, these materials are usually harmful since they have the ability to pass into the food chain resulting in human health problems. Several researchers suggested alternatives to the use of natural coagulants in pretreatment of drinking water (Leiknes *et al.* 2004).

It was indicated that the alum (organic materials) used in wastewater treatment plants has negative human health impacts and on the water drainage system (Ge *et al.* 2020). In addition, using higher amounts of alum in fresh water and wastewater treatment plants requires more processing costs. Cassava peels starch (CPS), therefore, was used in the form of natural coagulants in another study instead of alum materials in the wastewater treatment process to remove turbidity from fresh water and wastewater (Kumar 2020). Using natural coagulant CPS instead of alum for turbidity removal from raw water (turbidities ranging from 20 to 400 NTU) proved that there were not any harmful effects on human health with efficient removal of turbidity up to 81% at pH of 8. Moreover, results obtained from a previous study met the WHO and water quality standards (A & B) for drinking water supplies (Kumar 2020). It was also concluded that the application of CPS in the fresh water and wastewater treatment showed high removal efficiency as a natural coagulant instead of chemical coagulant for turbid particles in the water and wastewater, and it is safe for maintaining the health of water according to the recommended standards to discharge wastewater back to the environment after treatment processes (Kumar 2020).

Based on the survey in the Scopus database for ‘river water turbidity removal using natural coagulant’, there were 65 research articles. The major keywords of two keyword occurrence in which 186 keywords presented in Figure 2, using the VOSviewer algorithm. The exhibited keywords connection revealed the significance of this topic within the domain of environmental engineering and freshwater science management. Drinking water, potable water, chemical treatment, and chemical removal are the major links with the water turbidity and natural coagulants. Based on the timeline of years, limited researches have been adopted only 5 articles in 2021. However, it is worth mentioning that about 27 countries have displayed major interest in this research domain due to the necessity of providing easy and newly advanced technology for water treatment (Table 1). It is worth to have an idea for the regions that have focused on this kind of research. Based on Table 1 abstracted from the Scopus database, 27 countries were observed to study the development of natural coagulant for river water turbidity. China and Malaysia were on the top of those countries followed by Australia and Brazil. However, limited research was observed for Iraq and thus more investigations are needed. Recently, several studies confirmed the viability of natural coagulants for water treatment. For instance, natural polymers abstracted from *Sago* and *Tapioca* were used for river water turbidity and chemical oxygen demand (Zainol *et al.* 2020). The ability of *Scallop* shells were used as natural coagulant for water turbidity removal (Siswoyo *et al.* 2021). In another research, the authors tested the effectiveness of *Moringa oleifera* seeds as bio-coagulant for surface water turbidity treatment (Nhut *et al.* 2021). Hexane, saline and crude were extracted from *Kenaf* plant seed for determining a reliable coagulation to remove organic matter (Okoro *et al.* 2021).

The inspiration of the current research was adopted from the reported literature on the proposition of new natural coagulants, particularly for a country like Iraq. Hence, the research objectives are: i) to determine the effect of using locally plants-based bio-flocculants (natural coagulants) as coagulant aids on turbidity removal efficiency of raw water that has initial turbidity 200 NTU, pH of 7.5, and Total Dissolved Solids (TDS) of about 450 mg/L, ii) to find the optimum dosage (at the best turbidity removal efficiency) of natural coagulants that can be added for turbidity removal from raw water compared with other types of coagulants materials.

3. MATERIALS AND METHODS

The main purpose of the study is to apply natural Iraqi local plants such as Carob’s Pods Extract (CPE) and Mallow’s leaves Extract (MLE) as coagulant aids for surface water turbidity removal.

3.1. Water sampling

In this research, stream water was investigated, and water samples were collected during the wet season (January–April of 2020) after storm events. Figure 3 shows the sampling station map and Figure 4 presents the tests processes stages and measurements (data collection). All tests were carried out in the Dams and Water Resources Engineering Department, University of Anbar. Table 2 reports the characteristics of the raw water samples taken from Euphrates River near the large Ramadi drinking water treatment plant intake, Anbar province, Iraq. Euphrates River is considered as one of the essential surface fresh-water sources for Iraq region and its water quality is highly important (Al-Sulttani *et al.* 2021; Khaleefa & Kamel 2021). Turbidity and pH measurements were recorded in the field. Samples were left for 24 hours (settling period) and measurements recorded again in the laboratory. The turbidity of settled raw water was fixed at about 200 NTU by adding distilled water to raw samples, which was very high turbidity. Thirty litre containers of such samples were collected. All experiments were carried out within ASTM in the Environmental Lab of Dams and Water Resources Engineering Department in the University of Anbar in January–April of 2020.

3.2. Apparatus

The main apparatus used in this research included:

1. Multi-place flocculation stirrer (Jar Test),
2. Laboratory (Lovibond Turbidity Meter) (Nephelometric Turbidity Unit – NTU units).
3. Hot Plate and Magnetic Stirrer (Labtech Company).
4. Balance 210 gram (Kern Company).
5. pH meter (HANNA Company).
6. TDS meter (HANNA Company).

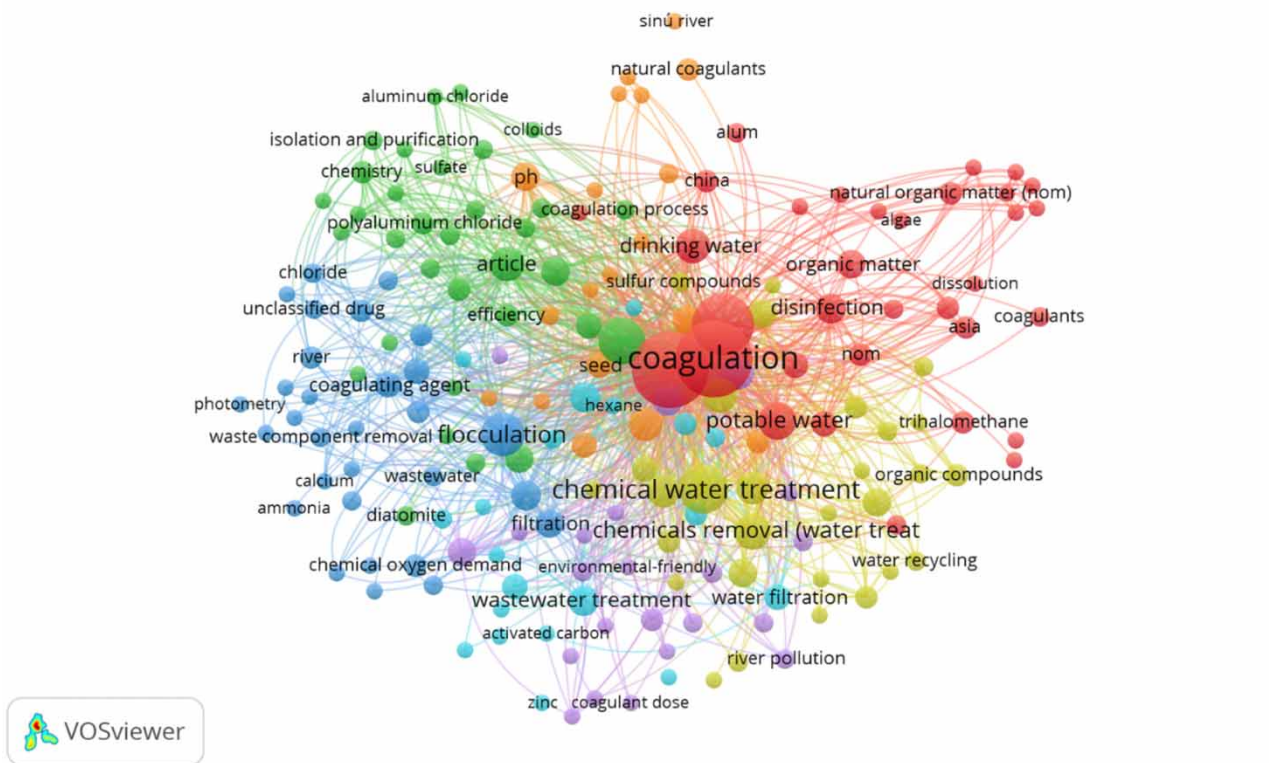
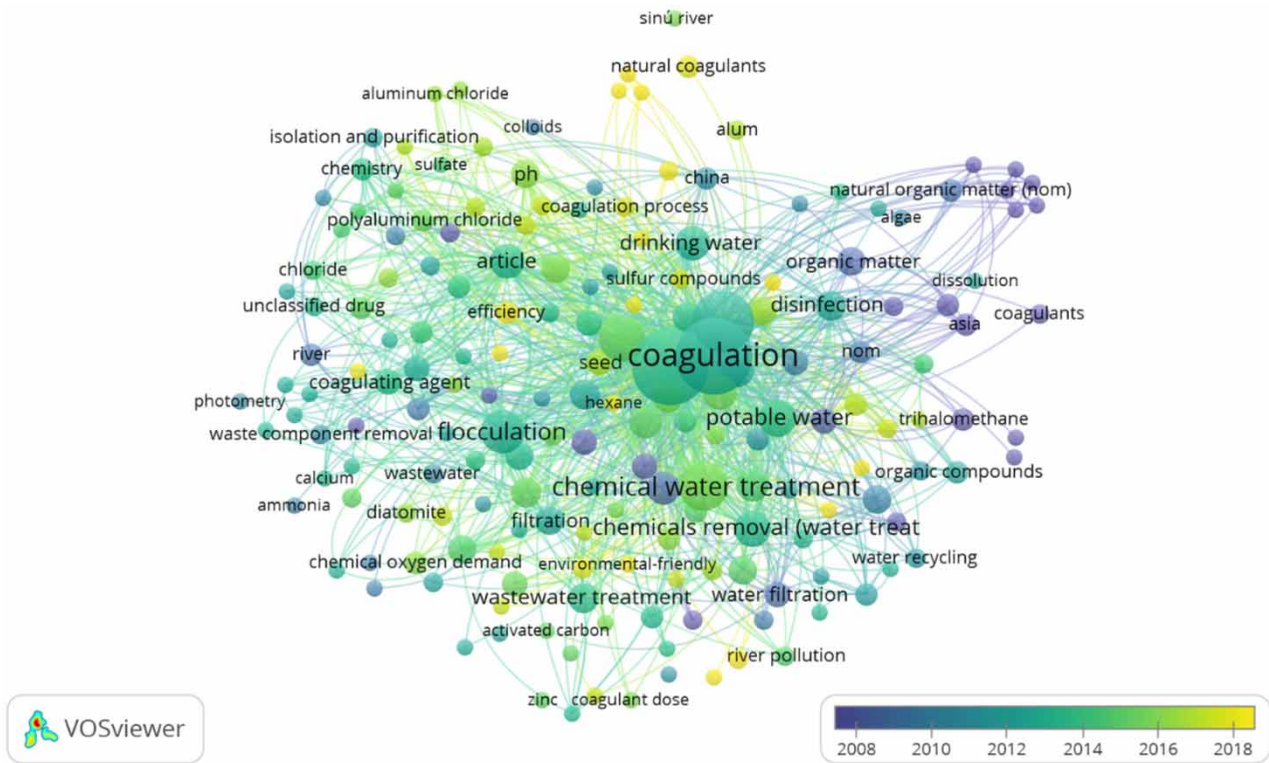


Figure 2 | The major keywords occurrence based on Scopus database for 'river water turbidity removal using natural coagulant'.

Table 1 | The number of established research on river water turbidity removal using natural coagulant and the number of the citations per country

Country	Published research	Citations
Australia	6	102
Belgium	2	13
Brazil	5	37
Canada	3	3
China	9	98
Colombia	3	21
Ecuador	1	10
Egypt	1	6
Ethiopia	3	13
India	1	0
India	1	3
Indonesia	3	0
Iran	4	122
Iraq	2	33
Japan	3	45
Kenya	1	44
Malaysia	9	23
Peru	1	3
Portugal	1	4
South Korea	3	19
Spain	3	139
Sri Lanka	1	1
Switzerland	1	19
Thailand	1	13
United Kingdom	3	53
United States	4	93
Viet Nam	1	1

3.3. Coagulants

Coagulation could be carried out using either chemical-based coagulants like alum or natural coagulants like natural plant-based coagulants (NPBCs) (Choy *et al.* 2014).

3.3.1. Alum

The common coagulant alum was applied in this research (i.e. $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$) and the chemical formula was adopted from the literature (Choy *et al.* 2014).

3.3.2. Natural plant-based coagulants preparation

Firstly, ML and CP were collected, washed with distilled water, drying for 1 hour at 40 °C and then ground manually to powder form. The extraction of active coagulants was carried out by mixing 0.5 g of the ML and CP powder with 100 mL of sodium chloride (NaCl) for 1 hour at 40 °C. NaCl with 0.3 molarity concentrations were used. The obtained mixture was centrifuged and filtrated. The clear solution was used as a coagulant aid in the subsequent experiments. This process followed the reported literature (Šćiban *et al.* 2009).

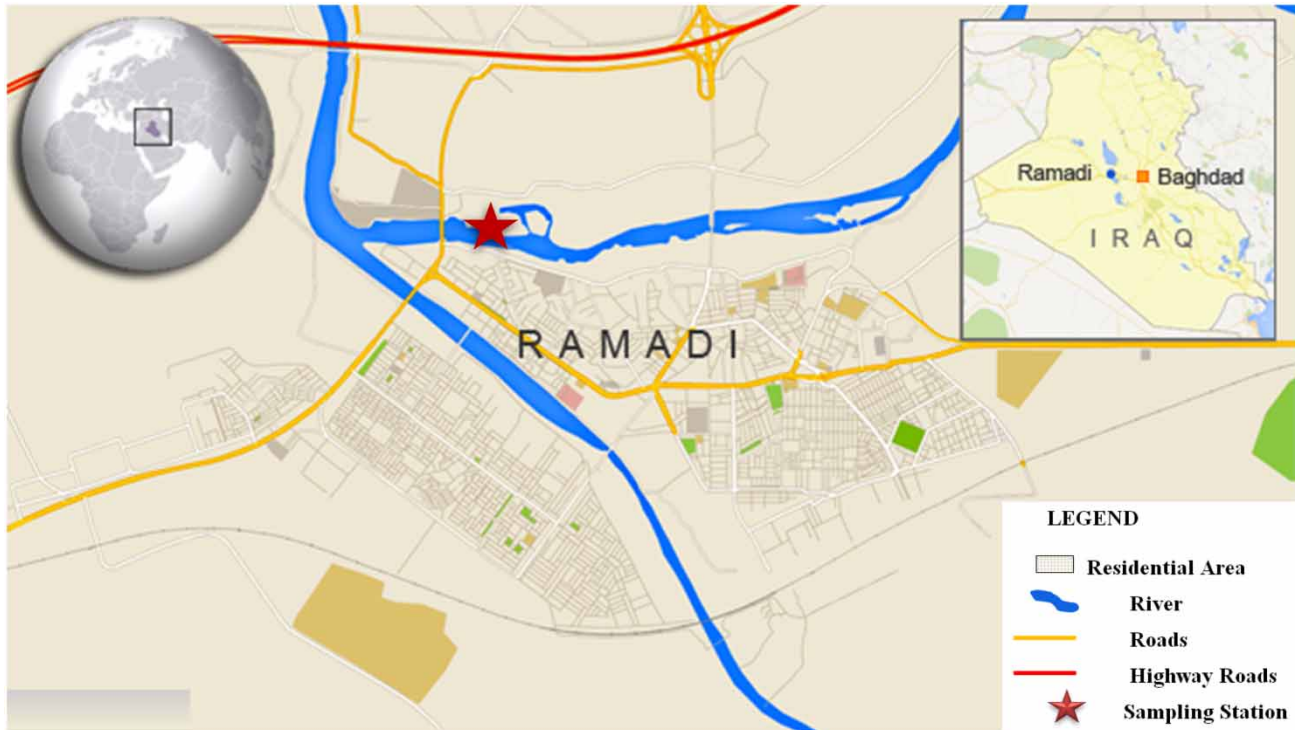


Figure 3 | The location map of the sampling station.

Fresh coagulants were extracted and diluted by double distilled water to obtain a stock of 10 mg/L and used directly to avoid aging effects, as pH and coagulation efficiency due to the microbial decomposition of the organic matters during storage.

Then, the coagulation efficiency of all the obtained NPBCs was evaluated using natural turbid water with initial average turbidity of 200 NTU (Nephelometric Turbidity Unit), water pH equal to 8 using 1 Molarity HCl and 1 Molarity NaOH and coagulant dose of 15, 20, 25, 30, 35, 40 mg/L were applied. Figure 5 shows the NPBCs coagulants aids methodology preparation.

Residual turbidity (T_s) was determined by applying the following equation:

$$T_s = T_0 - T_f \quad (1)$$

where T_s , T_0 and T_f are the residual, initial and final turbidity's (NTU) of the waters respectively.

The turbidity removal efficiency ($\eta\%$) was calculated by using the following equation:

$$(\eta\%) = \left(\frac{T_s}{T_0} \right) \times 100\% \quad (2)$$

where $\eta\%$ is turbidity removal efficiency (Salvato *et al.* 2003).

3.3.3. Flocculation experiments

Experiments were carried out using the standard conventional Jar test (6-jar apparatus) to determine the optimal coagulant dose. For experimental work, samples of water with average turbidity of 200 NTU were obtained. The samples were poured into the jar test unit. The set-up used was as follows: the turbid water was initially easily stirred at 250 rpm for 1 minute, then alum salt and coagulant aids (MLE or CPE) were added and the mixture was stirred for another minute at the same speed, then the mixture was mixed gently for 15 minutes at 50 rpm rotating speed, after that, the flocs were left to precipitate for 10–

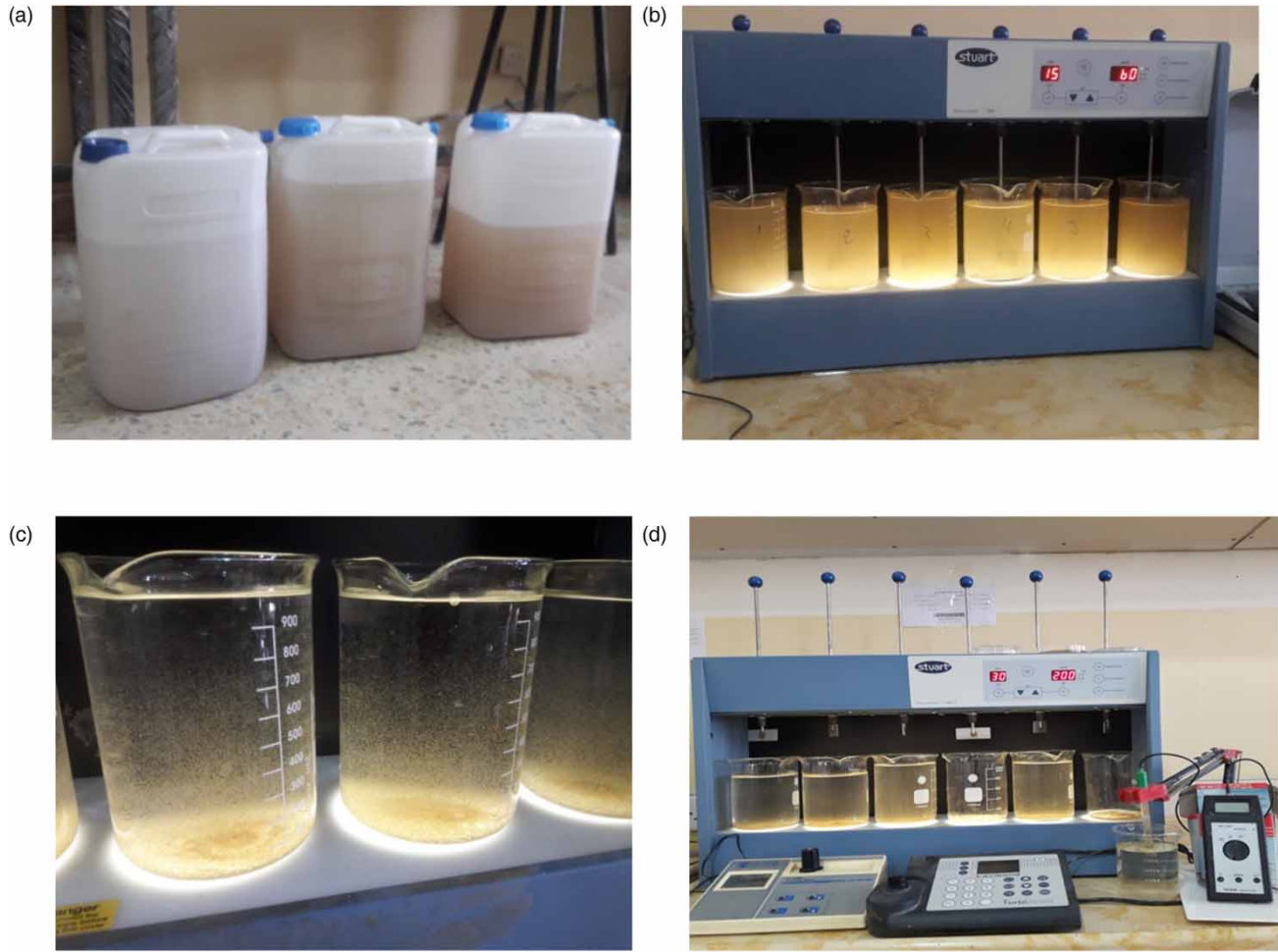


Figure 4 | Test processes stages; (a) sampling, (b) rapid mixing, (c) slow mixing and (d) settling and measurements.

Table 2 | Raw water characteristics

Set No.	Dosage of coagulant (mg/L)	Alum (%)	Dosage of alum (mg/L)	MLE (%)	Dosage of MLE (mg/L)	CPE (%)	Dosage of CPE (mg/L)
1	15-40	100	15-40	0	0	0	0
2	15-40	50	7.5-20	50	7.5-20	0	0
3	15-40	60	9-24	40	6-16	0	0
4	15-40	75	11.25-30	25	3.75-10	0	0
5	15-40	50	7.5-20	0	0	50	7.5-20
6	15-40	60	9-24	0	0	40	6-16
7	15-40	75	11.25-30	0	0	25	3.75-10

30 minutes and then the supernatant liquid was analyzed. Finally the optimum dose of coagulant could be determined (Salvato *et al.* 2003).

All tests were carried out at the temperature of 22 ± 1 °C. Although the pH did not alter much throughout flocculation, the pH value was controlled at pH 8. The integral design of a flocculation processes takes into account both particle destabilization and particle transport (Bhatia *et al.* 2007). The research studied the capability of using MLE and CPE as NPBCs coagulant aids with alum as a main coagulant. Different dosages of 15, 20, 25,30, 35, 40 mg/L were applied.

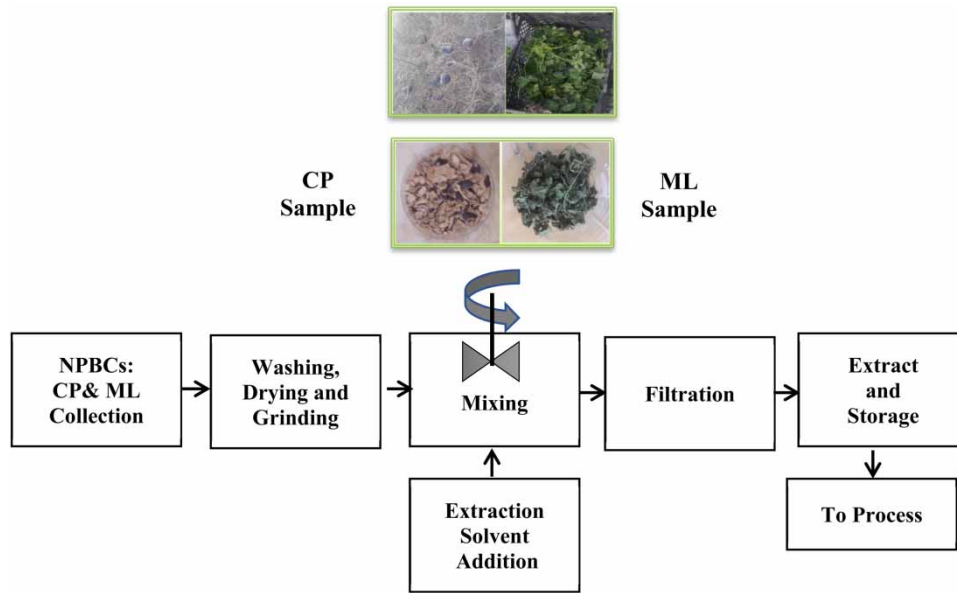


Figure 5 | NPBCs coagulants aids methodology preparation.

Based upon the coagulant dosages, settling times have differed. At the end of the settling period, 100 mL samples were taken from 1 cm below the water surface using suction apparatus. The magnitude of residual turbidity was recorded, and the turbidity removal efficiency of the alum used with each coagulant aid (MLE and SPE) material with different percentages were determined. These percentages were applied for all dosages added in the study. This method was repeated for each coagulant aid and for each coagulant aid percentage.

4. RESULTS AND DISCUSSION

The results of the laboratory work are presented in Figure 6(a)–(l). These findings were graphed against various parameters such as coagulant aids percentage dosages verse different parameters such as residual turbidity, turbidity removal efficiency. The pH values shown in Figure 7(a)–(g) were obtained using the Jar-Test. The original values of the parameters were as follows: 200 NTU turbidity, pH of 7.5, and TDS of about 460 mg/L.

4.1. Effect of coagulant type on turbidity removal

The removal efficiency of different NPBCs for the initial 200 NTU of raw river water was investigated in this study using alum as the main coagulant, MLE, and CPE with 100% ratio of alum. Figure 6(a) shows the results of residual turbidity by adding 100% of alum, MLE and CPE coagulants, the lowest concentrations of residual turbidities of 5.47, 97.65, and 125.76 NTU were measured by adding coagulant dosages of 30, 30, and 25 mg/L for alum, MLE, and CPE, respectively. The maximum removal efficiency of turbidity was found by adding 100% of alum, MLE, and CPE coagulants (Figure 6(b)). The turbidity removal efficiencies were 97.265, 51.175, and 37.12% for coagulant dosages of 30, 30, and 25 mg/L for alum, MLE and CPE, respectively. However, the residual turbidity and turbidity removal efficiency were measured by adding different MLE percentages ratio of alum as a coagulant aid (i.e. 100, 50, 40, 25, and 0%). According to Figure 6(c) and (d), it was observed that the minimum residuals turbidity were 97.65, 20.53, 16.83, 4.56, and 65.47 NTU by adding 100, 50, 40, 25, and 0%, respectively. Figure 6(d) reported that the maximum turbidity removals were 51.175, 89.735, 91.585, 97.72, and 67.265%, respectively. It can be concluded that the residual turbidity and turbidity removal efficiency were decreased to 4.56 NTU and of 97.72%, respectively, by adding a dose of 30 mg/L (22.5 alum: 7.5 MLE). Figure 6(e) and (f) shows the residual turbidity results and removal efficiency by adding CPE percentages (ratio of alum) coagulant aid of 100, 50, 40, 25, and 0% with alum. The minimum residuals turbidity were 125.76, 23.46, 19.32, 15.4 and 65.47 NTU, while the maximum turbidity removals were 37.12, 89.325, 90.34, 92.3, and 67.265%, respectively. The residual turbidity and turbidity removal efficiency, therefore, were decreased to 15.4 NTU of 92.3%, respectively, by adding 30 mg/L of 75% alum dosage (22.5 Alum: 7.5 CPE). The MLE coagulant aid was more efficient than the CPE coagulant aid as shown in Figure 6(g) and (h),

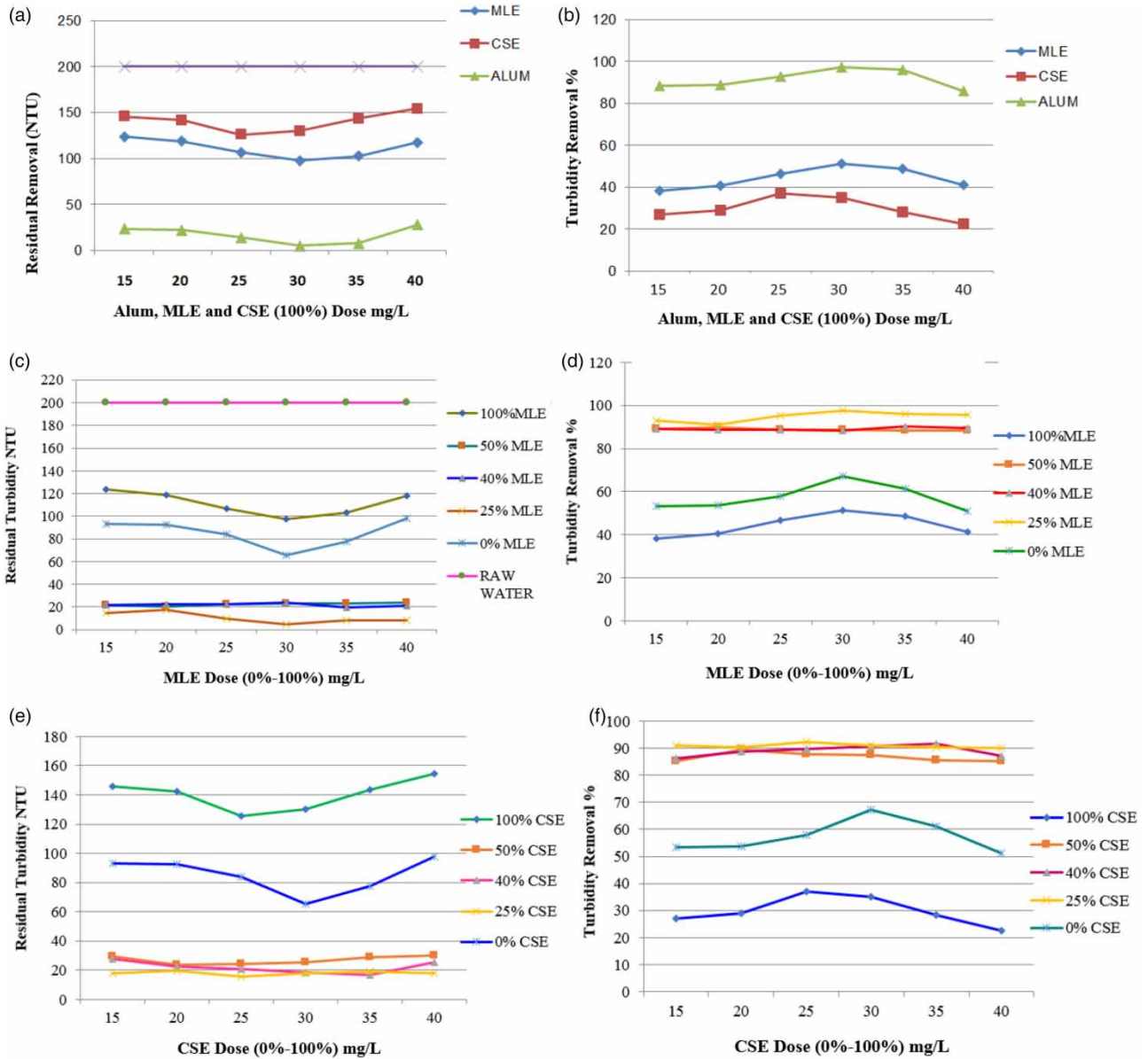


Figure 6 | (a) Residual turbidity vs alum, MLE and CSE dose; (b) Turbidity removal (%) vs alum, MLE and CSE (100%) dose mg/L; (c) Residual turbidity vs MLE dose (0–100%); (d) Turbidity removal % vs MLE dose (0–100%) mg/L; (e) Residual turbidity vs CSE dose (0–100%); (f) Turbidity removal % vs CSE dose (0–100%) mg/L; (g) Residual turbidity vs MLE and CSE dose (50%) mg/L; (h) Residual turbidity vs MLE and CSE dose (40%) mg/L; (i) Residual turbidity vs MLE and CSE dose (25%) mg/L; (j) Removal turbidity % vs MLE and CSE dose (50%) mg/L; (k) Removal turbidity % vs MLE and CSE dose (40%) mg/L; (l) Removal turbidity % vs MLE and CSE dose (25%) mg/L.

and they improved the separation of suspended solids remarkably. However, Figure 6(g)–(i) illustrates the residual turbidity by adding MLE and CPE at the same concentration or ratio. The foregoing results described showed clearly that alum of 22.5 mg/L in combination with 7.5 mg/L of MLE had a favourable performance and can be represented as the optimum coagulants dosages because these coagulants had given minimum residual turbidity and maximum turbidity removal efficiency. Figure 6(j)–(l) illustrates the turbidity removal efficiency by adding MLE and CPE at the same concentration or ratio. The results described above showed clearly that alum of 22.5 mg/L in combination with 7.5 mg/L of MLE had a favourable performance and can be represented as the optimum coagulants dosages because these coagulants had given minimum residual turbidity and maximum turbidity removal efficiency.

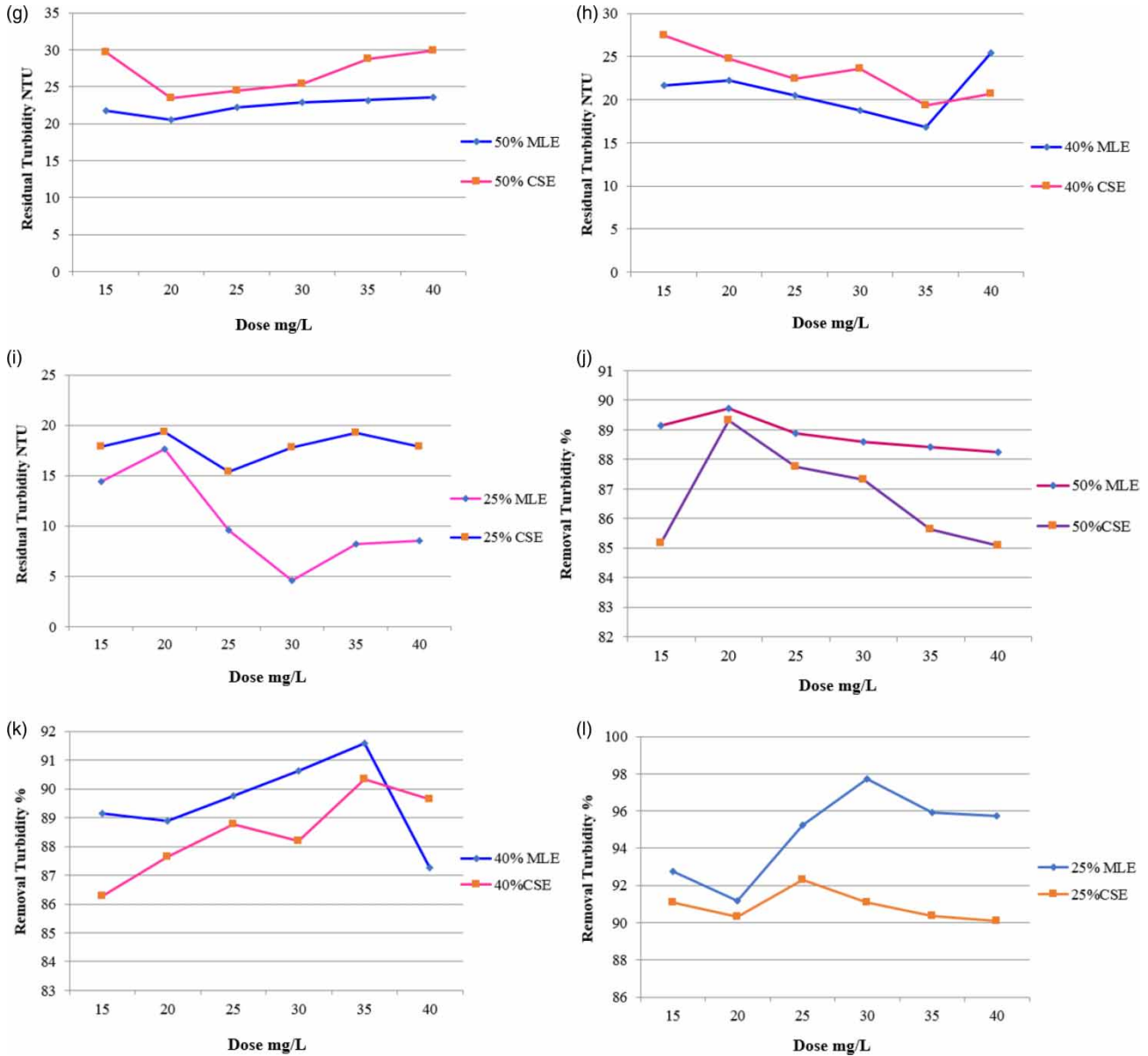


Figure 6 | (Continued.)

4.2. Effect of coagulant on pH

In precipitation, the pH of raw water takes a significant role (Misbahuddin & El-Rehaili 1995). The raw water has initial pH of around 7.6, based on the findings and Figure 7(a)–(g) reveals that when adding alum alone with a percentage of 100%, there is a slight change in the pH value. In addition, there is no further change when adding MLE and CPE as coagulant aids in combination with alum with all percentages of 50, 60 and 75%. Further, a small change in the pH was observed when adding MLE only (100%). The maximum magnitude of pH of 7.73 was recorded using 40 mg/L of MLE with the 100%. The values of TDS have not changed much and thus these values may not effect on water treatment efficiency. The major factors affecting turbid water treatment include coagulants type, coagulants percentages and pH value. Finally, it is worth reporting the summary percentages of the additives NPBCs aids (Table 3).

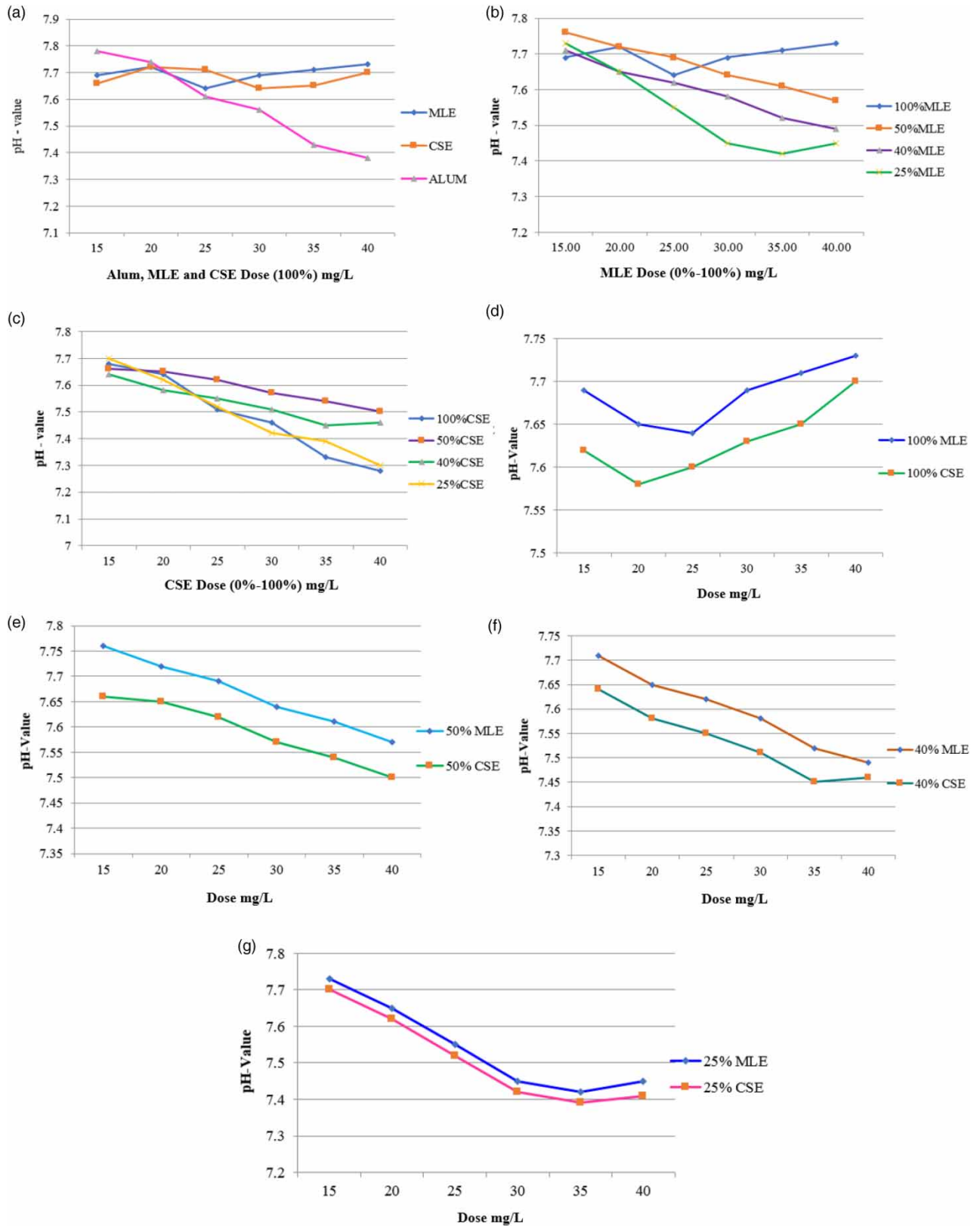


Figure 7 | (a) pH-Value vs alum, MLE and CSE dose (100%) mg/L; (b) pH-Value vs MLE dose (0–100%) mg/L dose; (c) pH-Value vs CSE dose (0–100%) mg/L; (d) pH-Value vs MLE and CSE dose (100%) mg/L; (e) pH-Value vs MLE and CSE dose (50%) mg/L; (f) pH-Value vs MLE and CSE dose (40%) mg/L; (g) pH-Value vs MLE and CSE dose (25%) mg/L.

Table 3 | Summary of coagulant dosages of alum and NPBCs (MLE & CPE)

Characteristic	Range value	Average settled raw water	No. of samples	Standard deviation
pH	7.5–7.7	7.7	5	0.109
Turbidity (NTU)	206–225	215.4	5	6.82
Total Dissolved Solids (TDS) mg/L	435–487	464	5	18.15

5. CONCLUSION AND RECOMMENDATIONS

The following research conclusions and recommendations are summarized from the current study:

1. High turbid water can be treated with high removal efficiency by adding natural plant-based bio-flocculants as a coagulant aid with 75% of ALUM, where the values that were recorded when using MLE were: final turbidity 4.56 NTU, removal turbidity efficiency of 97.72%. This value of turbidity complies with the Iraqi specification of drinking water.
2. Alum application is not strongly advised because it records more residual turbidity than if it is applied with other coagulant aids such as MLE and CPE with different concentrations, which will reduce the amount of alum added and thus reduce the cost.
3. Increasing the concentration of the coagulants has an efficient effect in increasing the turbidity removal efficiency and reducing the residual turbidity.
4. Increasing the MLE and CPE dosages does not result in a significant change in the pH and TDS values.
5. The research recommended to study the removal efficiency of the same coagulant aids with high turbid water of more than 200 NTU.

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AUTHORS CONTRIBUTIONS

Majeed Mattar Ramal: Data curation; Formal analysis; Methodology; Investigation; Visualization; Writing – original draft, - review & editing draft preparation; Resources. Arkan Dhari Jalal: Visualization; Writing – original draft, - review & editing draft preparation. Mohammed Fareh Sahab: Formal analysis, Project administration; Writing – review & editing. Zaher Mundher Yaseen: Supervision, Conceptualization; Project administration; Writing – review & editing.

CONSENT TO PARTICIPATE

Not applicable.

CONSENT TO PUBLISH

The research is scientifically consent to be published.

COMPETING INTERESTS

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

ETHICAL APPROVAL

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