Effect of Locally Available Fruit Waste on Treatment of Water Turbidity

Animetu Seghosime[1, 3*] Johannes Akpabla Mawuli Awudza [2] Richard Buamah [3]
Anthony Benjamin Ebeigbe[4] Sampson Oduro Kwarteng[3]
1.Department of Civil Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria
2.Department of Chemistry, College of Science, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
3.Department of Civil Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
4.Department of Physiology, College of Medical Sciences, University of Benin, Benin City, Edo State, Nigeria.

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Abstract
Turbidity is one of the main problems associated with surface water treatment. Chemical coagulants are already being used for treatment but their enormous cost, human and environmental issues associated with their use have led to searching for alternatives like natural coagulants (plant-based). Although the use of natural coagulants for drinking water treatment has been discussed for a long time, the practice is still not employed in most poor developing countries, probably due to availability of materials and their usage as food crops. Therefore locally available fruit waste are now being evaluated for their suitability. Laboratory scale studies using jar test experiments were performed on river water containing synthetic turbidity of kaolinite to analyze the effect of *Mangifera indica* (Duncan mango) and *Citrus aurantiifolia* (key lime) seeds as locally available fruit waste on treatment of water turbidity. Experiments were carried out using different turbidity levels classified as low, medium and high: 50, 100 and 150 NTU with pH kept constant at 7.25. Results indicated that the seed extracts of Duncan mango and key lime have coagulating potential. They were very effective for treatment of medium and high water turbidity. For treatment of high water turbidity using the seed extracts of Duncan mango and key lime as primary coagulants, 92.0 % and 91.1 % turbidity removal were achieved. Compared to alum, the turbidity removal effectiveness was: alum > Duncan mango seed extract>key lime seed extract for all water turbidity levels. The pH of the treated water were within neutral (basic) due to the buffering capacity of the seed extracts. Result further indicated that the seed extracts of Duncan mango and key lime have the potential for use as coagulant aids with alum as primary coagulant for treatment of low, medium and high water turbidity.
Keywords: *Mangifera indica*, *Citrus aurantiifolia*, Turbidity, Natural coagulants, Seed extracts, Fruit waste

1. Introduction

Water is a vital resource for human survival and it is essential for sustainable development, hence access to safe drinking water is important to human existence. As anthropogenic activities increase the rate of water pollution is also increasing. Poor quality water is included as one of the major causes of about 80% of all diseases and sicknesses in the world (Pritchard et al., 2009) and about 1.6 million people of the world's population still use contaminated water (Yongabi et al., 2011).

In poor developing countries, surface water is used as their main source of drinking water and water from such sources is unreliable as it is easily contaminated by suspended particles causing turbidity due to its exposed nature. These particles may provide attachment site for pathogenic organisms, hence for effective water disinfection, turbidity should almost be virtually eliminated. Large seasonal variations in turbidity is one of the problems associated with treatment of surface water (McConnachie et al., 1999).

One of the most widely used techniques for removing suspended particles from water to make it safe and attractive for drinking is coagulation/flocculation due to its simplicity and effectiveness (Choy et al., 2014). This process is achieved by addition of coagulants (either natural or chemical), which are used to aggregate these particles into larger ones (flocs) so that they settles easily to mitigate their removal (Teh et al., 2014b). In convectional water treatment, inorganic coagulants (e.g. aluminum and ferric salts) and synthetic polymers (e.g. polyacrylamide derivatives and polyethylene imine) are widely used because of their effectiveness (Ramavandi, 2014). However, because of the high cost of importation of these coagulants (in developing countries) coupled with the health and environmental issues associated with their use, there have been a growing research interest in natural plant based coagulants as alternatives to inorganic coagulant and synthetic polymers.

The use of natural coagulant, mainly polysaccharides and proteins represents a vital development towards sustainable environmental technology (Teh and Wu, 2014) as they are cost effective, biodegradable and are presumed to be safe for human health (Sciban et al., 2009). Natural plant extracts have been used for turbid water treatment for many centuries in India, China, Africa (Asrafuzzaman et al., 2011) and Egypt (Megersa et al., 2014). Nowadays, a number of effective plant based coagulants have been identified and some of these include *Moriga Oleifera,* nirmali, cactus and tannins, which are generally well known within the scientific community (Yin, 2010).

Most plant based coagulants that have been studied are vegetables, legumes, cactus, cereals, nut, and spices (Choy et al., 2013 and 2014) and most of the time these plants compete with food crops (Bodlund, 2013), thus escalating their procurement cost and hindering their uses. Hence there is need to search for more plant based coagulants with this factor in mind.

As population increases, economic activity and industrialization increases, waste generation also increases with large portion from fruit waste. This is because after consumption of the fruit, fruit waste including peels and seeds are generally discarded into the environment since they are of no commercial value. This leads to disposal problems which could be detrimental to the environment as a result of mishandling of the waste. Therefore, assessing suitability of fruit waste for water turbidity treatment will enable their application to be considered and help enhance the use of plant based coagulants, hence they are readily available, cheap and do not have to compete with food crops.

Fewer studies have attempted to investigate fruit waste for their coagulating capability and very few including *carica papaya* seeds and *citrus sinensis* peel/skin have been found effective; scientific investigation into other locally available fruit waste for their coagulating capability is lacking. Therefore this study is aimed at assessing the effect of locally available *Mangifera indica* (Duncan mango) and *Citrus aurantiifolia* (key lime) seeds (as fruit waste) on treatment of water turbidity. Previous studies show that these seeds contain proteins, carbohydrates (including starch), lipids, tannins and minerals (Elegbede et al., 1995; Fowomola, 2010). Since they are fruit wastes, they do not have to compete with food crops, hence they will be readily available and acquired at a low cost.

2. Materials and Methods

The seeds used for this study were obtained from fresh ripe fruits of *Mangifera indica* (Duncan mango) and *Citrus aurantiifolia* (key lime) purchased from a local market (Uselu) in Benin City, Edo State, Nigeria. They were identified and authenticated by a Botanist in the Department of Plant Biology and Biotechnology, University of Benin, Benin City. The raw water was obtained from Wiwi River at Duncanson Road Bridge Head, Kwame Nkrumah University of Science and Technology (KNUST) Campus, Kumasi, Ghana. Experiments were carried out at the Environmental Quality Engineering (EQE) Laboratory, Department of Civil Engineering, College of Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

2.1 Preparation of the Seed Extracts: Fresh ripe fruits of Duncan mango and key lime were sliced manually using a clean stainless steel knife to obtain their seeds. The key lime seeds were sun dried for a period of one week (to constant weight), then they were sorted to remove bad ones and properly sealed on a neatly labelled zip lock bag. Duncan mango seeds were sun dried for a period of four weeks, then they were shelled manually by stone cracking to obtain the seed kernels, which were further dried for another one week (to constant weight), then they were sorted to remove bad ones and properly sealed on neatly labelled zip lock bag and stored at room temperature till usage. About 50 g of each type of seed (Duncan mango seed kernel and key lime seed) were separately pulverized mechanically to fine powder using a stainless grain laboratory pulveriser and sieved to make it of appropriate size of about 425 µm.

Figure 1. Duncan Mango Seed Kernel and Key lime Seed

Figure 2. Duncan Mango Seed Kernel Powder and Key lime Seed Powder

Each type of seed powder was defatted using ethanol (96 %). About 30 g of the seed powder was packed in a thimble (made of cheese cloth) and placed inside the Soxhlet extractor which is connected to a flask and a condenser (setting up the Soxhlet extraction apparatus). About 350 to 400 ml of ethanol (96 %) was used to extract oil from the seed powder in the column; the apparatus was left running for about 7 to 8 hours and switched off when the extraction was completed. The cake was placed in the oven at 105 ^{o}C for about 7 to 8 hours to evaporate the ethanol. Each defatted seed powder was then extracted with 1 M sodium chloride solution: about 1 g of each defatted seed powder was added to 1 M sodium chloride solution. The suspensions were mixed using a rotary shaker or magnetic stirrer for 10 minutes, they were then filtered using Whatman Number.1 equivalent filter paper. The filtrate (resulting to 1 % w/v solution each) were used as the seed extracts. Fresh solutions of seed extracts were prepared at every day of use. The extracts are by-products of oil production. It is noteworthy that oil can also be removed by other means such as pressing.

2.2 Preparation of Aluminum Sulphate (Alum) Solution: Alum solution was prepared to also give 1% w/v solution, 1 g of alum powder was weighed and mixed to 100 ml with distilled water, then the solution was stirred for 10 minutes in order for the alum powder to be completely soluble into the distilled water.

2.3 Preparation of Turbid Water Samples: Water samples with low (50 NTU), medium (100 NTU) and high (150 NTU) turbidity were prepared by mixing river water with stock solution of kaolin clay in order to obtain the desirable turbidity ranges. To prepare the stock solution of kaolin clay; about 30 g of kaolin clay was mixed to 1000 ml with distilled water, the clay was soaked for 24 hours in order to hydrate particles. The resulting suspension was mixed together using a magnetic stirrer for 20 minutes to achieve uniform and homogenous sample. This sample was found colloidal and was added to the river water to achieve the desired turbidity just before coagulation at every day of use. The pH of the water sample was kept constant at 7.25 using 0.1 N hydrochloric acid (HCl). The average characteristics of Wiwi River at Duncanson Road Bridge Head, KNUST, Campus used for this study are presented in Table 1 below.

Table 1. Average Raw Water Characteristics of Wiwi River, Duncanson Road Bridge Head, KNUST, Kumasi, Ghana.

S/N	Parameters	Range	Average
1	Turbidity(NTU)	18-94	56
2	Electrical Conductivity (µs/cm)	201 - 323	262
3	Total Dissolved Solids (mg/L)	96 - 160	128
4	pH	6.98 - 7.52	7.25
5	Temperature (◦C)	27.5 - 28	27.8
6	Total Suspended Solids (mg/L)	23 - 105	64
7	Total Hardness (mg/L)	28 - 153	91
8	Nitrate (mg/L)	0.95 - 2.70	1.83
9	Nitrite (mg/L)	0.05 -0.07	0.06
10	Total Coliform (cfu/100ml)	11 - 23	17
11	Faecal Coliform (cfu/100ml)	7 - 13	10

2.4 Coagulation/Flocculation Experiment (Jar Test Operations): Standard jar test apparatus (Aqua lytic product) with six stirrers, consisting of rotation regulator of mixing rods was used to carry out the coagulation test on the river water samples using various coagulants (Duncan mango seed extract only, key lime seed extract only, alum only, combination of Duncan mango seed extract and alum in different proportions and combination of key lime seed extract and alum in different proportions). Six 1 litre beakers were used to analyze the effect of coagulants (Duncan mango seed extract only, key lime seed extract only, alum only) dosage on coagulation of the river water samples. The river water sample (400 ml) was filled into six beakers (1000 ml) out of which five were dosed with different volumes of the coagulant ranging from 5 to 25 ml, while one was left without coagulant to serve as control. The apparatus was coupled properly by putting the stirrers in the jar test kits and lowering them into each beaker, thus ensuring that the beakers were well centred, before the apparatus was turned on. The experimental conditions for coagulation/flocculation with the coagulants were: 1 minute of rapid mixing (150 rpm) followed by 10 minutes of slow mixing (45 rpm). Then, the treated water was allowed to settle for 60 minutes and the supernatant samples were withdrawn using ex-20 °C Citoglas pipette (10 ml) from 2 cm below the liquid level for analyses. The samples were analyzed for turbidity and pH. Then, the optimum dosage obtained for each of the seed extracts was combined with that of alum in different proportions (with alum added first before the seed extract) and used separately to treat the river water samples, maintaining the same experimental conditions as mentioned earlier. All tests were performed for the different turbidity levels (low-50 NTU; medium-100 NTU and High- 150 NTU). The turbidity reduction efficiency was calculated using the following equation (Giwa et al., 2016);

$$\text{Turbidity Reduction Efficiency (\%)} = \frac{T_0 - T_1}{T_0} \times 100 \quad (1)$$

where;

T_0 = initial turbidity

T_1 = final turbidity

2.5 Analytical Methods: All analytical methods including those used for characterizing the raw water correspond to standard methods (EPA, 1982; APHA, 1998). Turbidity was measured using Hanna turbidity meter (with a measuring range of 0 to 1000 NTU). The pH was measured using Cyber scan PC 300 series electronic pH meter.

3. Results and Discussions

Table 2. Turbidity Reduction Efficiency of Coagulants in Different Turbidity Levels

Initial Turbidity (NTU)		**50 (Low Water Turbidity)**	**100 (Medium Water Turbidity)**	**150 (High Water Turbidity)**
Coagulants	**Dosage (ml)**	**Turbidity Reduction (%)**	**Turbidity Reduction (%)**	**Turbidity Reduction (%)**
Duncan Mango Seed (DMS)	0	28.8	26.4	28
	5	45	74.3	84.67
	10	56.4	80.7	88.6
	15	**74**	87.1	91.53
	20	66.8	**87.5**	91.8
	25	65.4	85.7	**92.0**
Key Lime Seed (KLS)	0	28.8	26.4	28
	5	43.2	73.2	82.8
	10	52.6	78.1	87.13
	15	**66.4**	83.7	89.47
	20	61.6	**84**	90.2
	25	57.4	82.4	**91.1**
Aluminum Sulphate (AS)	0	28.8	26.4	28
	5	84.94	91.53	94.33
	10	85.66	92.65	95.06
	15	89.52	93.71	96.49
	20	**91.94**	95.67	97.26
	25	91.06	**96.98**	**97.91**

Table 2 shows turbidity reduction efficiency of coagulants (seed extracts, alum) in different turbidity levels. Results indicated that the seed extracts demonstrated appreciable efficiency in improving the quality of water in terms of turbidity reduction compared to alum. Optimal turbidity reduction efficiencies with initial turbidity values of 50 NTU (low water turbidity), 100 NTU (medium water turbidity) and 150 (high water turbidity) are: for Duncan mango seed (DMS) extract: 74, 87.5, 92.0 % respectively; for key lime seed (KLS) extract: 66.4, 84. 91.1 % respectively and for alum (AS): 91.94, 96.98, and 97.91 % respectively. These correspond to dosages of 15 ml for each type of seed extracts and 20 ml for alum; 20 ml for each type of seed extract and 25 ml for alum;

25 ml for each type of seed extract and 25 ml for alum. Previous studies have shown that extraction of soluble proteins from plant seeds using sodium chloride solution can greatly improve coagulation process due to the intense force exerted by the salt in breaking the plant cells or tissues (Alfred and Bridgeman, 2015). This may be explained by the salting-in effect of proteins at higher ionic strength (Okuda et al., 1999; Ghebremichael, 2004; Fahmi et al., 2014; Alfred and Bridgeman, 2015). The disparity between the coagulating activities of the seed extracts and alum may be attributed to the mixture of organic compounds present in the seed extracts compared to the pure compound contained in alum (standard coagulant). Higher turbidity reduction efficiency was recorded with the use of Duncan mango seed extract compared to key lime seed extract. Results also revealed that pH of the water remain largely unaffected after treatment with the seed extracts as values were more or less constant between 7.13 and 7.24. This was due to the buffering capacity of the seed extracts. These results are in agreement with those observed with sodium chloride crude extract of *Moringa Oleifera* seed (Ghebremichael et al., 2006) and okra seed (Alfred and Bridgeman, 2015).

Figure 3. Seed Extracts Dosage (ml) against Turbidity Reduction (NTU) for Low Water Turbidity

Figure 3 shows the plot of seed extracts dosage (ml) against turbidity reduction (NTU) for low water turbidity. Results indicated that the optimum dosage of Duncan mango seed (DMS) and key lime seed (KLS) extracts where better turbidity reduction was achieved is 15 ml and the corresponding turbidity reduction is 13 and 16.8 NTU. Results further indicated that beyond the optimum dosage, there was slight increase in residual turbidity, this is in agreement with works done by Katayon et al., 2006. This phenomenon is due to over dosing of coagulants (seed extracts) which saturates the surface of colloids and leads to insufficient sites for the formation of polymer bridge (Muyibi and Evison, 1995). This phenomenon is suggesting that the seed extracts (of Duncan mango and key lime) may contain cationic polymers.

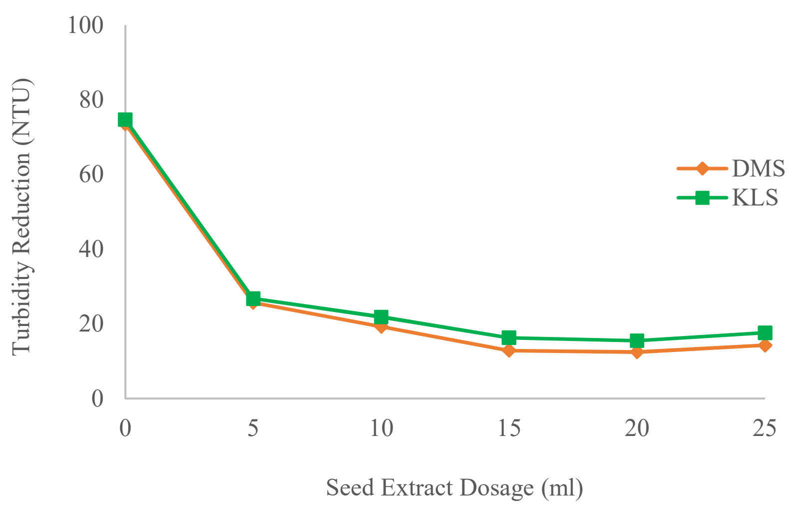

Figure 4. Seed Extracts Dosage (ml) against Turbidity Reduction (NTU) for Medium Water Turbidity

Figure 4 shows the plot of seed extracts dosage (ml) against turbidity reduction (NTU) for medium water turbidity. Results shows that the optimum dosages of the seed extracts (Duncan mango and key lime seed) where better turbidity reduction was achieved is 20 ml and the corresponding turbidity reduction is 12.5 and 15.5 NTU. Slight increase in residual turbidity was also observed beyond the optimum dosage.

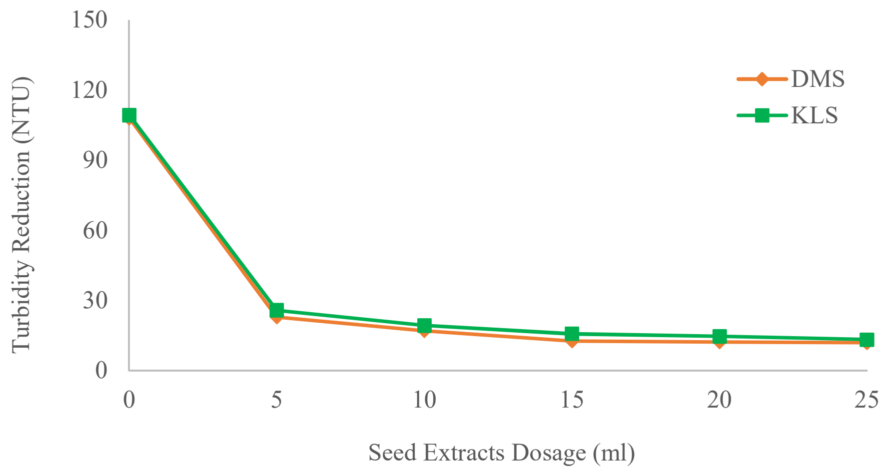

Figure 5. Seed Extracts Dosage (ml) against Turbidity Reduction (NTU) for High Water Turbidity

Figure 5 shows the plot of seed extracts dosage (ml) against turbidity reduction (NTU) for high water turbidity. Results indicated that as seed extracts dosages increase, turbidity decreases. This result is in agreement with those reported on previous finding on turbidity reduction using natural coagulants (Asraffuzaman et al., 2011; Marobhe, 2013). Greater turbidity reduction was observed at optimum dosage of 25ml (for both Duncan mango and Key lime seed extracts) and the corresponding turbidity reduction is 12 and 13.3 NTU respectively. Results further indicated that the seed extracts work better with high water turbidity. This is in consonance with the findings reported on the use of natural coagulants for water treatment (Nkurunziza et al., 2009; Asraffuzaman et al., 2011, Kihampa et al., 2011, Yongabi et al., 2011; Mangale et al., 2012a; Mangale et al., 2012b).

From the Figures (Figure 3, 4 and 5) above, it was deduced that as initial turbidity of water samples increased, the required optimum dosage of the seed extracts also increased. This is in agreement with previous findings on natural coagulants (Katayon et al., 2006; Blix, 2011). This results imply that as concentration of colloids increases, the required dosage of the seed extracts increases, suggesting that destabilization is stoichiometric, thus the process could be by adsorption and charge neutralization or adsorption and interparticle bridging. Optimal turbidity reduction values were above the World Health Organization (WHO) acceptable limit of 5 NTU (WHO, 2011), however the values obtained are still of significant quantum and previous studies have established that once turbidity reduction efficiency above 70 % is achieved (such as those obtained in this study) with natural coagulants, WHO acceptable limits can be obtained through filtration (Asraffuzaman et al., 2011; Pise and Halkude, 2015; Yongabi et al., 2011), however filtration was not a part of this study. Hence these seed extracts can help rural households of poor developing countries to produce drinking water, although seed extracts dosage needs to be carefully controlled so as to reach optimum destabilization. The plant species that produce these seeds (Duncan mango and key lime) are widely grown, thus the seeds will be readily available and will help to improve the life of rural people.

Table 3. Effect of Combination of Seed Extracts and Alum on Different Turbidity Levels

Initial Turbidity (NTU)		**50**		**100**		**150**	
Coagulants	**Proportion (%) Alum-Seed Extract**	**Dosage (ml) Alum-Seed Extract**	**Turbidity Reduction (NTU)**	**Dosage (ml) Alum-Seed Extract**	**Turbidity Reduction (NTU)**	**Dosage (ml) Alum-Seed Extract**	**Turbidity Reduction (NTU)**
Alum (AS) and Duncan Mango Seed (DMS)	00:100	0,15	13.00	0,20	12.50	0,25	12.00
	20:80	4,12	9.01	5,16	8.41	5,20	8.10
	40:60	8,9	6.01	10,12	5.30	10,15	5.50
	60:40	**12,6**	**2.31**	**15,8**	**1.82**	**15,10**	**2.31**
	80:20	16,3	5.00	20,4	4.15	20,5	4.04
	100:00	20,0	4.03	25,0	3.02	25,0	3.14
Alum(AS) and Key Lime Seed (KLS)	00:100	0,15	16.80	0,20	15.50	0,25	13.30
	20:80	4,12	9.29	5,16	8.78	5,20	8.54
	40:60	8,9	5.86	10,12	6.54	10,15	5.79
	60:40	**12,6**	**2.55**	**15,8**	**2.00**	**15,10**	**1.88**
	80:20	16,3	4.18	20,4	5.04	20,5	3.84
	100:00	20,0	4.03	25,0	3.02	25,0	3.14

Table 3 shows the effect of combination of seed extracts and alum on different turbidity levels. Results show that combination of seed extracts and alum resulted in significant turbidity reduction of treated water (for all turbidity levels) much lower than that of alum alone. For combination of alum and Duncan mango seed extract, optimum doses obtained were as follows: alum-12 ml, Duncan mango seed extract-6 ml for initial turbidity of 50 NTU; alum-15 ml, Duncan mango seed extract- 8 ml for initial turbidity of 100 NTU; alum-15 ml, Duncan mango seed extract-10 ml for initial turbidity of 150 NTU and the corresponding turbidity reduction were 2.31, 1.82 and 2.31 NTU respectively. The same optimum dose was observed for combination of alum and key lime seed extracts, the corresponding turbidity reductions were: 2.55, 2.0 and 1.88 NTU for low, medium and high turbidity initial levels respectively. These values are well below the WHO acceptable limit of 5 NTU (WHO, 2011), hence the seed extracts work better as coagulant aid using alum as primary coagulant. These results are in agreement with that reported by Muyibi and Okuofu (1995) when *Moringa oleifera* was used as a coagulant aid with alum as primary coagulant. These results further suggested that combination use of alum and seed extracts (60 and 40 %) can result to 40 % savings in alum, hence this will help reduce the cost of water treatment.

4. Conclusion

In this study, it was found that Duncan mango and key lime seed extracts have demonstrated considerable capability in reducing turbidity of river water (kaolin dosed) either as primary coagulant or coagulant aid (using alum as primary coagulant). As primary coagulant, the seed extracts of Duncan mango and key lime were more effective for treatment of medium and high river water turbidity. The seed extracts of Duncan mango and key lime have potentials for use as coagulant aid with alum as primary coagulant for treatment of low, medium and high river water turbidity. This study has revealed that locally available fruit waste (Duncan mango and key lime seeds) can aid coagulation, thus are suitable for water turbidity treatment. This could help reduce the incidence of water borne diseases in poor developing countries. These seeds are readily available, cheap (as they do not have to compete with food crops) and eco-friendly because of their biodegradable nature.

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