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ORIGINAL RESEARCH ARTICLE

ASSESSING THE POTENTIALS OF A PLANT-BASED COAGULANT (CYPERUS ESCULENTUS PULP) AS ALTERNATIVE TO ALUM IN CONVENTIONAL WATER TREATMENT PROCESS

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ABSTRACT

Globally, chemical coagulants such as alum are employed in water treatment during coagulation and flocculation process to improve drinking water quality. This process has an effect on human health. This research was carried out to assess the potentials of a plant-based coagulant (*Cyperus esculentus* Pulp) as substitute for alum or as coagulation aids. The water sample from river Gorao along Minna-Bida Road in Niger State were obtained in line with the standard laboratory procedures of the American Public Health Association (APHA) for the evaluation of the efficacy of the two coagulants (Plant-based Coagulant – *Cyperus esculentus*) and Aluminium Sulphate (Alum). Jar Test was done for some turbidity range. The results showed Turbidity and Colour removal efficiencies of 80.47% and 55.37% respectively. The Water Quality Index (WQI) shows that *Cyperus esculentus* produces good quality water (grade B) with WQI of 44.5. Recommendations arising from this study includes that further investigation should be carried out on other potential plant-based coagulants. Yellow variety of *Cyperus esculentus* should be investigated for its coagulation potentials and the use of *Cyperus esculentus* as coagulant is recommended as coagulant aid for reduction of turbidity in water.

1.0 Introduction

Water is a basic need required by plants and animals especially human being. Developing countries are faced with the challenge of potable water supply due to inadequate funding. The cost of water treatment is increasing and the quality of river water is not stable due to suspended and colloidal particle load caused by land development and high storm runoff during the rainy seasons. During the rainy season the turbidity level increases thereby increasing the cost of water treatment. This could affect the quality of drinking water being supplied to consumers. Therefore, it is of important to find a natural alternative for water coagulant to treat the turbidity. These alternatives to chemical coagulants are referred to as Nature-Based Solutions for Water (WWDR, 2018). Nature-Based Solutions for water may be employed to address water availability, improved water quality and reduce risks associated with water related disasters and climate change (WWDR, 2018). Globally, the amount of resources available to meet human needs is limited. Safe drinking water is essential to the health and wellbeing of a community, and water from all sources must have some form of purification before consumption (Arnoldson *et al.*, 2008, Muhammad *et al.*, 2015).

Drinking water treatment involves a number of combined processes based on the quality of the water source such as turbidity, amount of microbial load present, others may include cost and availability of chemicals in achieving desired level of treatment (Muhammad *et al.*, 2015). Conventional methods used for purification of water include coagulation, sedimentation, filtration, aeration and disinfection.

In drinking water treatment, the coagulation process is used to destabilize suspended particles and to react with organic materials in the raw water. Proper coagulation is essential for good filtration performance and for disinfection by product (DBP). Common Coagulants are aluminium sulphate, ferric chloride, poly-aluminium chlorides and synthetic polymers. The use of coagulants such as alum is one of the commonest methods employed which reduce the repulsive force between particulate matter, encouraging particle collision and floc formation (Muhammad *et al.*, 2015).

Similarly, in wastewater treatment, coagulation has been practiced with the intention of removing colloidal impurities causing turbidity in the water (Saharudin and Nithyanandam, 2014). Aluminium and iron coagulants are the most commonly used for the treatment of wastewater. However, when aluminium is used as a coagulant in wastewater treatment, it could have adverse effect on human health such as intestinal constipation, loss of memory, convulsions, abdominal colic's, loss of energy and learning difficulties (Sulaiman *et al.*, 2017). Therefore, nowadays great attention is given to the improvement and implementation of natural coagulants in wastewater treatment too. Natural coagulants can be extracted from animals, microorganisms and also from natural plants origin (Saharudin and Nithyanandam, 2014).

Turbid Water that is murky or cloudy in appearance caused by impurities imparts an unpleasant taste to the water and thus has become the impetus behind the need for water treatment (Choy *et al*., 2015). Such colloidal particles generally contain fine particles that are difficult to settle by gravity and are usually negatively charged (Kim *et al.,* 2001). Throughout flocculation, the size of the flocs will continue to grow until they reach the steady-state floc size distribution.

Muhammad *et al.* (2015) conducted a study on water melon for water treatment and recommended that more natural sources should be investigated for potential coagulation abilities.

Similarly, Sulaiman *et al.* (2017), carried out a study on *Moringa oleifera* for water treatment and concluded that *Moringa oleifera* seed extract is a potential source for water treatment due to its efficiency.

Some plant-based coagulants have been investigated by various authors till date. *Moringa oleifera* seeds extracts were investigated by Ogunlela and Famakinwa (2016, Amagloh and Benang (2009), Oria-Usifo (2014 and Sulaiman *et al*. (2009).

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Similarly, Citrullus lanatus (Water Melon) seeds extracts was investigated by Muhammad *et al*. (2015) and Phoenix dactylifera (Date Palm) seed extracts was investigated by Saleem *et al*. (2019) and Al-Sameraiy (2012). Additionally, many other plant-based coagulants comprising Habiscus esculentus, Jatropha curcas, Ceratonia siligua (Locust Bean), Hylocereus undatus (Dragon fruit), Mangifera indica (Mango), Pisum sativum (Pea), Tamerindous indica (Tamarind), Zea May (Corn) and Vigna unguiculata (Cowpae) were investigated by Saleem *et al*. (2019). Vigna unguiculate was also investigated by Choy *et al*. (2015).

Muhammad *et al.* (2015) concluded their research on the use of water melon as a potential coagulant for water treatment by recommending that more natural sources should be investigated for potential coagulation abilities. Naturally occurring coagulants are usually presumed safe for human health (Ogunlela and Famakinwa, 2016). The above narratives justify the reason why we are investigating the potential of Tiger nuts (*Cyperus Esculentus*) pulp in comparison with alum in this study.

A number of studies have pointed out that the introduction of natural coagulants and adsorbents as a substitute for metal salts may ease the problems associated with chemical coagulants. Using natural coagulants instead of aluminium salts might give advantages, such as lower cost of water production, less sludge production and ready availability of reagents. There are also disadvantages such as increased concentration of nutrients and chemical oxygen demand (COD) in the treated water due to the organic nature of this type of coagulants (Muhammad *et al*., 2015).

From the foregoing, the development of natural, environmentally-friendly/biodegradable, renewable, cost-effective, easy to use and alternative sources of water treatment by recycling and re-use of organic wastes especially for use in rural areas and developing countries can therefore not be over-emphasized.

Classification of Tiger Nut extracted from the review work of Bamishaiye and Bamishiaye (2011) and Oyedele *et al.* (2015) reveals that Tiger Nut (*Cyperus esculentus)* is a grass-like tuber plant and an annual/perennial plant. It is mainly available in the north and thrives in a few southern regions in Nigeria in areas synonymous to the sudan and guinea savannah. It is available in black, brown and yellow specie. Its uses include human consumption, livestock fees and erosion control. Its native name in Hausa language is 'aya' and it belongs to the family of *Cyperaceae.* Its chemical composition includes Sodium, Calcium, Potassium Magnesium, Iron, Zinc and traces of Copper while it's nutrient constituents includes Moisture, Lipid, Fibre, Protein, Ash, Starch, reducing sugar and total sugar. The aim of the study is to determine the potential of using Tiger-Nuts (*Cyperus esculentus)* pulp as coagulant in water treatment.

2. Materials and Methods

2.1 Materials Procurement and Instrumentation

The materials used for the study includes Tiger Nut (*Cyperus esculentus*) – Dried Brown Variety with Origin from Jibiya in Katina State, Nigeria and Aluminium Sulphate (Alum) obtained from the Lower Usuma Dam Water Treatment Plant in Abuja, Distilled Water and Raw Water from River Goroa obtained from Gorao river along Minna-Bida road, Niger State, Nigeria.

Laboratory Reagents employed were as specified by the Standard Method for the Examination of Water and Wastewater by the American Public Health Association (APHA). They include Hydrocholoric Acid, Methyl Orange indicator, Calcium Oxide, Sodium Hydroxide. Sulphate, HR Nitrate, Nitrite and Phosphate Pillets.

Equipment used includes Flocculator (Stuart SW6), Conductivity Meter (Jenway 4520), COD Reactor (HACH), Magnetic Stirrer (STIR), Spectrophotometer (HACH, DR 5000), Calorimeter (HACH DR/890), Turbidity Meter, Dissolved Oxygen Metre, pH Meter, Digital Weighing Balance and Burner. Others include Laboratory Equipment such as Titration Apparatus, Beakers, Conical Flasks, Measuring Cylinder, Spatula, Grinding Machine, Pestle and Mortar, Two (2) 150ml and Eighteen (18) 75ml plastic bottles for Water Samples.

2.2. Methods

2.2.1. Raw Water Sample, Coagulants Sample Collection and Experimental Procedure

The raw water sample was collected from River Goroa, Minna-Bida Road, where local Gold mining occurs. All standard procedures for sample collection, storage, transportation and preservation stipulated by APHA were observed. Tiger nuts (*Cyperus esculentus*) were obtained from some Traders in Jibiya Market, Katsina State. Alum and *Cyperus esculentus* Coagulant solutions were prepared using 10g/100ml of distilled water and added to the water samples at various doses during the Jar Test to determine its effect on flocculation and sedimentation as well as coagulant optimum dose. The above process was repeated using a combination of Alum and plant-based materials as coagulants aid. The raw water sample was tested before and after treatment. Thereafter, physical, chemical and bacteriological characteristics were conducted in accordance with the procedures of the American Public Health Association (APHA), American Water Works Association (AWWA) and the World Environment Federation (WEF) standard for the examination of water and wastewater. Jar Tests were conducted to determine optimum or effective dosage of a coagulant to be applied in treatment of the raw water. In this case, alum was replaced by prepared Tiger Nut Wastes respectively to determine the optimum dose. A Stuart Flocculator equipped with a six (6) number of paddles for rapid and slow mixing is used. A Turbidimeter is used for turbidity measurements in the process after a given settling time. 100ml of the raw water were measured in six number 100ml beakers each and the paddles inserted in each. The flocculator was switched on at a speed of 250rpm for 3 minutes for rapid mixing. After 3 minutes, the speed was reduced to 25rpm for slow missing and this continued for 17 minutes for coagulation/flocculation. 30 minutes settling time was allowed before the residual turbidity and other water quality parameters were measured. The raw water and coagulated water samples are presented in Figure 1 (a) and (b) for clarity. Figure 2 shows the nature of *Cyperus esculentus* plant, fruit, seed and seed power to be used as coagulant aid.

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Figure 1(a): Raw Water Samples

Figure 1(b): Coagulated Water Samples

A. Alum Crystal

B. Tiger Nut Plant

C. Tiger Nut Tuber (Brown Variety)

D. Tiger Nut Pulp (Grinded)

Figure 2: Alum Crystal, Tiger Nut Plant, Tuber and Prepared Bio-Coagulant.

2.2.2. Preparation of Coagulant Solutions

A. Alum Coagulant Solution

Alum was sourced from the Lower Usuma Water Treatment Plant Store, Abuja and subsequently broken down into crystals and crushed in the laboratory into smooth powdered form. 10g of the powdered alum was measured on the weighing scale and mixed with 100ml distilled water and stirred properly with the aid of electric magnetic stirrer in the laboratory.

B. *Cyperus esculentus* Pulp as Coagulant Solution

Dried *Cyperus esculentus (Brown Variety)* were sourced from Jibiya in Katsina State, Nigeria and subsequently used in production of milk. The waste generated from the extraction of milk was then sun properly sun-dried, ground and sieved using the least available domestic sieve. 10g of the powdered *Cyperus esculentus* pulp was measured on the weighing scale and mixed with 100ml distilled water and stirred properly by the aid of electric magnetic stirrer in the laboratory. Figures 3 and 4 show the research flow charts and the one for the preparation of the bio-coagulant. Figure 5 shows the flocculator used for the experiment.

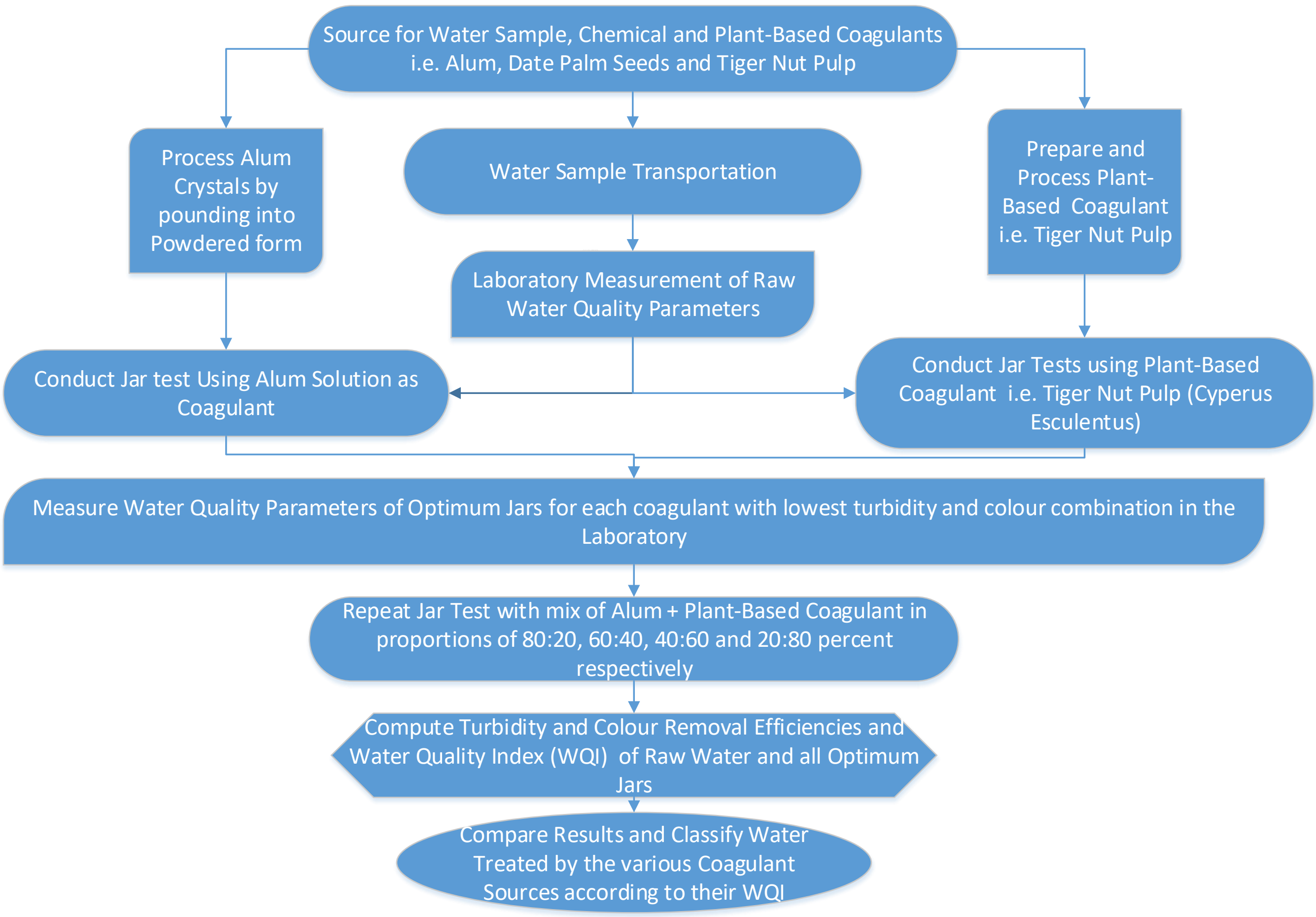

Figure 3: Research Flow Chart

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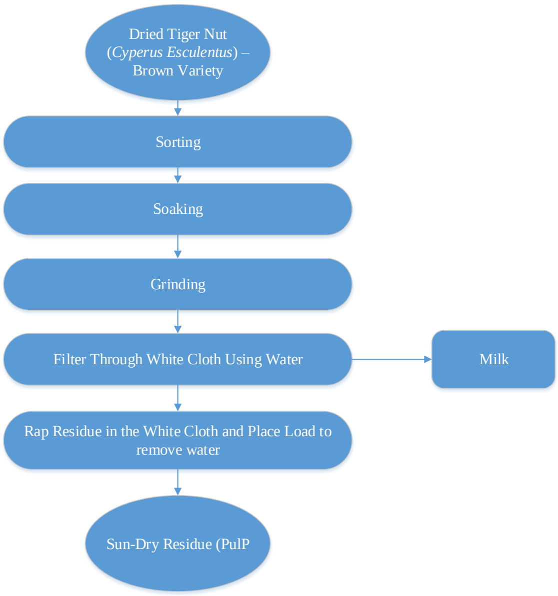

Figure 4: Flow Diagram for Preparation of *Cyperus esculentus* Bio-Coagulant

Figure 5: Jar Test Equipment (Flocculator)

2.2.3. Water Quality Tests

The quality of the Raw Water/Wastewater is tested before and after treatment with the optimum dose obtained from the jar test (after filtration) for its physico-chemical and Bacteriological parameters in line with the APHA Examination of Water and Wastewater guidelines and compared with native or WHO (2012) water quality standards for conformity or otherwise. Some of the physico-chemical water quality parameters investigated includes *p*H, Turbidity, Colour, Electrical Conductivity, Total Dissolved Solids (TDS), Aluminium, Iron, lead, Calcium, Magnesium, Manganese, Sulphate, Chloride, Nitrate, Nitrite, Chromium, Hardness, Alkalinity, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Dissolved Oxygen (DO).

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2.2.5 Methods for Determination of Water Quality Parameters.

The Methods for the determination of Water Quality parameters in the laboratory are as stipulated by the American Public Health Association Handbook for the Examination of Water and Wastewater.

2.2.6. Method for Water Quality Index Determination

The Weighted Arithmetic Water Quality Index was employed in the determination of the water quality indices for the raw water, chemical and plant-based coagulated water samples. Weighted arithmetic water quality index method classified the water quality according to the degree of purity by using the most commonly measured water quality variables. The method has been widely used by various scientists and the calculation of WQI was made by using the following equation

$$\mathrm{WQI} = \frac{\sum \mathrm{QiWi}}{\mathrm{Wi}} \tag{1}$$

The quality rating scale (Qi) for each parameter is calculated by using this expression:

$$\mathrm{Qi} = \frac{100(\mathrm{Vi}-\mathrm{Vo})}{(\mathrm{Si}-\mathrm{Vo})} \tag{2}$$

Where,

Vi is estimated concentration of *i*th parameter in the analysed water

Vo is the ideal value of this parameter in pure water

Vo = 0 (except pH =7.0 and DO = 14.6 mg/l)

Si is recommended standard value of *i*th parameter

The unit weight (w_i) for each water quality parameter is calculated by using the following formula:

$$\mathrm{Wi} = \frac{K}{Si} \tag{3}$$

Where,

K = proportionality constant and can also be calculated by using the following Equation.

$$K = \frac{1}{\sum (1/Si)} \tag{4}$$

K is equal to unity (Armah *et al*, 2012).

3. Results and Discussion

The results obtained from the laboratory investigation of the raw and treated water samples using Alum and *Cyperus esculentus* are compared with WHO (2012) guidelines for drinking

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water quality in this section. The results were further analysed to ascertain the efficiencies of turbidity and colour removal for the three coagulants. Table 1 below shows the inherent average raw water parameters.

Table 1: Average Raw Water Quality Parameters

S/No.	Parameter	Chemical Notation	Unit	Concentration 25th Feb., 2020	Concentration 19th March, 2021	Average Conc.	Maximum Limit (WHO)	Maximum Limit (NSDWQ)
	A. Physical Parameters							
1	Colour	Colour	Pt.Co	405	1383	894	15	15
2	Odour	Odour		Unobjectionable	Unobjectionable			
3	Taste	Taste		Unobjectionable	Unobjectionable			
4	Temperature	T	^oC	27.7	27.8	27.75		Ambient
5	Turbidity	Tur.	NTU	50	192	121	5	5
6	pH	*pH*		7.22	7.05	7.135	6.5 - 8.5	6.5 - 8.5
7	Electrical Conductivity	EC	µS/cm	286	222	254	250	1000
8	Total Dissolved Solid (TDS)	TDS	mg/L	251	144	197.5	1000	500
	B. Chemical Parameters							
9	Aluminium	Al	mg/L	22.4	32.4	27.4	0.2	0.1
10	Alkalinity		mg/L		106	106	120	
11	BoD	BOD_5	mg/L	102	1.9	51.95	6	2
12	Dissolved Oxygen	DO	mg/L	5.5	7	6.25	5	7.5
13	Chloride	Cl	mg/L	24.9	31.9	28.4	250	250
14	Calcium	Ca	mg/L	32.1	30	31.05	75	75
15	Magnesium	Mg	mg/L	17.1	22	19.55	50	0.2
16	Manganese	Mn	mg/L		1.2	1.2	0.1 to 0.5	0.4
17	Chromium	Cr	mg/L	0.08	0.05	0.065	0.1	0.05
18	CoD	CoD	mg/L	4	11.00	7.5	10	1000
19	Copper	Cu	mg/L	0.016	0.86	0.438	1 to 2	
20	Zinc	Zn	mg/L		0	0	2	5
21	Iron	Fe	mg/L	3.11	1.62	2.365	0.3	0.3
22	Lead	Pb	mg/L	0.001	0.003	0.002	0.01	0.01
23	Sodium	Na	mg/L	40		40	200	200
24	Potasium	K	mg/L	14		14		
25	Sulphate	SO_4	mg/L	7	7.00	7	250	100
26	Flouride	F	mg/L	0.7	0	0.35	1.5	1.5
27	Nitrite	NO_2	mg/L	0.139	0.091	0.115	3	0.2
28	Nitrate	NO_3	mg/L	7.46	12.5	9.98	50	0.2
29	Hardness		mg/L		120	60	200	150
30	Phosphate	PO_4^{3-}	mg/L			0.26		
	C. Bacteriological Parameters							
31	Total Coliform Count	TCC	MPN	84	1530	807	0	10
32	e-Coli (*Faecal* Coliform)	e-Coli	u/100r	14	645	329.5	0	0

Note: *All measurements requiring measuring devices were repeated at least three times.*

3.1. Coagulated Water Using Alum

Two jar tests were conducted using Alum as coagulant in 2020 and 2021 respectively. The jar test results using alum solution as coagulant in 2020 and 2021with floc formation time of less than a minute were achieved. The results of Jar Tests carried out using Alum solution as coagulant in 2020 and 2021 were well documented with floc formation time of majorly less than a minute. The computation of turbidity and colour removal efficiencies are presented in Tables 2-5.

Table 2: Trial Turbidity Removal Efficiency for 100% Alum 2020

Jar	Alum Dose	Initial Turbidity (T_o) (NTU)	Final Turbidity (T_f)	Turbidity Removal Efficiency $T_e = (T_o - T_f)/T_o *100$
1	10	121.00	2.74	97.74
2	20	121.00	2.30	98.10
3	30	121.00	2.67	97.79
4	40	121.00	2.73	97.74
5	50	121.00	3.17	97.38
6	60	121.00	2.74	97.74
			Average Te	**97.75**

Table 3: Turbidity Removal Efficiency for 100% Alum 2021

Jar	Alum Dose	Initial Turbidity (T_o) (NTU)	Final Turbidity (T_f)	Turbidity Removal Efficiency $T_e = (T_o - T_f)/T_o *100$
1	10	121.00	4.95	95.91
2	20	121.00	5.41	95.53
3	30	121.00	5.78	95.22
4	40	121.00	6.64	94.51
5	50	121.00	7.16	94.08
6	60	121.00	6.91	94.29
			Average T_e	**94.92**

Average Turbidity Removal Efficiency for Alum = (97.75 + 94.92)/2 = 96.34

Table 4: Trial Colour Removal Efficiency for 100% Alum 2020

Jar	Alum Dose	Initial Colour (C_o) (Pt. Co)	Final Colour (C_f)	Colour Removal Efficiency $C_e = (C_o - C_f)/C_o *100$
1	10	894.00	1.00	99.89
2	20	894.00	BR	
3	30	894.00	BR	
4	40	894.00	BR	
5	50	894.00	15.00	98.32
6	60	894.00	6.00	99.33
			Average C_e	**99.18**

BR – Below Range

Table 5: Colour Removal Efficiency for 100% Alum 2021

Jar	Alum Dose	Initial Colour (C_o) (Pt. Co)	Final Colour (C_f)	Colour Removal Efficiency $T_e = (C_o - C_f)/C_o *100$
1	10	894.00	215.00	75.95
2	20	894.00	154.00	82.77
3	30	894.00	65.00	92.73
4	40	894.00	BR	
5	50	894.00	BR	
6	60	894.00	BR	
			Average C_f	**83.82**

Average Colour Removal Efficiency for Alum = (99.18 + 83.82)/2 = 91.50

3.2. Coagulated Water Using 100% *Cyperus esculentus*

Jar test was conducted using *Ceperus esculentus* pulp solution as coagulant. The computation of turbidity and colour removal efficiencies arising from the results of the jar test are presented in Tables 6 and 7.

Table 6: Turbidity Removal Efficiency Using 100% *Cyperus esculentus*

Jar	Cyperus Esculentus	Initial Turbidity (T_o) (NTU)	Final Turbidity (T_f)	Turbidity Removal Efficiency $T_e = (T_o - T_f)/T_o *100$
1	10	121.00	31.90	73.64
2	20	121.00	20.80	82.81
3	30	121.00	22.80	81.16
4	40	121.00	23.80	80.33
5	50	121.00	20.20	83.31
6	60	121.00	22.30	81.57
			Average T_e	**80.47**

Turbidity Removal Efficiency Ratio = T_e*(Cyperus esculentus*/T_e*(Alum) x 100*

= (80.47/96.34) x 100 = 83.53%

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Table 7: Colour Removal Efficiency Using 100% *Cyperus esculentus*

Jar	Cyperus Esculentus Dose	Initial Colour (C_o) (Pt. Co)	Final Colour (C_f)	Colour Removal Efficiency $C_e = (C_o - C_f)/C_o * 100$
1	10	894.00	508.00	43.18
2	20	894.00	388.00	56.60
3	30	894.00	392.00	56.15
4	40	894.00	403.00	54.92
5	50	894.00	344.00	61.52
6	60	894.00	359.00	59.84
			Average C_f	**55.37**

Colour Removal Efficiency Ratio = C_e*(Cyperus Esculentus)*/C_e*(Alum) x 100*

= (55.37/91.50) x 100 = 60.50%

3.3. Combination of Alum and Plant-Based Coagulants

3.3.1 Coagulated Water Test Results – Combination of Alum and Cyperus esculentus as coagulation aid in Varying Percentages.

Jar Test was conducted at the optimum *Cyperus esculentus* coagulant dose of 50 mg/L and a lower dose of 40 mg/L for the purpose of comparison using a combination of alum and *Cyperus esculentus as* coagulant using Alum: *Cyperus esculentus* ratio of 80%:20%, 60%:40%, 40%:60% and 20%:80% respectively. This step was predicated on the fact that the turbidity and colour removal efficiencies of *Cyperus esculentus* even though close to that of alum did not exceed it. It was clear that 80% alum and 20% *Cyperus esculentus* coagulant produced the optimum jar with turbidity of 6.40 NTU and colour of 71 Pt.Co at a temperature of 28.0°C.

3.4. Summary of Results for Turbidity and Colour Removal Efficiencies and Optimum Dose and Combination of the Plant-Based Coagulants with Alum

The summary of the Turbidity and Colour removal efficiencies as well as the optimum dose and percentage coagulant combination with Alum are presented in Tables 8 and 9 below.

Table 8: Summary of Turbidity, Colour Removal Efficiencies, Optimum Dose and Proportion of Coagulant Combination with Alum.

S/No	Coagulant	Turbidity Removal Efficiency Te (%)	Colour Removal Efficiency Ce (%)	Te(Alum Average)/Te	Ce(Alum Average)/Ce	Optimum Proportion in Combination with Alum Alum/Nature-Based Coagulant	Optimum Combined Coagulant Dose D(%)
1	Alum	94.92 - 97.75	83.82 - 99.18	N/A	N/A	N/A	N/A
2	Cyperus esculentus	80.47	55.37	1.20	1.65	80/20	50

NOTE: Averages of T_e and C_e for Alum are 96.34% and 91.50% respectively. Alum is 20% more efficient in Turbidity removal and 65% more efficient in colour removal than *Cyperus esculentus* coagulant from the results of the study.

Table 9: Consolidated Experimental Results

S/No.	Parameter	Chemical Notation	Unit	Maximum Limit (WHO)	Raw Water	Coagulant: Alum Coagulation 2020	Alum Coagulation 2021	Average for Alum	*Cyperus Esculentus* (C.E) Coagulation 100%	80% Alum + 20% C.E@ 40mg/L	80% Alum + 20% C.E@50mg/L
	A. Physical Parameters										
1	Colour	Colour	Pt.Co	15	1,383.00	BR	154	154	344	105	71
2	Odour	Odour		non-objectionable	non-objectionable	non-objectionable	non-objectionable	non-objectionable		non-objectionable	non-objectionable
3	Taste	Taste		non-objectionable	non-objectionable	non-objectionable	non-objectionable	non-objectionable		non-objectionable	non-objectionable
4	Temperature	T	°C		27.80	27.70	27.80	27.75	29.60	28.30	28.00
5	Turbidity	Tur.	NTU	5	192.00	50.00	192.00	121.00	20.20	7.15	6.40
6	pH	*pH*		6.5 - 8.5	7.05	7.22	7.05	7.14	7.40	7.20	7.20
7	Electrical Conductivity	EC	μS/cm	250	222.00	286.00	222.00	254.00	241.00	249.00	253.00
8	Total Dissolved Solid	TDS	mg/L	1000	144.00	251.00	144.00	197.50	144.40	147.30	140.30
	B. Chemical Paramaters/Cations										
9	Aluminium	Al	mg/L	0.2	32.40	1.4	1.4	1.40	1.4	1.5	1.4
10	Alkalinity		mg/L	120	106.00	106	106	106	94	86	84
11	BoD	BOD_5	mg/L	6	1.90	0.80	0.80	0.80	0.40	1.20	1.00
12	Dissolved Oxygen	DO	mg/L	5	7.00	8.00	8.00	8.00	8.00	7.20	8.80
13	Chloride	Cl	mg/L	250	31.90	35.80	21.80	28.80	18.00	18.00	18.00
14	Calcium	Ca	mg/L	75	30.00	35.30	24.00	29.65	25.60	17.60	25.60
15	Magnesium	Mg	mg/L	50	22.00	10.20	10.90	10.55	25.90	30.20	26.30
16	Manganese	Mn	mg/L	0.1 to 0.5	1.20	2.50	1.60	2.05	0.90	0.40	0.30
17	Chromium	Cr	mg/L	0.1	0.05	0.01	0.01(BR)	0.00	0.00	0.00	0.00
18	CoD	CoD	mg/L	10	11.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Copper	Cu	mg/L	1 to 2	0.86	0.004	0.004	0.004	0.008	0.009	0.003
20	Zinc	Zn	mg/L	2	0.00						
21	Iron	Fe	mg/L	0.3	1.62	0.07	0.07	0.07	0.27	0.05	0.11
22	Lead	Pb	mg/L	0.01	0.003	0.003	0.003	0.003	0.001	0.001	0.001
23	Sulphate	SO_4	mg/L	250	7.00	66.00	21.00	43.50	3.00	14.00	15.00
24	Flouride	F	mg/L	1.5	0.00						
25	Nitrite	NO_2	mg/L	3	0.091	0.005	0.008	0.0065	0.009	0.002	0.002 (BR)
26	Nitrate	NO_3	mg/L	50	12.50	0.20	0.80	0.50	4.40	1.60	1.30
27	Hardness		mg/L	200	120.00	182.00	96.00	139.00	90.00	96.00	96.00
28	Phosphate	PO_4^{3-}	mg/L		0.26	0.32	0.39	0.355	4.00	0.62	0.14
	C. Bacteriological Parameters										
29	Total Coliform Count	TCC	MPN	0	1530.00	0.00	46.00	46.00	58.00	146.00	74.00
30	e-Coli (*Faecal* Coliform)	e-Coli	Cfu/100m	0	645.00	0.00	12.00	12.00	24.00	46.00	34.00

3.5. Water Quality Index Determination and Coagulated Water Classification

Weighted Arithmetic water Quality Index was employed in the determination of the Water Quality Indices after the use of all coagulants in this research. Initial computations of WQI and the summary of the computations is tabulated in table 10 and 11.

Table 10: Computation of WQI for Raw Water

S/No	Parameter	Notation	Unit	Raw Water Sample	Standard Permissible Level as per WHO Guidelines	Ideal Value	Unit Weight (Wi)	Quality Rating Qi	Qi*Wi
				Vi	Si	Vo	(1/Si)	((Vi - Vo)/(Si - Vo))*100	
1	Calcium	Ca	mg/L	31.05	**75**	0.00	0.0133	41.40	0.55
2	Magnesium	Mg	mg/L	19.55	**50**	0.00	0.0200	39.10	0.78
3	Manganese	Mn	mg/L	1.20	**0.5**	0.00	2.00	240.00	480.00
4	Chromium	Cr	mg/L	0.07	**0.1**	0.00	10.00	65.00	650.00
5	Iron	Fe	mg/L	2.365	**0.3**	0.00	3.33	788.33	2,627.78
6	Lead	Pb	mg/L	0.002	**0.01**	0.00	100.00	20.00	2,000.00
7	Chloride	Cl	mg/L	28.40	**250**	0.00	0.00	11.36	0.05
8	Sulphate	SO_4	mg/L	7.00	**250**	0.00	0.00	2.80	0.01
9	Nitrate	NO_3	mg/L	9.98	**10**	0.00	0.1000	99.80	9.98
10	Nitrite	NO_2	mg/L	0.115	**3**	0.00	0.33	3.83	1.28
11	Dissolved Oxygen	DO	mg/L	6.25	**5**	14.60	0.20	86.98	17.40
12	Biochemical Oxygen Demand	BOD_5	mg/L	51.95	**6**	0.00	0.17	865.83	144.31
13	Chemical Oxygen Demand	COD	mg/L	7.50	**10**	0.00	0.10	75.00	7.50
14	Turbidity	Tur.	NTU	121.00	**5**	0.00	0.20	2,420.00	484.00
15	Colour		Pt-Co	894.00	**15**	0.00	0.07	5,960.00	397.33
16	Total Alkalinity		mg/L	106.00	**120**	0.00	0.01	88.33	0.74
17	Total Hardness	TH	mg/L	9.98	**200**	0.00	0.01	4.99	0.02
18	*pH*	*pH*		7.14	**8.5**	7.00	0.12	9.00	1.06
19	Total Dissolved Solids	TDS	mg/L	197.50	**1000**	0.00	0.00	19.75	0.02
20	Electrical Conductivity	EC	µS/cm	254.00	**250**	0.00	0.00	101.60	0.41
21	Aluminium	Al	mg/L	32.40	**0.2**	0.00	5.00	16,200.00	81,000.00
						$\Sigma W_i =$	**121.68**	**$\Sigma Q_i W_i =$**	**87,823.21**
							$WQI = \Sigma Q_i W_i / \Sigma W_i$	**721.77**	
								Grade E: Unsuitable for Drinking Purpose	

Table 11: Consolidated Results for Water Quality Index and Water Quality Classification for the Coagulants/Coagulant Mix Used

S/No	Description of Coagulant/Coagulant Mix	WQI	Water Quality Classification	WQ Interpretation as Per WAWQI
1	Raw Water	721.77	Grade E	Unsuitable for Drinking Purpose
2	100% Alum	68.21	Grade C	Poor Water Quality
3	100% Cyperus Esculentus	44.54	Grade B	Good Water Quality
4	80% Alum + 20% Cyperus Esculentus	39.61	Grade B	Good Water Quality

3.6 Discussion of Results

3.6.1 Colour

The initial average water colour in Table 1 was 1383 Pt-Co. while the least colour out of the coagulants combination used from Tables 2 to 5 stands at 71Pt.Co using 100% Alum and 20% *Cyperus esculentus* coagulant at 50mg/L. The W.H.O and NSDWQ acceptable maximum standard for drinking water is 15Pt-Co (Table 1). This indicates that the alum-*Cyperus esculentus* combination in the above proportion reduced the initial average colour of the raw water 19.479 times (**1,948**%) to 71Pt.Co. Though, above the W.H.O guideline and NSDWQ by 56 Pt.Co.,

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the processes of filtration and disinfection is expected to improve the colour in a conventional water treatment facility.

3.6.2 Turbidity

The initial raw water turbidity was 192NTU from Table 1 while the least turbidity out of the coagulants used from Tables 2 to 5 stands at 6.40 NTU using 80% Alum and 20% *Cyperus esculentus* at 50mg/L coagulant dose at 50 NTU. The W.H.O and NSDWQ acceptable maximum standard for drinking water is 5 NTU (Table 1). This indicates that the *Cyperus esculentus* reduced the initial turbidity of the raw water 30 times (**3,000**%) to 6.40 NTU. Though slightly above the W.H.O guidelines and NSDWQ by 1.40 NTU, the processes of filtration and disinfection is expected to bring the turbidity value within acceptable range in a conventional water treatment facility. The floc appearance and settling time using alum were mainly more than and less than a minute in both Jar tests performed in 2020 and 2021 respectively from observation. However, using 100% *Cyperus esculentus*, the floc appearance and settling time was mainly less than a minute.

3.7. Water quality index and water quality classification

The computation of Water Quality Index as exemplified on Table 10 and summarised in Table 11 shows that 100% *Cyperus esculentus* and 80% Alum + 20% *Cyperus esculentus* at 50mg/L produces Grade B (Good Water Quality) with WQI values of 44.54 and 39.61 respectively. The raw water was established to have a water quality index of 721.77, Grade E and unsuitable for drinking purposes. The potency of 100% *Cyperus esculentus* as in optimum combination with alum as a plant-based coagulant aid was therefore evidently validated by this result.

4.0 Conclusion

The conclusions arising from this research are drawn as follows:

In the work reported, the physical parameters before and after the jar tests, including the resultant analysis of *Cyperus esculentus* pulp shows that it has the potentials to serve as bio-coagulant.

While *Cyperus esculentus* recorded turbidity and colour removal efficiencies of 80.45% and 55.37%. Comparatively, the turbidity and colour removal efficiencies of Alum from the research was 97.75% and 99.18% respectively. This implies that alum is more effective than *Cyperus esculentus* coagulant but the turbidity removal efficiency of *Cyperus esculentus* coagulant is more than 80% which is also good.

Finally, a combination of alum and *Cyperus esculentus* coagulant reveals that the optimum dose of 50mg/L suffices for 80% Alum and 20% *Cyperus eculentus* as coagulants. *Cyperus esculentus* coagulant functions optimally and effectively in combination with alum rather than when acting alone. Therefore, *Cyperus esculentus* have the capacity to limit the use of alum coagulant by at least 20%.

The recommendations arising from this study are as follows:

1. Further investigation should be carried out on other potential plant-based coagulants to improve access to clean water for people living in rural areas.

2. Investigation of the potential of yellow variety of tiger nut (*Cyperus esculentus*) as a coagulant in water treatment should be conducted.

3. *Cyperus esculentus a*lone has the potential to substantially reduce turbidity and improve overall water quality and its use as a plant-based coagulant aid and partial alternative to alum is recommended.

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