ASSESSMENT OF THE POTENTIALS OF A PLANT-BASED COAGULANT (*CYPERUS ESCULENTUS* PULP) AS SUBSTITUTE FOR ALUM IN CONVENTIONAL WATER TREATMENT PROCESS

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ABSTRACT

In a bid to providing potable water, chemical coagulants are employed in water treatment for the purpose of coagulation and flocculation. This process have 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, coagulation aids or sources of dilution. The water sample from river Gorao along Minna-Bida Road in Niger State were 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 – PBC) and Aluminium Suphate (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.*

KEYWORDS: *Alum, Colour, Cyperus Esculentus, Plant-Based Coagulants, Turbidity, Water Quality, Water Quality Index.*

1.0 INTRODUCTION

Water supply is a basic need required for living creatures and human being specifically. Developing countries and third world countries are facing potable water supply problems because of inadequate financial resources. 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 seasons, the turbidity level increases and the need for water treatment chemicals increase as well, which leads to high cost of treatment which the water treatment companies cannot sustain. As a result, the drinking water that reaches the consumer is not properly treated (Muyibi *et al*, 2009 cited by Muhammad *et al*, 2015). Therefore, it is of great importance 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 living creatures is limited. Safe drinking water is essential to the health and welfare of a community, and water from all sources must have some form of purification before consumption (Arnoldson *et al*, 2008 cited by 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 in water and others include cost and availability of chemicals in achieving desired level of treatment (Muyibi *et al*, 2009 cited by Muhammad *et al*, 2015). Conventional methods used for purification of water include coagulation, sedimentation, filtration, aeration and also chemical treatment.

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 and it reduces the repulsive force between particulate matter, encouraging particle collision and floc formation (Moramudaii and Fernando, 2001 cited by Muhammad *et al*, 2015).

Similarly, in wastewater treatment, coagulation has been practiced since earliest times and the main objective is to remove colloidal impurities hence also removing turbidity from the water (Saharudin and Nithyanandam, 2014). Aluminium and iron coagulants are commonly used in most industries for the treatment of wastewater. However, when aluminium is used as a coagulant in wastewater treatment, it can cause several bad effect on human health such as intestinal constipation, loss of memory, convulsions, abdominal colic's, loss of energy and learning difficulties. Therefore, nowadays there have been great attention in the improvement and implementation of natural coagulants in wastewater treatment too. These natural coagulants can be formed or extracted from animals, microorganisms and also plants (Saharudin and Nithyanandam, 2014).

2.0 AIM AND OBJECTIVES

The aim of the research is to determine the potential of using the waste of a Plant-Based Coagulant (PBC)s, Tiger-Nuts (*Cyperus Esculentus)* pulp in the coagulation/treatment of turbid river water with specific emphasis on turbidity and colour removal. The specific objectives are to:

I. Determine the coagulation potential of plant-based coagulant (*Cyperus Esculentus)* in the coagulation/treatment of raw river water.
II. (*Cyperus Esculentus)* on individual water quality parameters (Physical, Chemical and bacteriological) with emphasis on Turbidity and Colour.
III. Establish on a comparative basis, the possibility of using the plant-based coagulant as stand alone or in combination with alum and ascertain the optimum proportion of the coagulant mix.

3.0 SCOPE OF RESEARCH

The scope in this research is limited to the investigation of the potential of plant products and wastes (Re-use) of Tiger-Nuts (*Cyperus Esculentus)* as coagulant and/or disinfectants in the treatment of raw surface water. The American Standard for the Examination of Water and Wastewater published by the American Public Health Association (APHA) was employed in the laboratory investigation.

4.0 LITERATURE REVIEW

The health implications of overdose or long term side effects, cost, availability, disposal of sludge and environmental concerns of modern water treatment chemicals has led to a global awareness on the need for natural alternatives in water and wastewater treatment. 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 are generally too fine 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) carried out a study titled "Water Melon Seed as a Potential Coagulant for Water Treatment" and recommended that more natural sources should be investigated for potential coagulation abilities amongst other conclusions.

Similarly, Sulaiman *et al* (2017), carried out a study titled "*Moringa Oleifera* Seed as alternative natural coagulant for potential application in Water Treatment: A Review" and concluded that *Moringa Oleifera* seed extract is a potential source for water treatment due to it's efficiency. When used for the treatment of wastewater, excellent results were obtained. The seeds are environmentally-friendly because they do not further deteriorate the environment. Also due to its availability and maximum effluent removal from both domestic and synthetic wastewater, the application of the seeds in wastewater treatment in undeniable. He further recommended the extraction of oil from the seeds before using as a coagulant for water treatment in order to achieve optimum effluent reduction.

Also, Ogunlela and Famakinwa (2016), carried out a study titled "The Use of *Moringa Oleifera* Seed Powder for Treating Recirculatory Aquaculture System (RAS) Discharge" and quoted that Amagloh and Benang (2009) in the study of comparison of effectiveness of *Moringa Oleifera* and alum, at 95.0% confidence level, showed that there was significant difference among all the treatments at the varying loading dose concentrations on the *p*H. Increase in alum dosage leads to increase in acidity of water but the reverse was observed with the Moringa treatment. The use of natural materials of plant origin to clarify turbid water is not a new idea (Sani ,1990, Ndabigengesere *et al*., 1995, Folkard and Sutherland, 2001) cited by Amagloh and Benang (2009). Among all the plant materials that have been tested over the years, powder processed from the seeds from *Moringa oleifera* has been shown to be one of the most effective as a primary coagulant for water treatment and can be compared to that of Alum (conventional chemical coagulant). It was inferred from their reports that the powder has antimicrobial properties. Also, Oria- Usifo (2014) in a comparative coagulation studies between alum and *Moringa oleifera* concluded that compared to the commonly used coagulant chemicals, *Moringa Oleifera* has a number of advantages: it is of low cost, it produces biodegradable sludge, it produces lower sludge volume and it does not affect the pH of the water. The above listed advantages make *Moringa Oleifera* consumer and environmentally friendly low cost alternative with significant potential both in developing and developed countries. One major advantage that *Moringa Oleifera* seed has over all other coagulants is that it's readily available at cheaper amount. It can be propagated from seed or from cutting of the stem. Within 3 years of planting one tree will produce 300 to 400 pods every year and a mature tree can produce up to 1000 pods. Frequent pruning of the growth tips will maintain and increase leaf growth and the height can be controlled to make harvesting easier (HDRA, 2002).

Aside *Moringa Oleifera* and Water Melon, Saleem and Bachman (2019) carried out an extensive Contemporary review on Plant-Based Coagulants for applications in water treatment from various related literatures and came up with a list of about 46 plant-based coagulants with the use of various parts such as seeds, grains and roots as coagulants. A brief list of some popular plant-based coagulants within the African sub-region that have been investigated are contained in table 1.0 below:

Table 1.0: Some Investigated Plant-Based Coagulants

S/No	Plant Name	Plant Part	Reference(s)
1.	*Moringa Oleifera*	Seeds	Ogunlela and Famakinwa (2016), Amagloh and Benang (2009), Oria-Usifo (2014), Sulaiman *et al* (2017).
2.	*Citrullus lanatus* (Water Melon)	Seeds	Muhammad *et al* (2015)
3	*Abelmoschus esculentus/Hibiscus esculentus (okra)*	Mucilage	Saleem *et al.* (2019)
4	*Jatropha Curcas*	Seeds	Saleem *et al.* (2019)
5	*Phoenix Dactylifera*	Seeds, Pollen grains	Saleem *et al.* (2019) Al-Sameraiy (2012)
6	*Ceratonia Siliqua (Locust Bean)*	Seeds	Saleem *et al.* (2019)
7	*Hylocereus Undatus (Dragon fruit)*	Fruit foliage	Saleem *et al.* (2019)
8	*Mangifera Indica (Mango)*	Seeds	Saleem *et al.* (2019)
9	*Pisum Sativum (Pea)*	Seeds	Saleem *et al.* (2019)
10	*Tamerindous Indica (Tamarind)*	Seeds	Saleem *et al.* (2019)
11	*Vigna Unguiculata (Cowpea)*	Seeds	Saleem *et al.* (2019), Choy *et al.* (2015)
12	*Zea May (Corn)*	Grain	Saleem *et al.* (2019)

The use of surface and groundwater for drinking and domestic purposes in most rural communities within many developing countries has become common practice. This source of water usually requires treatment prior to consumption because this water contains dissolved and suspended solids. The essential removal of these contaminants from this source of water can be carried out through coagulation, a process in water treatment involving the destabilization of colloidal particles to form *flocs* that can then be easily removed. This destabilisation is achieved by the addition of positively charged *ions* known as coagulants to water containing colloidal particles, which are almost always negatively charged. Over previous decades, chemical coagulants have been used in water treatment for the removal of suspended solids and the reduction of the turbidity of water, bacteria and viruses. The common types of these chemical coagulants are aluminium sulphate, ferrous sulphate and ferric sulphate. The application of chemical coagulants in water and wastewater treatment has been determined to cause impurities present in colloidal forms to adhere upon contact, forming *flocs* which can then be easily removed (Bhuptawat *et al*, 2007 and Pritchard et al 2010 cited by Bakare, 2016). However, chemical coagulants are not readily available in developing countries, can be quite expensive for people living in remote rural areas in developing countries, and can pose adverse effects on public health if not applied at the correct dose. Therefore, the use of natural coagulants of plant origin is a viable alternative to chemical coagulants. It has been widely documented that extracts from plants such as *Moringa Oleifera* have proven effective in the removal of suspended solids, in turbidity removal, in softening of hard water, and also in the reduction of slurry produced as compared with that produced by chemical coagulants (Folkard *et al*, 1989, Muyibi and Evision, 1995 and Ndabigengesere *et al*, 1998 cited by Bakare, 2016). The use of *Moringa Oleifera* leaves the seeds as waste or by-product. Similarly, the consumption of Date palm and Tiger nuts produces the seeds and chaff or pulp as by-products. This organic by-products may be said to be wastes most especially after oil extraction when practicable, but could however, be recycled as natural coagulants for the treatment of water and wastewater

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 justifies 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 (Daniyan *et al*, 2011 cited by Muhammad *et al*, 2015).

The findings of Al-Sameraiy (2012) in a paper titled " A Novel Water Pre-treatment Approach for Turbidity Removal Using Date Palm Seeds and Pollen Sheath" reveals that date palm seeds are environmentally-friendly, It achieved a significant reduction in turbidity to less of 5 NTU that meeting WHO drinking water guidelines for all tested synthetic turbid water, It produced excellent water quality having residual turbidity less of 0.1 NTU, decreased the settling time to 30 minutes and minimize risks of alum dose required to 60% and was therefore recommended as pre-treatment approach in advanced water treatment.

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.

Table 2.0: Characterisation of *Cyperus Esculentus*

S/No.	**Description**	*Cyperus Esculentus* **(Tiger Nut)**
1	Nature of Plant	Grass-like Tuber Plant
2	Botanical Name	*Cyperus Esculentus*
3	Chemical/Nutrient Composition	Moisture, Lipid, Fibre, Protein, Ash, Starch, reducing sugar and total sugar. Sodium, Calcium, Potassium Magnesium, Iron, Zinc and traces of Copper.
4	Plant Type	Annual/Perennial Plant

5	Parts used for Water Treatment in existing researches.	By-Product of Milk or oil extraction.
6	Availability in Nigeria	Mainly in the North but also thrives in a few Southern regions.
7	Specie	Black, Brown and Yellow. The yellow variety is preferred to all other varieties because of its inherent properties like its bigger size, attractive colour and fleshier body. The yellow variety also yields more milk, contains lower fat and higher protein and less anti-nutritional factors especially polyphenols.
8	Native Names	Aya *(in Hause Language)*, Ground Almond
9	Common Uses	Human Consumption and Livestock feed.
10	Suitable Vegetation Belt	Guinea and Sudan savannah.
11	Environmental Benefits	Controls soil erosion.
12	Family	*Cyperaceae*

5.0 MATERIALS AND METHODS

5.1 MATERIALS & INSTRUMENTATION

The material and equipment used for this research are as follows:

i. Aluminium Sulphate (Alum)
ii. Tiger Nut (*Cyperus Esculentus*) – Dried Brown Variety with Origin from Jibiya in Katina State, Nigeria.
iii. Laboratory Reagents as specified by the Standard Method for the Examination of Water and Wastewater by the American Public Health Association (APHA).
iv. Two (2) 150ml and Eighteen (18) 75ml plastic bottles for Water Samples
v. Grinding Machine
vi. Distilled Water
vii. Pestle and Mortar
viii. **Equipment:** Equipment used includes Flocculator/Standard Jar Test Equipment, Magnetic Stirrer, Calorimeter, Turbidity Meter, Dissolved Oxygen Metre, pH Meter, Digital Weighing Balance and Burner. Laboratory Equipment used includes Titration Apparatus, Beakers, Conical Flasks, Measuring Cylinder, Spatula.

5.2 METHODS

5.2.1. Raw Water Sample and Coagulants Sample Collection

The raw water sample to be subjected to treatment in this study was sourced from River Goroa, Minna-Bida Road, where local Gold mining occurs. All standard procedures for sample collection, storage, transportation and preservation stipulated by APHA was observed. Tiger nut (*Cyperus Esculentus*) were sourced carefully after engagement with relevant stakeholders and Renowned Suppliers/Traders in the line of business of Tiger Nuts from Jibiya, Katsina

State. Alum and *Cyperus Esculentus* Coagulant solutions were successively prepared using 10g/100ml of distilled water and added to the water samples at various doses for the conduct of Jar Test to determine the effect on flocculation and sedimentation as well as the optimum dose for the coagulants. The above process was repeated using a combination of Alum and each of the plant-based coagulants too in varying proportions. The raw water sample was also tested for physical, chemical and bacteriological characteristics 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 before the application of the artificial (Alum)/natural coagulants (*Cyperus Esculentus* Pulp) and at the optimum doses of the natural substrates and their respective water quality index computed to validate the results of the water quality tests or otherwise.

Plate i: Raw Water Samples

A. Alum Crystal	**B. Tiger Nut Plant**
	
C. Tiger Nut Tuber (Brown Variety)	**D. Tiger Nut Pulp (Grinded)**
	

Plate ii: Alum Crystal, Tiger Nut Plant, Tuber and Prepared Bio-Coagulant.

5.2.2. Preparation of Coagulant Solutions

A. Alum Coagulant Solution

Alum was sourced from the Lower Usuma Water Treatment Plant Store 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 by 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, grind 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.

Research Flow Chart

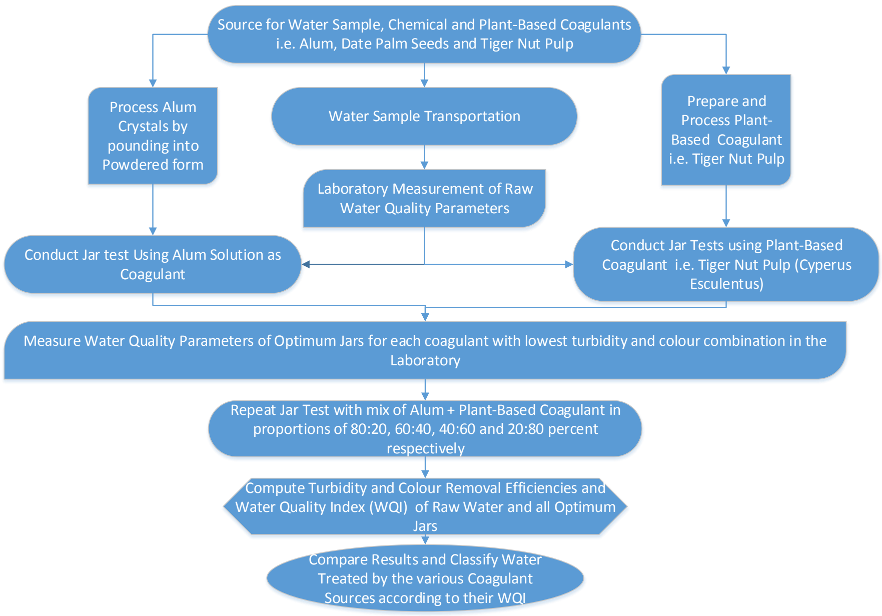

Figure 1.0: Research Flow Chart

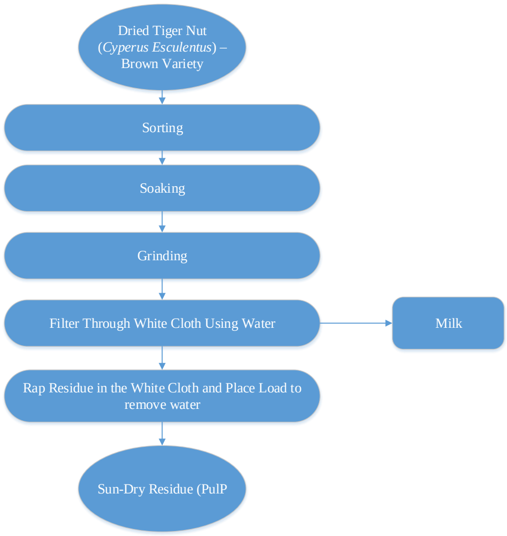

Figure 2.0: Flow Diagram for Preparation of *Cyperus Esculentus* Bio-Coagulant

5.2.3. Experimental Procedure – Water Quality and Jar Tests

Physico-Chemical and Bacteriological water quality parameters where determined in the laboratory on the raw water and coagulants treated water in line with the standard procedures for the examination of Water and waste water stipulated by the American Public Health Association (APHA) and American Water Works Association (AWWA). 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 Date Palm Seeds and 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.

Plate iii: Jar Test Equipment (Flocculator)

5.2.4. 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 it's physico-chemical and Bacteriological parameters in line with the APHA Examination of Water and Wastewater guidelines and compared with native or WHO water quality standards for conformity or otherwise. For the Purpose of this study, we shall use twenty-one (21) Physico-chemical water quality parameters were employed in the determination of Water Quality Indices. They are ***pH, 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.***

5.2.5 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.

5.2.6. 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 the various scientists and the calculation of WQI was made by using the following equation already explained in chapter 2.

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

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

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

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:

$$\mathrm{Wi} = \frac{K}{Si} \quad \ldots\ldots 3$$

Where,

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

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

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

6.0 RESULTS AND DISCUSSION

The results derived from the laboratory investigation of the raw water sample in relation to the World Health Organisation guidelines for drinking water quality and the use of Alum and *cyperus esculentus* consecutively and in varying proportions in coagulation are presented in this section. The results were further analysed to ascertain the efficiencies of turbidity and colour removal for the three coagulants for the purpose of comparison. Water Quality Indices were also computed to classify the water obtained after coagulation with the various coagulants to corroborate the results so obtained.

Table 3.0: Average Raw Water Quality Parameters

	A. Physical Parameters							
S/No.	Parameter	Chemical Notation	Unit	Concentration		Average Conc.	Maximum Limit (WHO)	Maximum Limit (NSDWQ)
				25th Feb., 2020	19th March, 2021			
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	Cfu/100mL	14	645	329.5	0	0

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

6.1. Coagulated Water Test Results - Alum

Two jar tests were conducted using Alum as coagulant in 2020 and 2021 respectively. The test carried out in 2020 was a trial test. 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 arising from the results of the jar tests are presented in tables 4.0, 5.0, 6.0 and 7.0 below.

Table 4.0: 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 5.0: 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 6.0: 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 7.0: 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**

6.2. Coagulated Water Test Results – 100% *Cyperus Esculentus*

Jar test was conducted using *cyperus esculentus* pulp solution as coagulant in place of alum. The results of Jar Tests carried out is presented in Appendix I. The computation of turbidity and colour removal efficiencies arising from the results of the jar test are presented in tables 9.0 and 10.0 below.

Table 8.0: Turbidity Removal Efficiency for 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)x100 = **83.53%**

Table 9.0: Colour Removal Efficiency for 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 = $C_e(\text{Cyperus Esculentus})/C_e(\text{Alum}) \times 100$

$$= (55.37/91.50)\text{x}100 = \mathbf{60.50\%}$$

6.3. Combination of Alum and Plant-Based Coagulants

6.3.1 Coagulated Water Test Results – Combination of Alum and *Cyperus Esculentus* in Varying Percentages.

Jar Test was conducted at the optimum *Cyperus Esculentus* coagulant dose of 50 mg/L and second best optimum dose of 40 mg/L for the purpose of comparison using a combination of alum and *Cyperus Esculentus* coagulants at proportions of Alum: *Cyperus Esculentus* 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. 80% alum and 20% *Cyperus Esculentus* coagulant was found to produce the optimum jar with turbidity of 6.40 NTU and colour of 71 Pt.Co at a temperature of 28.0^{o}C. Please refer to Appendix K for the Jar Test result.

6.4. 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 table 10.0 and 11.0 below.

Table 10.0: Summary of Turbidity, Colour Removal Efficiencies, Optimum Dose and Proportion of Coagulant Combination with Alum.

S/No	Coagulant	Turbidity Removal Efficiency	Colour Removal Efficiency	Te(Alum Average)/Te	Ce(Alum Average)/Ce	Optimum Proportion in Combination with Alum	Optimum Combined Coagulant Dose
		Te (%)	Ce (%)			Alum/Nature-Based Coagulant	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.

Table 11.0: 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

6.5. 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 and the summary of the computations is tabulated in table **13.0 and 14.0** below.

Table 12.0: 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
						ΣW_i =	**121.68**	**ΣQ_iW_i =**	**87,823.21**
							WQI = $\Sigma Q_iW_i/\Sigma W_i$	**721.77**	
								Grade E: Unsuitable for Drinking Purpose	

Table 13.0: 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

6.6 Discussion of Results:

Colour: The initial average water colour was 1383 Pt-Co. while the least colour out of the coagulants combination used stands at 71 Pt.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. 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., the processes of filtration and disinfection is expected to improve the colour in a conventional water treatment facility.

Turbidity: The initial raw water turbidity was 192 NTU while the least turbidity out of the coagulants used 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 5NTU. 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 guideline 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. However, using 100% *cyperus esculentus*, the floc appearance and settling time were mainly less than a minute.

6.7. Water Quality Index and Water Quality Classification

The computation of Water quality Index as summarised in table 14.0 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 well as in optimum combination with alum as a plant-based coagulant was therefore evidently validated by this result.

7.0 RECOMMENDATIONS

The recommendations arising from this research are as follows:

1. Further investigation be carried out on other potential plant-based coagulants especially those that produces a lot of environmental wastes with the aim to having many option of plant-based coagulants at the disposal of end users. This will also enhance access to clean water in rural areas thereby helping to attain the sustainable development goal on water and sanitation.

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

3. *Cyperus Esculentus* alone has the potential to remove turbidity and improve overall water quality and it's use is recommended.

8.0 CONCLUSION

The conclusion arising from this research are drawn in the order of the objectives of the research as earlier stated.

In the first instance, the results of the physical parameters prior to and after the conduct of jar tests and the resultant analysis of *cyperus esculentus* pulp shows that it has the potentials to serve as bio-coagulant.

Secondly, the Water Quality Index was computed for the raw water, alum and *cyperus esculentus* pulp as well as combination of alum and *cyperus esculentus* coagulant at effective dose. The result obtained classified the water in each case as indicated on table 13.0. The raw water was classified as grade E (Unsuitable for drinking purpose) and grade D (Very Poor Water Quality) with WQI of 721.77. Similarly, 100% *cyperus esculentus* and 80% Alum + 20% *cyperus esculentus* were classified as Grade B (Good Water Quality) with WQI of 44.54 and 39.61 respectively.

Thirdly, 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 optimum dose of 50mg/L suffices for 80% Alum and 20% *cyperus esculentus* 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%.

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