JOURNAL OF METEOROLOGY AND CLIMATE SCIENCE
J. Met & Clim. Sci. 22(1): 149-173 (June, 2023)

Turbid water treatment with Kenaf (*Hibiscus cannabinus*) Fibers and Moringa seeds (*Moringa oleifera*): An Application of Nature-Based Solutions

Grace O. OLUWASANYA[1&2], Enovwo E. ODJEGBA[2&4], Adebayo Y. SADIQ[2&3], Abayomi O. BANKOLE[2&4*] and Olufiropo S. AWOKOLA[2]

[1]United Nations University, Institute of Water, Environment and Health, Hamilton, Ontario, Canada
[2]Federal University of Agriculture, Abeokuta (FUNAAB), P.M.B 2240, Ogun State, Southwest Nigeria
[3]Kent State University, Kent, Ohio, USA
[4]Universidade Estadual Paulista (UNESP), Sao Paulo, Brazil
[*]Corresponding author: Bankole: bankoleabayomi3@gmail.com;
Oluwasanya: grace.oluwasanya@gmail.com

Abstract

Applying Nature-based Solutions (NBS) in water treatment is increasingly gaining popularity globally as attest by many studies all over the world. This study explored household usable nature-based water treatment techniques from locally available plants of Kenaf Fibers and moringa seeds in the treatment of turbid surface water in Abeokuta, Nigeria. (How did you get the kenaf and moringa? Please state it). The kenaf Fibers were pre-treated with a hypochlorite solution and sun-dried, and the moringa seeds were pulverized. Four treatment options were investigated: raw (turbid) water with the moringa seed powder alone, secondly with kenaf fibers alone and thirdly with kenaf-moringa combination, and the moringa-kenaf combination. Water samples were collected at the end of each 'treatment' option and tested for selected water quality parameters. The biosorption efficiency was established through a comparative assessment of the pre-and post-treatment concentrations of the selected parameters. Expectedly, the treatment options had different effects on the water quality parameters. However, Kenaf-moringa and moringa-kenaf both had the most prominent effect. Moringa-kenaf combination recorded best turbidity (2.73 NTU) and iron (6.16 mg/L) removal, respectively. Kenaf-moringa also recorded the best removal for zinc (0.02 mg/L), bicarbonate (122.00 mg/L), magnesium (22.00 mg/L), and water hardness.

This justifies the potential for the combination than the use of the individual plant as a household usable NBS water treatment approach.

Keywords: Nature-based solutions, kenaf Fibers, moringa seeds, water quality, water treatment technology

INTRODUCTION

Applying Nature-based Solutions (NBS) in water treatment has gained increased popularity globally. The term NBS was mentioned by the World Bank for the first time in 2008 (Bauduceau et al., 2015; Ramírez-Agudelo et al., 2020). Though regarded as a European ideology (Escobedo et al. 2019; Hanson et al. 2020). This NBS cuts across green technologies such as ecosystem conservation, sustainable development, and mitigation and adaptation approach (Kooy et al. 2020; Ramírez-Agudelo et al. 2020; de Lima et al. 2022). The first definition of NBS is credited to the European Union and stated as cost-effective solutions inspired and supported by nature providing environmental, social, and economic benefits to help build resilience (Oral et al., 2021; de Lima et al., 2022). Nature Base Solution exists in varying degrees from simple to complex technological interventions centered on improving human well-being. It is therefore safe to assert that any form of environmental intervention that includes the utilization of natural/environmental products to improve water quality is regarded as a nature-based solution.

In water treatment, the diversity and complexities associated with point and non-point source pollutants necessitated the need to turn to nature for answers. Using plants and some agricultural by-products in water treatment may be as old as civilization but advancements in technology led to the development and adoption of conventional water treatment methods. Today, all roads lead back to nature for solutions. Also, the conventional municipal water treatment process is not affordable at household level, thus subjecting water to various forms of traditional water treatment methods including plants (Alfred and Sangodoyin 2013; Mahdavi et al. 2017; Ridzuan et al. 2018; Alam et al. 2020; Gula et al., 2022). The efficacy of plants in water treatment is proven (Abe et al., 1997; Ngah and Hanafiah 2008; Alfred and Sangodoyin 2013; Jopony et al. 2013; Mahdavi et al. 2017; Yuliastri et al. 2016; Tunggolou and Payus 2017; Ridzuan et al. 2018; Alam et al. 2020; Adeeyo et al. 2021; Gula et al. 2022). Commonly used plants include moringa (*Moringa oleifera)*, kenaf (*Hibiscus cannabinus*), jatropha (*Jatropha curcas L.*), and agricultural by-products such as rice husks, sugarcane bagasse, coconut husk, pistachio nut and groundnut husk (Abe et al., 1997; Namasivayam & Sureshkumar, 2008; Ngah & Hanafiah, 2008; Ridzuan et al., 2018; Papadaki et al., 2021).

Kenaf (Figure 1) is a fast-growing (can be as tall as 3 – 5 meters within 6 months) crop that belongs to the Malvaceae family, and it adapts to a wide variety of climatic and soil conditions. It is consumed by humans and animals for food and parts of the stem are used as fuel and for fiber production. Kenaf is famous as an industrial crop and originated in Africa (Lee et al., 2021; Harussani & Sapuan, 2022) and is now cultivated across Asia (Alexopoulou et al., 2013; Arumingtyas, 2015; Kim et al., 2021) and other parts of the world. Kenaf plant seeds have been used for coagulation (Jones & Bridgeman, 2019; Okoro et al., 2021) and the fibers in the removal of water hardness (Gharehchahi et al., 2014) and heavy metals (Jopony et al., 2013a; Shamsudin et al., 2016; Saeed et al., 2021; Tan Peng Jun et al., 2021). It is, however, observed that studies on kenaf for comprehensive drinking water treatment are limited. Major studies on kenaf are on the efficiency of the fibers in pulp making as a substitute for wood pulp and for textiles (Ashori, 2006; Kakoty et al., 2019; Umair et al., 2020; Zainal et al., 2021). Moringa (Figure 2) is equally a fast-growing tree crop from the Moringaceae family and native to Asia (Paikra et al., 2017) but is now globally cultivated. There are 13 species of the moringa plant of which *Moringa oleifera* is the most common (Anzano et al., 2021). Moringa is famously used as food and medicine due to its rich nutritional content that has earned the plant a unique name - the miracle tree.

This study focus on the biosorption efficiency of selected plants to develop a cost-effective and sustainable household water treatment method from locally sourced and easily accessible agricultural by-products. Kenaf fiber and moringa seeds are both selected due to their availability, ease of cultivation and rapid growth (Jopony et al., 2013a; Gharehchahi et al., 2014; Jones & Bridgeman, 2019) in Nigeria, and the tropics. This study seeks to provide a simplified, affordable, and effective nature-based household drinking water treatment technique, that can be applied by all - the vulnerable groups (women, girls, children, the sick and the elderly) in particular.

Figure 1: Kenaf plant, fibre, and seeds (Source: Authors)

Figure 2: Leaves, fruits, and seeds of moringa plant
(Source: https://www.agrifarming.in/moringa-seed-germination-procedure-spacing-yield)

METHODS

The raw water samples used in the study were obtained in June – July 2019 from the three main surface water sources (Osaara stream, Sokori and Ogun Rivers) that traverse Abeokuta metropolis, Ogun State, Nigeria. The kenaf fibers were obtained from the Institute of Agricultural Research and Training, Ibadan, Nigeria, pre-treated with a solution of sodium hypochlorite (household bleach) and water, mixed in the ratio 1 part bleach to 20 parts water to sanitize the fibers and remove dirt/discolouration. The fibers were then sun dried and stored in a clean container before use.

The moringa seeds were pulverized with the aid of a grinding machine. Known weight of moringa powder (10, 20, 30, 40 and 50 grams) were dosed into a fixed volume (1 litre) of raw water to pre-test the amount of moringa needed. The mixture was stirred rapidly for 2 mins and then slowly for 15mins (Sotheeswaran et al., 2011). The weight with the best coagulation efficiency was then selected and used to prepare a stock solution. The kenaf fiber was pre-tested with samples from the raw water using known weight of 40, 50 and 60 grams respectively, the weight with the highest treatment efficiency (60 g) was selected.

The experimental set-up (Figure 3) contained four (4) levels of treatments – raw (turbid) water with moringa seed powder only (Treatment 1), kenaf Fibers only (Treatment 2), Kenaf before moringa combination (Treatment 3), and Moringa before kenaf combination (Treatment 4).

Water quality analysis was carried out in five (5) stages: Raw water pre-treatment phase (Stage 1), Moringa only treatment phase (Stage 2), kenaf fibers treatment only phase (Stage 3), Kenaf-moringa treatment combination (Stage 4) and moringa-kenaf treatment combination phase (Stage 5). The kenaf-moringa combination implied that the raw water was first treated with kenaf and then moringa, and vice-versa for moringa-kenaf. The water samples were tested for pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, magnesium, calcium, nitrate-NO_3, chloride, and biological (Total Bacterial Count (TBC), *Staphylococcus spp.* and *Enterobacter spp.*) parameters. The physico-chemical parameters (pH, EC, TDS) were tested in-situ with a combo pH meter (pH 200 multi-meter), other parameters were analyzed in triplicate following the established standard procedure, by APHA (2017).

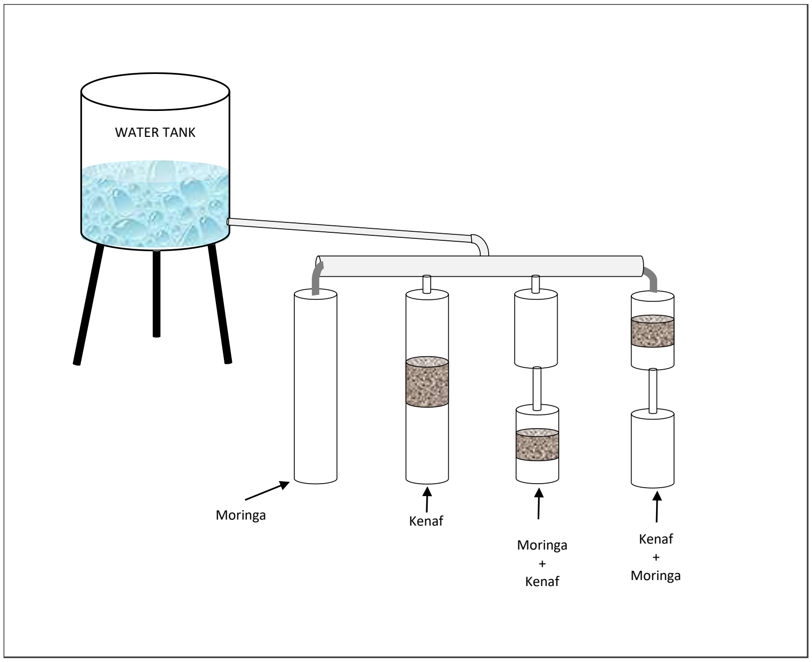


Figure 3: Turbid water treatment with Kenaf (Hibiscus cannabinus) Fibers and Moringa seeds (Moringa oleifera: Experimental Layout.

Pre-treatment and post-treatment water quality results were compared to determine the level of reduction in the concentrations of the water quality parameters tested. The difference between the pre-treatment and post-treatment concentration values were used in the determination of the biosorption or removal efficiency of the different treatment phases. The removal efficiency of the treatments was estimated by dividing the difference between pre-treatment concentration of parameters (A) and post-treatment concentration of the analysed parameters (B) and then dividing it by the pre-treatment concentration of parameters (A) the result is later multiplying the result by 100 to obtain the removal efficiency in percentages (Equation 1).

$$Removal\ efficiency = \frac{A - B}{A} \times 100 \qquad \text{...................Equation 1}$$

The post-treatment concentrations of the assessed water quality parameters were checked against the individual water quality parameter thresholds from World Health Organization (WHO) Guidelines for

Drinking Water Quality, WHO (2017). The entire research framework is presented in Figure 4.

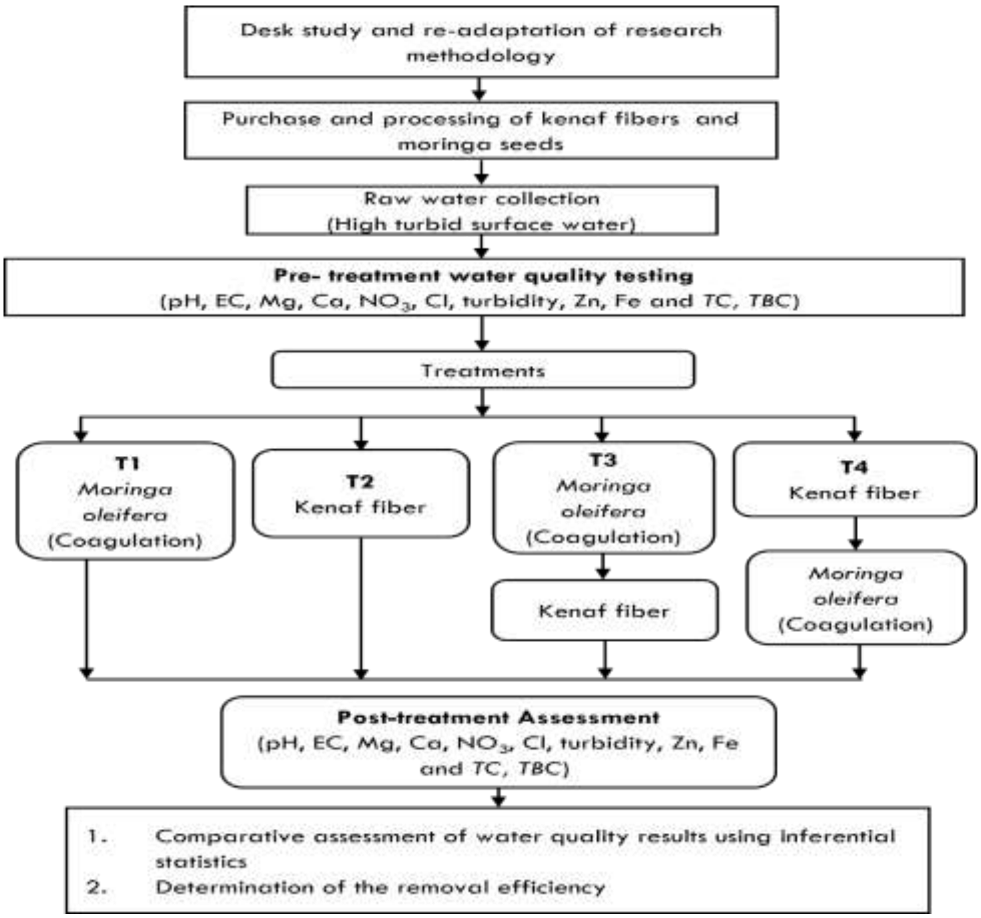


Figure 4: Turbid water treatment with Kenaf (*Hibiscus cannabinus*) Fibers and Moringa (*Moringa oleifera*) seeds: The Research Framework.

RESULTS AND DISCUSSION

The summary of the results from the water quality analysis is presented in Table 1.The four treatments had varying effects on pH, turbidity, hardness, magnesium, bicarbonate, iron, zinc, and microbial parameters (*Staphylococcus spp.* and *Enterobacter spp*). Significant reductions of the pre-treatment concentrations are observed relative to the post-treatment concentrations. The percentage removal efficiencies for the parameters with significant reductions in concentrations is presented in Figure 5. Kenaf-moringa combinations had the best performance on pH, with a removal efficiency of 6% and reducing pH concentrations from alkaline to nearly neutral (Figure 5). Although 6% reduction may appear small, the pH of the raw water sample this is because the pH of the water sample is within the neutral range (close to 7.0), hence the small percentage reduction.

Moringa is reported by (Basra et al., 2014; Narayasamy & Saud, 2014) to be the major factor for the change in pH by previous studies. Alfred and Sangodoyin (2013) also reported that kenaf had no influence on pH in a study involving water purification with kenaf. If the assertions of these authors are to be followed, the disparity in the pH of moringa only treatment (7.20) and kenaf-moringa combination (6.96) says otherwise.

Table 1: Summary of water quality results from the turbid water treatment with Kenaf (Hibiscus cannabinus) Fibers and Moringa seeds (Moringa oleifera) in Abeokuta, Nigeria

Parameters	Raw water	Moringa	Kenaf	Moringa + Kenaf	Kenaf + Moringa	Thresholds (WHO, 2017)
pH	7.40	7.20	7.38	7.09	6.96	6.5 – 8.5
EC (µS/cm)	290.00	299.00	289.00	297.00	300.00	1000 µS/cm
TDS (mg/L)	145.00	149.00	144.00	148.00	150.00	500 mg/L
Turbidity	14.20	6.30	3.80	2.73	6.80	5 NTU
Hardness (mg/L)	103.00	92.80	87.80	89.00	83.00	-
Ca (mg/L)	63.00	57.00	59.80	60.67	61.00	-
Mg (mg/L)	40.00	35.80	28.00	28.33	22.00	-
HCO_3^- (mg/L)	187.88	146.40	152.74	134.20	122.00	200 mg/L
Fe (mg/L)	8.84	8.58	7.89	6.16	8.59	0.30 mg/L
Zn (mg/L)	0.05	0.03	0.03	0.03	0.02	1.5 mg/L

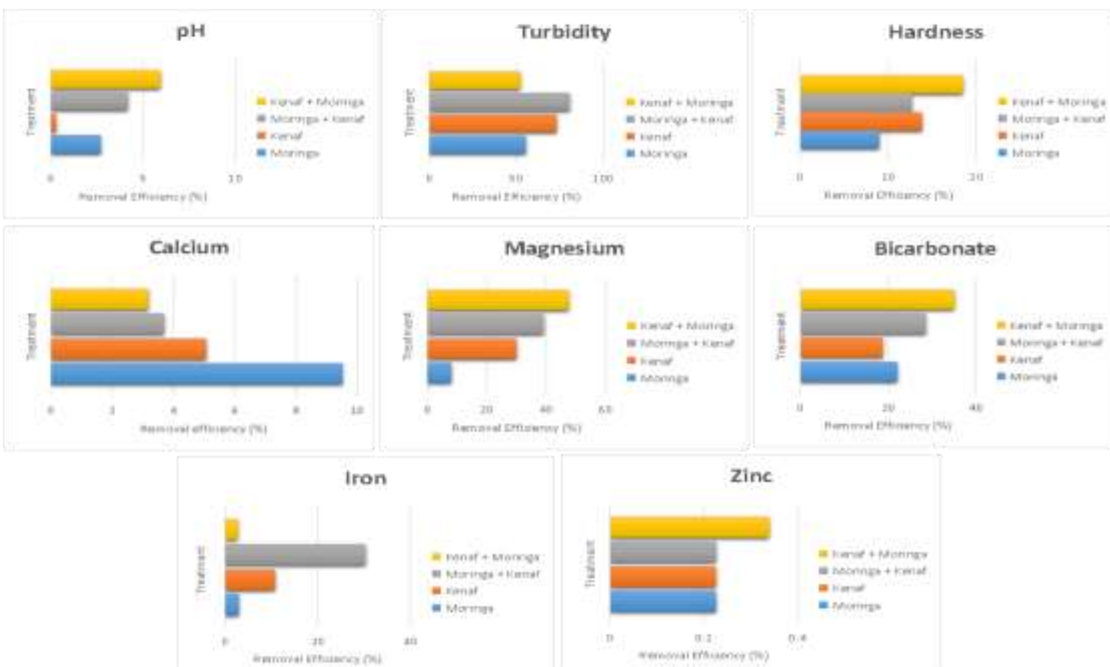


Figure 5: Removal efficiencies (%) of four water treatment options on selected water quality parameters from turbid water treated with Kenaf (Hibiscus cannabinus) Fibers and Moringa seeds (Moringa oleifera) in Abeokuta, Nigeria.

However, a difference of ±2 may be considered negligible and then the conclusions of Basra et al. (2014) and Narayasamy and Saud (2014) may be upheld. Basra et al. (2014), Vieira et al. (2010) and Ueda Yamaguchi et al. (2021) alluded to some soluble protein in moringa seeds that helps in coagulation. The amino acids in moringa seeds protein according to Ndabigengesere et al. (1995) and Basra et al. (2014) helps with pH changes from acidic to alkaline level. Importantly, a pH value of 6.96 is generally within the acceptable limits 6.5 – 8.5 (WHO, 2017).

Moringa-kenaf combinations had the highest impact on turbidity (Figure 5). It is believed that the strong coagulant properties of moringa could be responsible. However, the efficiency of kenaf fibers in the removal of turbidity has also been reported by Mahdavi et al. (2017). The performance of kenaf only treatment in this study further supports the report of Mahdavi et al. (2017). The efficiency of moringa-kenaf combinations over kenaf-moringa combination may be due to coagulation prior to treatment with kenaf fiber in moringa-kenaf combinations. Although, protein (and by extension amino acids) in kenaf fibers has been established in literature (Kim et al., 2021), But 2.73 NTU (Moringa-kenaf) and 3.8 NTU (Kenaf only) both conform to acceptable limit of 5 NTU (WHO, 2017) for turbidity.

Kenaf-moringa combination is the most effective in water hardness removal (Figure 5). Water hardness removal by kenaf fiber was reported by Gharehchahi *et al.* (2014), while the efficiency of moringa in same was reported by both Fahmi et al. (2011) and Muniz et al. (2020). Gharehchahi et al. (2014) utilized kenaf Fibers in testing the reduction of water hardness by varying the fiber length and the time of contact with water being treated. Key findings indicate better performance with increased contact time and fiber length. Fahmi et al. (2011) in accessing the effectiveness of moringa in the removal of hardness observed that the removal efficiency increased with increased dosage of moringa. Muniz et al. (2020) also reported the effectiveness of moringa; describing the method as low-cost and eco-friendly. Though the combined effectiveness of kenaf fibers and moringa seed powder in water hardness removal is clear in this study, however, further study is needed to identify the active ingredients in kenaf fiber responsible for the fiber's effectiveness in water hardness removal. WHO (2010) classifies water regarding hardness as soft (60 – 120 mg/L), hard (120 – 180 mg/L) and hard (> 180 mg/L), and WHO (2017) stated there is no health-based guideline for water hardness. The water used in the study can therefore be classified as soft. Hardness in water is caused by calcium and magnesium, hence elevated hardness levels may become additional source of dietary intake of these elements for humans (Galan et al., 2002; Sengupta, 2013).

Kenaf-moringa was also the most effective treatment for magnesium (Figure 5). This can be related to a previous study on kenaf and hardness removal (Gharehchahi et al., 2014) since magnesium causes water hardness. Moringa has also been used in the removal of hardness and by extension magnesium in different studies (Muyibi and Evison 1996; Muyibi and Okuofu 1996; Hettiarachchi et al. 2017). Limited studies on the components of kenaf fibers can be responsible for treatment of magnesium. Since kenaf and moringa separately reduces hardness (magnesium inclusive), this may explain the effectiveness of kenaf-moringa combination, closely followed by moringa-kenaf combination. Although, water is an important pathway of absorption of magnesium into the human body (Hettiarachchi et al., 2017), excess magnesium can result in diarrhea due to its laxative effects (Sengupta, 2013).

Moringa alone recorded the best performance (Figure 5) for calcium. Although calcium is a component of hardness, it is expected to follow similar trend with hardness and magnesium – in which kenaf-moringa combination has the highest level of impact. It is not clear what may be responsible. But the effectiveness of moringa in removing calcium in water is well reported (Muyibi and Okuofu 1996; Kumar and Trivedi 2017; Muniz et al. 2020; Semanka et al. 2022). Calcium is needed in the human body in small amount particularly for bone development but can become toxic when in excess. Calcium when ingested in toxic levels over a long term is linked to diseases that can become fatal, particularly cardiovascular diseases (Rosborg 2014; Rapant et al. 2017; Stevanovic et al. 2017).

Moringa-kenaf and kenaf-moringa are the most effective treatment combinations for iron and zinc respectively. Noori Ali (2021) in accessing the potential of moringa in the removal of heavy metals from water and wastewater reported 100% removal of iron. Likewise, Lee and Rowell (2004) while investigating the removal of heavy metal ions using aqueous solutions from lignocellulosic Fibers established the efficiency of kenaf fibers in the removal of zinc ion. Lignocellulosic materials refer to plants and plants derived biomass.

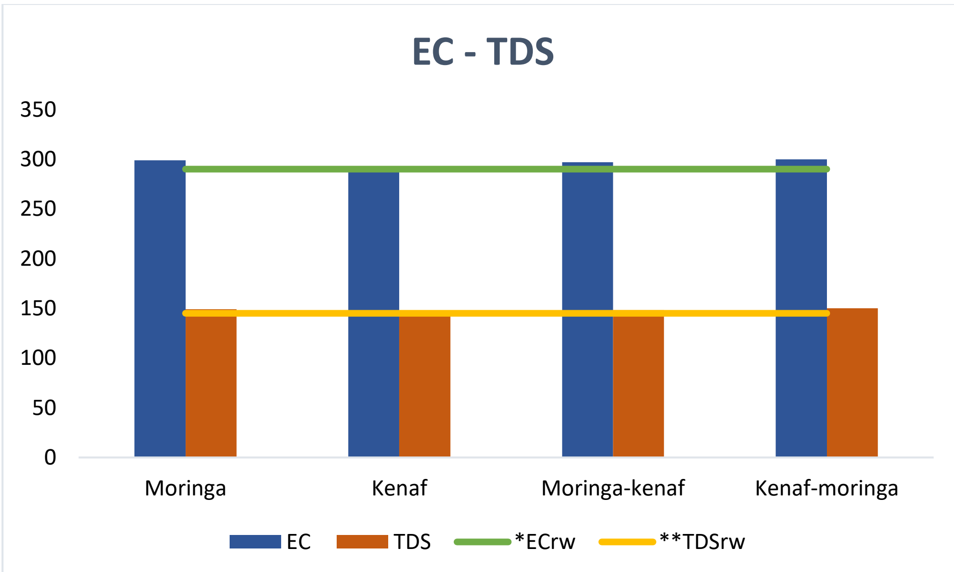
Laszlo and Dintzis (1994) attributes the efficiency of lignocellulosic materials in removing heavy metals to the capacity for ion-exchange and sorption characteristics due to their polymer and structure. Vaughan et al. (2001) and Lee and Rowell (2004) emphasized that tannin and lignin (polyphenolic compounds) properties of lignocellulosic materials are perceived to be the sites for attachment of heavy metals. Moringa and kenaf contain polyphenolic compounds hence their effectiveness in removing heavy metals. Therefore, using moringa/kenaf combination may lead to increased heavy metal removal particularly where the pollutant load in water (for instance in municipal/industrial wastewater) is high.

Drinking water rarely contains zinc concentrations in levels higher than 0.1 mg/L (WHO, 2017). Sankhla et al. (2019) attributed zinc contamination to anthropogenic sources like municipal wastewater. Zinc toxicity could result in gastrointestinal, cardiovascular, carcinogenic, and neurological issues (Blanc, 1991; Sankhla et al., 2019).

All four treatments had little effect on the concentrations of electrical conductivity and total dissolved solids (Figure 6). It is expected that for raw water pH of 7.40, electrical conductivity and total dissolved solids would be low (Islam et al., 2017). For instance, it is reported that moringa is mostly effective when the pH values of the water to be treated is below 6 or greater than 11 (Sasikala & Muthuraman, 2016; Tunggolou & Payus, 2017). Studies on kenaf in electrical conductivity and total dissolved solids assessment is limited.

Moringa-kenaf combination has 100% removal efficiency for *Staphylococcus spp.* and *Enterobacter spp*. The values of *Staphylococcus spp.* and *Enterobacter spp*. detected in the raw water sample were 0.4 x 10^5 cfu/g and 0.2 x 10^5 cfu/g respectively. The moringa-kenaf combinations yielded a better result relative to the kenaf-moringa treatment. Studies have reported varying percentage reduction in microbial parameters in water after treatment with moringa. Abatneh et al. (2014) and Sané et al. (2022) reported up to 67%, and 98% reduction respectively in microbial parameters in their studies. Ninety-nine percent removal was also recorded by Costa et al. (2013).

Similarly, some studies reported the positive impact of kenaf on microbial parameters (Hurley et al., 2018; Jones & Bridgeman, 2019). Moringa is probably the major active ingredient in the moringa-kenaf combination responsible for the microbial removal. Though, if the assertion that moringa alone is the active ingredient, moringa only treatment and kenaf-moringa combination should have had equal effect on the microbial parameters. Kenaf may indeed be contributing to microbial removal, but further research is advised.



*ECrw = Electrical Conductivity for Raw water
**TDSrw = Total Dissolved Solids for Raw water

Figure 6: Graph of Electrical Conductivity and Total Dissolved Solids from the turbid water treatment with Kenaf (Hibiscus cannabinus) Fibers and Moringa seeds (Moringa oleifera) in Abeokuta, Nigeria

Is Nature-based Solutions for water treatment an effective substitute for conventional treatment processes?

There are still several questions surrounding the use of NBS in water treatment, particularly on a large scale. Major challenges include calibration, diversity of pollutants, continued emergence of complex pollutants and sustainability, among others. Awad et al. (2013) in a study to assess the weakness of moringa in water treatment, reported that sedimentation process was slow and large quantities of moringa would be required for water treatment especially on a large scale. Ghebremichael (2004) highlighted the release of organic matter and nutrients into water as one of the challenges facing the use of moringa in large scale water treatment. Ghebremichael (2004) added that organic matter in water influences processes such as oxidation and adsorption, increases disinfectant consumption, and can result in bacterial re-growth. Ghebremichael (2007) proposed the use of simple ion exchange approach to purify moringa seeds thereby preventing the release of organic matter into the treated water.

Should the idea of nature-based water treatment on a large scale be shelved? We argue, certainly not! There is the current drive for decentralization of municipal water supply and wastewater systems, hence, the use of these plants at a much smaller scale can be attempted. The availability of these plant for use with regards to quantity may be a major concern (Pal et al., 2021; Alazaiza et al., 2022). In addition, considering the diversity of pollutants, it is difficult to have a nature-based solution that would be comprehensive enough to address the increasingly diverse contaminants. Therefore, a combination of NBS solutions (as used in this study) could be the way to go. Nonetheless, there are questions that would require answers, such as, how many combinations would be sufficient, in what quantity and for how long. Alazaiza et al. (2022) reviewed the application of nature-based solutions in the removal of diverse pharmaceuticals in water and the studies were contaminant specific, with the contaminants requiring particular conditions to be attained to ensure effective removal. This could mean that a form of ‘conflict’ may be encountered in a treatment process where several contaminants are present in water; ‘narrowing’ the quality of water that may be treated using nature-based techniques.

However, this could pave a way for the development of a 'synthetic material' that would mimic the removal efficiencies of several nature-based materials combined. Arguably, the idea of 'synthetic material' may suggest that the intent of nature-based solutions in this context is defeated; this is not meant to discredit the efficiency of NBS in water treatment (Alfred and Sangodoyin 2013; Mahdavi et al. 2017; Ridzuan et al. 2018; Alam et al. 2020; Gula et al., 2022). But a positive outlook is rather to keep learning from nature to achieve sustainable water treatment techniques.

Still, the efficiency and cost effectiveness of NBS, particularly at small scale levels (household) cannot be ruled out; this has been the major goal of this study. To achieve Goal 6, target 6.1 of the Sustainable Development Agenda, access to safe, affordable, and adequate drinking water, at household level, is vital. In low- and middle-income countries where access to drinking water supply is limited, it is believed that NBS, when appropriately practiced would improve water quality, thereby increasing access to safe water and promotes public health protection. Understandably, several NBS methods have been practiced, the combination method proposed in this study could solve improving water quality. Noteworthy is that the method is devoid of complex processes and additives such that it can be replicated. Also, the method is simple enough and can be practiced by many, especially women and girls, since they are often saddled with the responsibility of providing drinking water for the household.

CONCLUSION

The study shows the effectiveness of the combination of 'kenaf Fibers and moringa seed powder' in high turbid water treatment. Kenaf fibers and moringa seed powders performed better in combination when used interchangeably and their efficiency is specific to the different parameters. The kenaf Fibers used were obtained from several varieties, which were already combined and stored, so it is not clear if the result of the study would be different if the varieties of the kenaf plant was identified. Hence, further studies on the efficiency of different kenaf species may be an added value. With further research, moringa-kenaf combination could provide alternative and affordable water treatment technologies at household and community levels. Potential use of kenaf fiber (an agro-by-product) in water treatment processes resonates as a nature-based solution and should help minimize solid waste pollution, and improve the environment, aside public health protection.

FUNDING

Special thanks to the National Water Resources Institute (NWRI), Kaduna, Nigeria and FUNAAB/NWRI Southwest Regional Centre for National Water Resources Capacity Building Network (NWRCBNET) for funding this project.

ACKNOWLEDGEMENT

The authors acknowledge the contributions of Ms. Temitope Aroyeun of the Department of Environmental Management Toxicology, Federal University of Agriculture, Abeokuta, Nigeria.

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