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African Journal of Environmental Science and Technology

Full Length Research Paper

The effectiveness of *Moringa Oleifera* seed coagulant in reducing the turbidity and modifying the physico-chemical characteristics of water

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***Moringa oleifera* plant is unique due to its coagulation effect on turbid water. However, the extent to which the seed's powder coagulant changes the physico-chemical characteristics of treated water has not been discussed in previous studies. In addition, there are limited data and information on the optimum concentration of *M. oleifera* seed powder coagulant and the nature of the sludge that forms after the treatment of water. The aim of this study is to examine the extent to which *M. oleifera* seed powder can be used as a coagulant in treating different types of turbid waters and how it changes the physico-chemical characteristics of treated water. Samples of turbid water were subjected to various dosages of dry *M. oleifera* seed powder concentrations to determine the degree of clarification, changes in physico-chemical characteristics of water and the proportion of sludge formed after coagulation process. The results showed that *M. oleifera* seed powder leads to reduction of water turbidity from 461 NTU to about 15 NTU within 45 min. Significant clarification of turbid water occurred at the mean optimum concentration of *M. oleifera* seed powder coagulant (0.20 g/l) and maximum optimum concentration of 0.50 g/l. The mean water turbidity reduction efficiency was 64% with the maximum efficiency of 95%. Increasing coagulant concentration above 0.50 g/l led to an increase in water turbidity, electrical conductivity, salinity and total dissolved solids (TDS). The sludge formed after water treatment was found to be equivalent to 10% of the total volume of treated water. There are also significant differences in the effectiveness of coagulant derived from various provenances of *M. oleifera* found in Eastern and Coastal regions of Kenya in terms of turbidity reduction.**

Key words: Moringa oleifera, turbidity, water treatment, coagulation, physico-chemical parameters.

INTRODUCTION

In most of the developing countries, water turbidity is one of the major factors of physical contamination indicators that limit the direct use of river water for drinking and for various household purposes such as washing and

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cleaning. In view of its limitation to uses of water, the measurement of turbidity is considered to be an important key test of water quality (APHA/AWWA/WEF, 2012; ISO 2016). Turbidity is usually caused by large quantity of suspended solid matter consisting of particles of many different sizes. Large suspended materials are normally heavy and therefore settle rapidly at the bottom of containers. However, suspended solids consisting of very small colloidal particles usually settle very slowly. These small solid colloidal particles are the principal causes of turbidity in most waters found in rural areas of Kenya and Africa at large.

Turbidity in water can have both water safety and aesthetic implications for drinking-water supplies (WHO, 2007). Although turbidity does not represent a direct risk to public health, it can be an indicator of the presence of pathogenic microorganisms (WHO, 2007). Highly turbid waters can have microbial pathogens attached to the particles. Previous studies have shown that high turbidity of drinking water is also associated with a higher risk of people developing gastro-intestinal diseases (Crump et al., 2005; Mann et al., 2007; Tinker et al., 2010). This is especially important for poor rural households with depressed immunity, because pathogenic organisms such as viruses or bacteria can attach themselves to the suspended solids and be ingested by humans when water is drunk without being subjected to any form of treatment. This can lead to various intestinal diseases that can significantly affect the health and productivity of people living in rural areas of Africa. Disinfection of water using chlorine is also not effective without removal of suspended solids because suspended solid particles shield viruses and bacteria. Suspended solids also protect bacteria from ultraviolet (UV) sterilization of water reducing the effectiveness of UV sterilization (Crump et al., 2005; Mann et al, 2007; WHO, 2007; Tinker et al., 2010).

Provision of clean turbidity free potable water is considered critical for the enhancement of societal development in arid and semi-arid lands (ASALs) of Africa. Most of the water found in lakes, reservoirs and rivers in arid and semi-arid lands of Africa is usually characterized by high turbidity which is occasioned by high input of sediments in water during rainy season (Kitheka, 2013, 2014, 2019; Njogu et al., 2018). Most people in remote rural areas of Eastern Kenya use this turbid water especially during rainy seasons when most water sources exhibit high turbidity. It is also important to note that most of the communities living in arid and semi-arid lands are poor with very low income levels and cannot afford expensive water treatment solutions. For instance, in Kitui County in Eastern Kenya, 60% of the population lives below the poverty line (Kitui County CIDP, 2019-2022). In this respect, treatment of water is not considered a priority by the people, including the County Government. The meager income earned by local communities is normally channeled to the purchase of food stuffs and other essential goods, including education of children. As a result, most of the people in rural areas consume raw untreated water increasing risk of contracting various diseases. Consumption of untreated water is one of the many factors contributing to low life expectancy among most of the communities living in arid and semi-arid lands of Kenya and Africa at large. The government cannot allocate resources for treatment of water abstracted from various sources in expansive arid and semi-arid lands of Kenya and Africa. This is occasioned partly by the scattered nature of the population settlements and impracticality of providing treated water to all people due to scarcity of resources. The provision of clean piped treated water has therefore been focused on urban areas at the expense of rural areas in arid and semi-arid lands.

The search for cheap and better water treatment technologies for rural areas of Africa can contribute in the achievement of the Sustainable Development Goals 3 and 6 related to provision of water and sanitation to poor communities (UN, 2015). These goals can be achieved by investing in alternative and cheap methods of treating raw water in rural areas for example through the use of *Moringa oleifera* seed powder as a coagulant (Muyibi, and Evanson, 1995; Kasolo et al., 2010). The traditional methods of water treatment which are still widely used in most developing countries include the use of aluminium sulphate (Alum) and chlorine (LeChevallier et al., 1981; Elliott et al., 2008; Kotlarz et al., 2009; Preston et al., 2010; WHO/UNICEF, 2012). The use of these chemicals in rural areas is still low in most developing countries partly due to their high costs that make conventional water treatment technologies impractical in remote and widely scattered rural villages of Africa. These chemicals are also out of reach of most poor communities living in arid and semi-arid lands of Africa. Furthermore, there is little awareness on the appropriate use of this potentially toxic chemical for water treatment (Tunggolou and Payus, 2017). Other water treatment technologies that have been applied in developing countries include the use of slow sand filters. However, the use of slow sand filters for treatment of turbid raw water in rural areas has been with limited success due to limited knowledge dissemination and impracticality of this technology (Elliott et al., 2008). Therefore, there is a need to explore other cheaper options for treatment of water in rural areas of Kenya and Africa. *M. oleifera* seed coagulant which is derived from natural plant sources is considered to be a viable option. It is non-toxic to both human and livestock uses and can easily be made available to communities in arid and semi-arid lands since it can be introduced as a domestic agroforestry tree in rural areas (Nautiyal and Venkataraman, 1987; Morton, 1991; Sotheeswaran, et al., 2011). The plant is also advantageous because it has many other beneficial uses due to its high nutritional value which is essentially for maintaining health.

This study is therefore important as it aims at determining the extent to which *M. oleifera* seed coagulants can be used in treating water in marginalized rural areas. This study is also important in view of the need to develop cheap and locally available water coagulants for use by marginalized rural communities in Africa. *M. oleifera* seeds coagulant can enable these communities access clean and potable water and thereby safeguard their health and sanitation (Mayer and Stelz, 1993; Fahey, 2005; Bongoni, 2019). This can lead to a reduction in the occurrence of water borne diseases and improvement of productivity of communities in marginalized arid and semi-arid regions (Amagloh, 2009; Bongoni, 2019). The study is also important as it addresses one of key United Nations Sustainable Development Goal related to water and sanitation (UN, 2015). The study also makes contribution in raising awareness on the potential application of *M. oleifera* coagulant in the treatment of turbid water in arid and semi arid lands of Kenya and Africa.

In the present study, experiments were conducted to establish the extent to which *M. oleifera* seed powder coagulants can be used to treat different types of waters found in the Arid and semi –arid region of Eastern Kenya. Waters of different chemical composition were tested to establish the extent to which *M. oleifera* seed powder can cause clarification of the turbid water. The extent of clarification of raw water was on the basis of changes in turbidity and total suspended sediment concentrations (TSSC) at various concentration of *M.oleifera* seed coagulant. Of interest was determination of changes in the concentration of various physico–chemical parameters such as salinity, total dissolved solids (TDS) and conductivity, because these parameters can impart taste to water making it objectionable. Of interest also was the determination of the time it takes for turbid water to clear i.e. for the turbidity and TSSC to reduce by 90% or even greater. Attempt was also made to determine if there are any significant differences in the rate of clarification of different types of turbid waters found in arid and semi-arid lands of Eastern Kenya. In this regard, a comparison was made between the clarification rate of raw water drawn from seasonal rivers, perennial rivers and surface water reservoirs or water pans.

There is scarcity of studies on the changes in the physico-chemical characteristics of water treated with *M.oleifera* seed coagulant. Most of the previous studies on the physico-chemical characteristics of *M. oleifera* focused on establishing the physico-chemical composition of its seeds oil. Most of these studies have shown that *M.oleifera* seed oil has a fatty acid profile and is highly unsaturated because of the high percentage of oleic acid (Anwar and Rashid, 2007; Baypoli et al., 2014; Barakat and Ghazal, 2016). Studies have also been undertaken on the diverse health and nutritional benefits of *M.oleifera* leaves and seeds (Moyo et al., 2011; Gopalakrishnan et al., 2016). However, these are not the subject of this study as it focuses on establishing the extent to which *M. oleifera* seeds coagulant changes the physico-chemical characteristics of treated water and the extent to which coagulant concentration and level of water turbidity determines the volume of sludge formed during the treatment of water. These are novel aspects of current *M.oleifera* seed coagulant research that have not been addressed adequately in previous studies.

Study objectives

The aim of the study is to determine the extent to which *M.oleifera* seed coagulant can be used for the treatment of turbid water and how the coagulant changes the physico-chemical characteristics of water. The specific objectives of the study are as follows:

1. Determine the optimum concentration of *M.oleifera* seed powder coagulant that causes significant reduction of water turbidity.
2. Elucidate on the changes in the physico-chemical characteristics of water treated with *M.oleifera* seed powder coagulant.
3. Assess the magnitude of sludge formation during treatment of turbid water with *M.oleifera* seed coagulant.

MATERIALS AND METHODS

Study area description

Kitui County in which this study was conducted has a surface area of 30,496 km^2 (Figure 1). The main town in the county is Kitui town which is located about 160 km South East of Nairobi. The topography of the county can be divided into an Upland and Lowland area. The Upland area includes the Yatta Plateau in the west and the Kitui Mountains in the East. Elevations in the Upland area vary between 600 and 1800 m above sea level. The Lowland area which covers the majority of the county is a relatively dry gently eastward-sloping peneplain with elevation varying from 400 to 600 m above sea level (Borst and de Haas, 2006). The central part of Kitui County consists of an undulating plateau, deep valleys and mountains that rise to an elevation of 1800 m above sea level.

The climate of Kitui County is generally hot and dry with erratic and unreliable rainfall typical of arid and semi-arid climatic zones. The total annual rainfall ranges between 750 and 1150 mm with 40/60 percent reliability. Air temperature ranges between 16 and 34^{o}C (Horst and de Hass, 2006). Vegetation in Kitui County is characterized by scrublands and wooded bushland (Lind and Morrison, 1974). The county is located within the Mozambique belt and is generally occupied by the basement complex system consisting mainly of metamorphic rocks (Nyamai et al., 2003). The major sources of water are seasonal rivers, and water pans. The only perennial rivers are Athi and Tana rivers that flow to the south and north of the county, respectively. The river flows are characterized by very low or no flows in dry season and high flows during rainy seasons (cf. Borst and De Haas, 2006). The flows are usually turbid due to high sediment concentration associated with

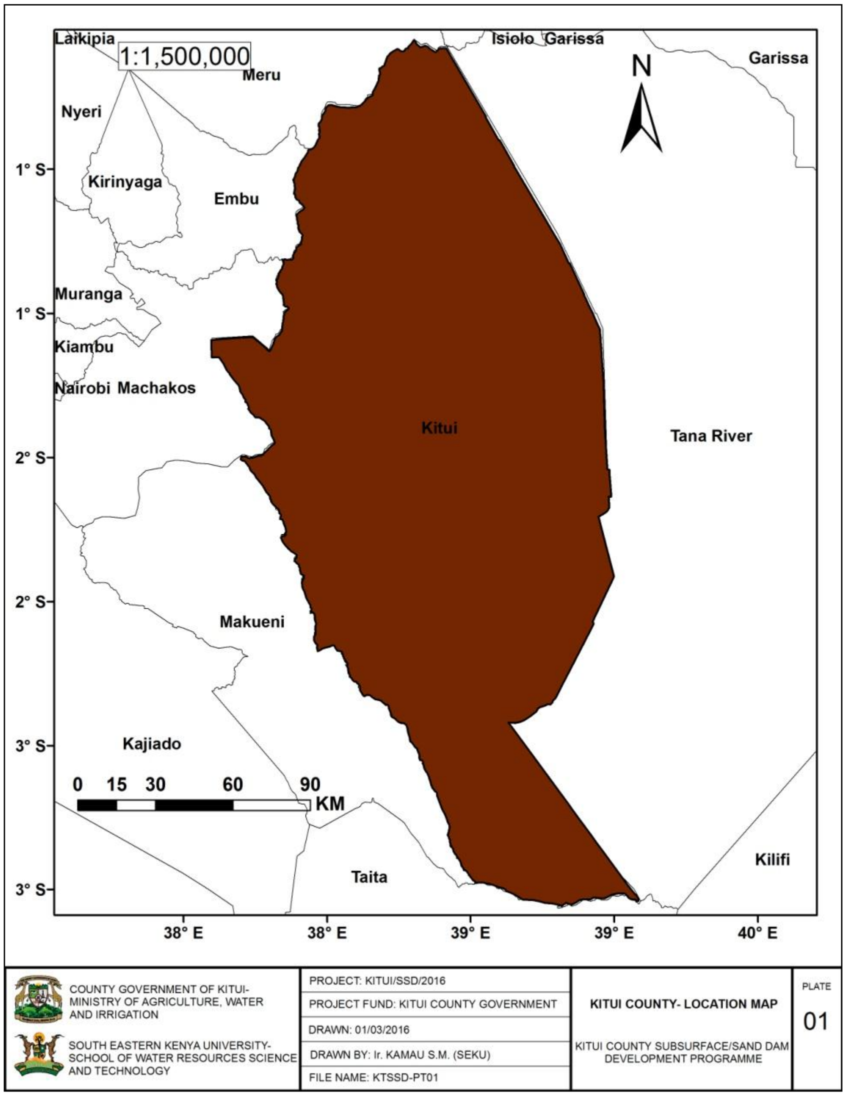

Figure 1. Location of Kitui County in Eastern Kenya.

high rates of soil erosion in the catchment areas. The population in the county is 1,136,000 with relatively low population density of 33 people per square km (GOK, 2019). Most people live in scattered villages with no piped or treated water supplies. Most people depend on turbid seasonal rivers, wells, water pans and small dams for their daily water requirements (Kitui County Government, 2018). More than 50% of the population lives below absolute poverty level and life expectancy is low ranging from 55-57 years (GOK, 2019). Human activities such as clearing of land for agriculture, settlements, charcoal making and cutting of indigenous trees for carving have in the recent past promoted land degradation. Cultivation and livestock keeping are important socio-economic activities in the county. The samples of turbid water were obtained from various sources at Mwingi, Bisa Hargeisa and Usueni.

Samples of turbid water were obtained from various sources in Kitui County in the period between August 2018 and March 2019. These sources are Ngomano sya Ngo'mbe water pan situated near Mwingi; Bisa Hargeisa water pan situated near Ngune and river Tana water obtained at Usueni in the northern border of Kitui County. The dry mature seeds of *M. oleifera* were collected at Likoni, Kisauni, Mtwapa, Gede near Malindi, Voi, Mbololo, Maungu, Kibwezi and Makindu areas.

Physico-chemical evaluation of *M. oleifera* seed

The physico-chemical evaluation of *M.oleifera* seed coagulant was basically undertaken to determine the changes in the physico-chemical properties of water treated at different concentrations of the coagulant. In this respect, the basic physico-chemical properties of water that were of interest were turbidity, total suspended sediment concentrations (TSSC), salinity, temperature, electrical conductivity and the total dissolved solids (TDS). Most of the previous studies focused on the evaluation of the physico-chemical properties of *M.oleifera* seed oil (Abdulkarim et al., 2005; Anwar and Rashid, 2007; Dollah et al., 2016; Mune et al., 2016), which differs from the focus of this study.

Sampling of different water bodies was done using an integrated water sampler. The water samples were stored in 5 litre plastic jerricans and were subsequently transported to the laboratory at the Main Campus of South Eastern Kenya University in Kitui for analysis. For each of the water sources, the turbidity was determined in the field using Hanna Instruments HI93703 Microprocessor turbidity meter capable of measuring turbidity in the range of 0 to 1000FTU. Conductivity, TDS, salinity and temperature were also determined in the field using portable Martini Instruments Mi306 EC/TDS/NaCl/Temperature meter (APHA/AWWA/WEF, 2012).

Determination of effectiveness of moringa seed coagulants

Various experiments were conducted to determine the effect of *M. oleifera* seed coagulant concentrations using seeds that were obtained from previously mentioned sources. The dried seeds of *M. oleifera* were ground in the laboratory using a pestle and mortar into a fine powder. The emphasis was put on obtaining fine powder because this provides increased surface area for the reaction with suspended solids in turbid water. It was noted that the powder is more effective as a coagulant compared to the whole seed or coarsely ground seeds. The ground power was subsequently weighed using a sensitive electronic balance in the laboratory. Various small portions of the powder were weighed for the purpose of determining the required coagulant concentrations. The weighed powder was then careful transferred to a one litre plastic bottle containing turbid water and shaken vigorously to allow effective mixing of the coagulant in the water.

Three sets of experiments were undertaken. The first experiment aimed at determining the time it takes for the turbid water to clear after adding various concentrations of the *M. oleifera* seed powder coagulant. In this experiment, samples of turbid water-moringa coagulant mixture were observed to determine the maximum length of time it takes for the water turbidity to attain the lowest turbidity level. The turbidity was measured using a turbidity meter and time was recorded by using an electronic stop watch.

The second experiment was aimed at determining the flocculation rate for water samples with different *M. oleifera* seed coagulant concentrations. The flocculation rate was determined by timing the clearance of water within 30 min. After 30 min, the turbidity in each of the 20 bottles was measured using a turbidity meter. In addition, the thickness of the sludge that settled at the bottom of the transparent bottle after 30 min was measured using a ruler. The volume of sludge was then expressed as the percentage of the volume of turbid water under treatment. A control water sample in which no *M. oleifera* seed coagulant was added was used to determine the baseline.

The experiments were also undertaken to determine changes in the levels of physico-chemical parameters in water after adding various concentrations of *M. oleifera* seed coagulant. After 30 min, measurements of electrical conductivity, total dissolved solids (TDS), salinity, and temperature were carried out in each of the water samples. The physico-chemical parameters were measured using an electronic meter.

The above experiments were repeated for water samples collected from water pans, perennial rivers, seasonal rivers and dams/reservoirs to determine whether the nature of water could bring about significant variations in the effectiveness of *M. oleifera* seed coagulant in the treatment of turbid water.

Determination of phenotypic differences in moringa seed coagulants

There are various *M. oleifera* tree provenances in Kenya. The aim of this component of the study was to determine whether there are significant differences in the effectiveness of *M. oleifera* seed coagulant derived from various provenances in Kenya. Dry seeds of various *M. oleifera* tree provenances were therefore collected at Kibwezi, Maungu and Gede. Turbid water samples were collected from sources detailed in the previous sections. For each *M. oleifera* provenance, experiments were conducted to determine the time it takes for water to clear for different coagulant concentrations. For each turbid water sample, replicate experiments were carried out using *M. oleifera* coagulant derived from Kibwezi, Maungu and Gede provenances. These experiments were carried out for *M. oleifera* seed coagulant concentrations ranging from 0.00025 to 1.5 g/l and for water turbidity ranging from 28 to 340 NTU.

Data analysis

The results of laboratory based experiments were entered into excel sheets. The data analysis was carried out using Microsoft excel statistical packages. The methods of data analysis that were applied in this study include regression analysis, correlation analysis, analysis of variance, and use of measures of central tendency.

RESULTS

Physico-chemical characteristics of water

The levels of physico-chemical parameters were determined for various water sources based on fieldwork that was conducted in August 2018. For most of the water sources, the level of salinity, total dissolved solids (TDS), and electrical conductivities were well within the World Health Organization (WHO) and Kenya Bureau of Standards (KEBS) drinking water standards (Table 1). However, in all cases, the level of water turbidity was generally higher than the recommended WHO drinking standard (WHO, 2017). The turbidity of water is among the water characteristics that are objectionable to most rural communities. Reduction of water turbidity can therefore go a long way in improving lives of rural communities. There was indication that the local communities were concerned with the high turbidity of water. In order to reduce turbidity, water was usually stored in 20 litre jerricans for some time at home to allow suspended sediments to settle. However, this was noted to be ineffective due to presence of colloidal particles in water that takes a long time to settle at the bottom. It was noted that it can take as long as 7 days for the water to become clear. Therefore, water storage does not effectively reduce water turbid because most of the turbidity is caused by clay colloidal particles with extremely low settling rate <0.00006m/s. This therefore points to the fact that most of the communities in arid and semi-arid lands consume water with high suspended sediment concentration (TSSC) that may cause various health complications (Crump et al., 2005; Mann et al, 2007; Tinker et al., 2010). The introduction of *M. oleifera* seed coagulant to these communities would be of

Table 1. The levels of physic-chemical parameters for various water sources based on measurements conducted in August 2018.

Water source	Turbidity (NTU	Salinity (%)	Temperature (°C)	Conductivity (μS/cm)	TDS (mg/l)
Ngomano sya Ngo'mbe water pan	228	0.4	25.8	188.3	94.2
Bisa Hargeisa Water pan	15	0.2	25.2	240.5	120.2
River Tana at Usueni	51	0.5	23.5	252.3	126.8

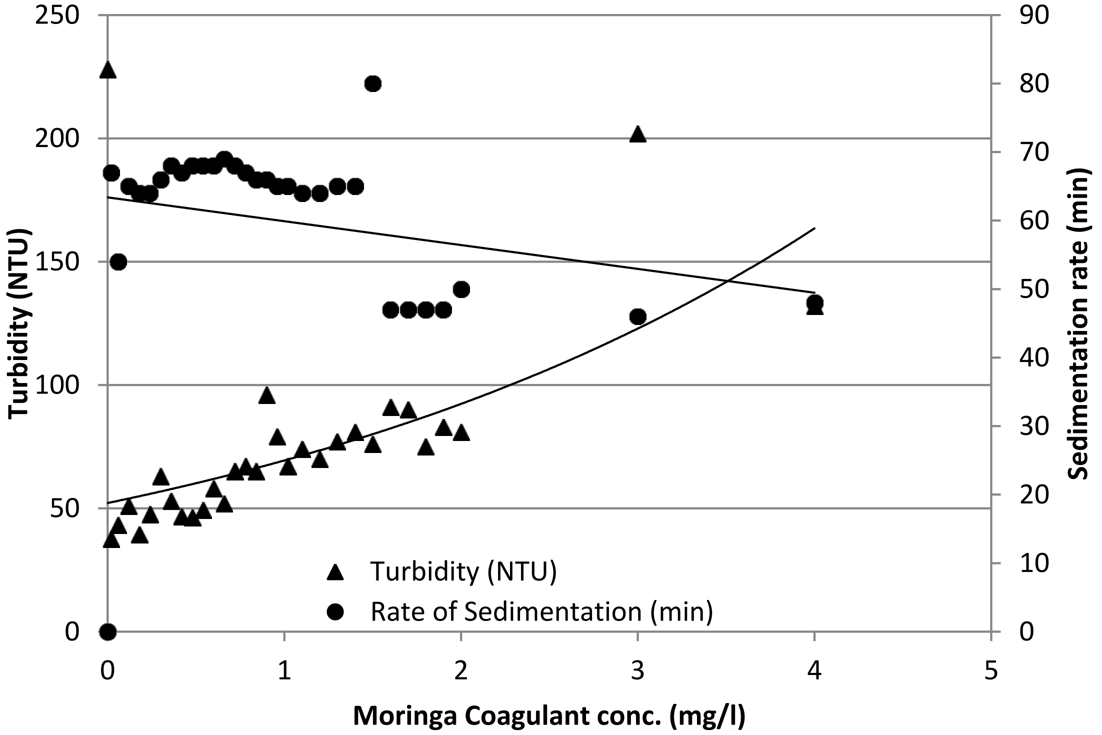

Figure 2. Water turbidity and sedimentation rate at various concentration of Moringa seed powder coagulant for Ngomano Sya Ng'ombe Water Pan water sample.

great help as it will enable them to obtain relatively clean water for various domestic uses.

Relationship between *M. oleifera* seed coagulant and water turbidity

There is a significant relationship between *M. oleifera* seed powder coagulant concentration and water turbidity. Figures 2 to 4 show the variation of water turbidity at various concentrations of *M. oleifera* seed powder coagulant for Ngomanosya Ng'ombe, Bisa Hargeisa and river Tana water samples. For the relationship between *M. oleifera* coagulant concentration and turbidity change for Ngomanosya Ng'ombe, Bisa Hargeisa and river Tana water samples, the correlation coefficients *r* were 0.62, 0.68 and 0.62, respectively, indicating a strong positive relationships.The variations of *M. oleifera* seed coagulant explained 38-47% of the variations in water turbid meaning other physico-chemical process are also contributing to the changes in turbidity. The water turbidity reduced to a range of 15-65 NTU from the initial turbidity ranging 51-461 NTU. This is however much high than the recommended World Health Organization drinking water turbidity of <5 NTU (WHO, 2017).

However, it was observed that as the coagulant concentration increases, the water turbidity increases exponentially. Beyond the optimum coagulant concentration of 0.02g/l, there was a tendency for the water to become cloudy due to the high levels of coagulant. This agrees with the study of Tunggolou and Payus (2017) that showed that above optimum *M. oleifera* seed powder coagulant concentration of 0.015g/l, the turbidity reduction efficiency decreases. In our case, the decrease in turbidity reduction efficiency occurred at Moringa coagulant concentration of 0.2 g/l.

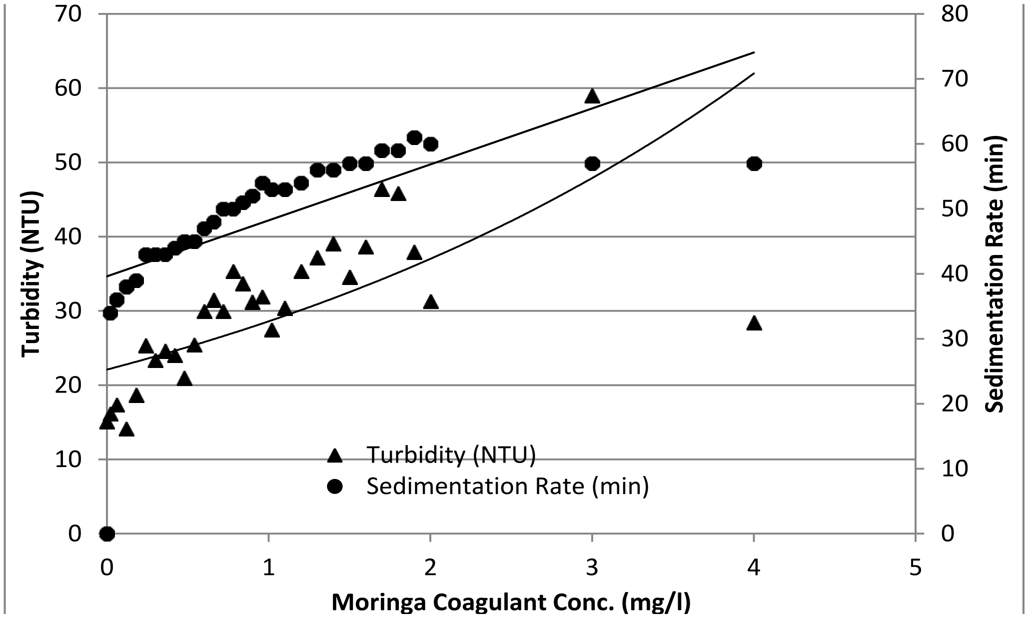

Figure 3. Water turbidity and sedimentation rate at various concentrations of Moringa seed powder coagulant for Bisa Hargeisa Water Pan water sample.

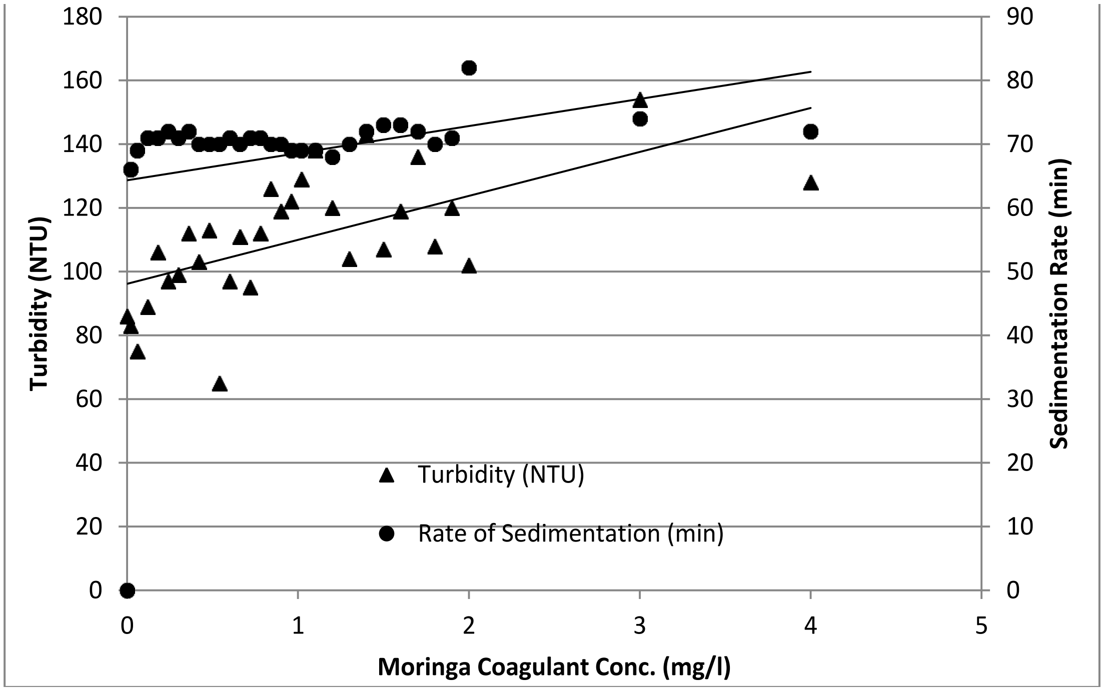

Figure 4. Water turbidity and sedimentation rate at various concentrations of Moringa seed powder coagulant for river Tana water at Usueni.

There is also a significant relationship between water turbidity and sedimentation rate for water samples drawn from various sources. The sedimentation rate increases as the water turbidity increases. The exception was in the case of Ngomanosya Ng'ombe water pan sample where sedimentation rate decreased as turbidity and coagulant

Table 2. The optimal *Moringa oleifera* seed powder coagulant concentrations and turbidity reduction efficiency for different water sources

Water source	Optimum Moringa seed coagulant conc. (g/l)	Initial turbidity (NTU)	Final turbidity (NTU)	Turbidity reduction efficiency (%)
Ngomano Water Pan	0.02	228	37.5	83.6
Katumba Water Pan	0.40	379	19	94.9
Tana River 2	0.06	86	75	12.8
Bisa Hargeisa	0.12	15	14	6.7
Kisole Earth Dam	0.04	461	59	87.2
Tana River	0.02	51	15	70.6
Ngomani Water Pan with Maungu Moringa	0.50	77	28.1	63.5
Kisole Earth Dam water with Gede Moringa	0.50	334	61	81.7
Ngomano Water Pan with Kibwezi Moringa	0.10	211	51	75.8
MEAN	0.20	204.7	40	64
MIN	0.02	15	14	7
MAX	0.50	461	75	95

concentration increased. However, this decrease was not statistically significant as R^2 was 0.048.

Moringa seed coagulant effects on clarification rates

The *M. oleifera* seed powder coagulant concentration affects sedimentation rate and thickness of sludge after water treatment. The sedimentation rate is the time taken for the water to become clear with turbidity of <15 NTU. Following addition of *M. oleifera* seed powder coagulant, on average basis the water turbidity reduced from as high as 461 NTU to about 15 NTU within 30-69 min. This is equivalent to 96.7% turbidity reduction efficiency. This shows that *M. oleifera* seed powder coagulant causes a significant turbidity reduction making water much clearer.

Effectiveness of *M. oleifera* seed coagulant differs among various provenances. Maungu moringa seed coagulant concentration of 0.5g/l yielded the lowest water turbidity of 28NTU with water clarification time of 27 minutes. Gede Moringa seed coagulant concentration of 0.5g/l also provided the lowest water turbidity of 61 NTU at clarification time of 68 minutes. For Kibwezi moringa, the lowest turbidity was 51 NTU that was affected at a Moringa seed coagulant concentration of 0.10g/l with clarification time of 41 min (Table 2). Therefore, considering all the *M. oleifera p*rovenances that were used in this study, it can be noted that on average basis the lowest mean turbidity that can be attained at mean Moringa coagulant concentration of 0.20g/l is 15 NTU. Water with turbidity of 15 NTU is quite clear. Considering turbid water samples drawn from various sources, the mean optimum *M. oleifera* seed powder coagulant concentration was found to be 0.20g/l with the minimum and maximum coagulant concentrations being 0.02 and 0.50 g/l, respectively. The mean turbidity reduction efficiency was 64% with the maximum efficiency of 95%.

Attempt was made to determine the water clarification times (that is, how long it takes for turbid water to become significantly clear) for different *M. oleifera* provenances. The water turbidity clarification time was found to range 30 to 66 min. The length of time it takes for water turbidity to be significantly reduced is determined by the optimum Moringa seed extract concentration for different provenances and also the concentration of suspended solids in water. At the optimum concentration, the mean clarification time is of the order of 45 min.

Moringa seed coagulant effects on sludge thickness

During treatment of turbid water using *M. oleifera* seed coagulant, sludge (coagulated sediment material) settles at the bottom of the sample bottom. Figure 5 shows the variations of clarification rate at various concentration of Moringa seed coagulant for Ngomanosya Ng’ombe Water Pan water samples. There was a decrease in sedimentation rate as the *M. oleifera* coagulant concentration increased. Sludge thickness varied at various concentration of Moringa seed coagulant for Ngomanosya Ng’ombe Water Pan water sample (Figure 5).

The thickness of the sludge tended to increase as the coagulant concentration increased. Therefore, by adding more *M. oleifera* coagulant in water, the quantity of sludge deposits tended to increase. The lowest quantity of sludge was at a coagulant concentration of 0.10g/l when the sludge thickness was 0.5cm. At a coagulant concentration of 1.0 mg/l, the sludge thickness was much higher being 0.75 cm. The sludge thickness is related to the amount of coagulant concentration because the turbidity was constant for all the samples that were

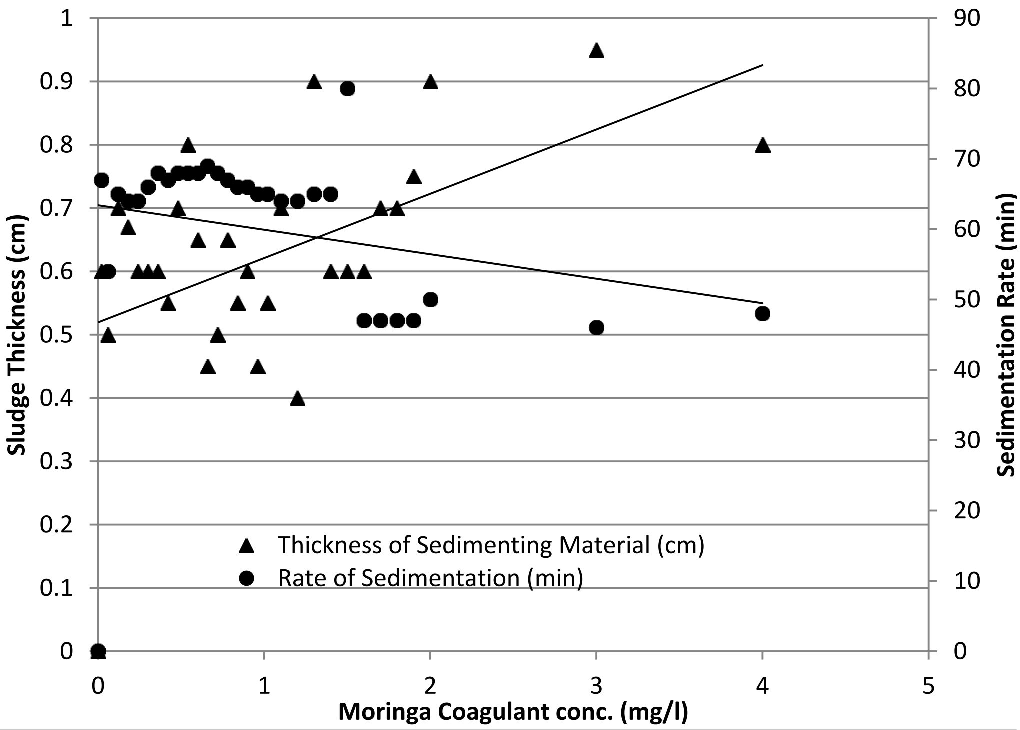

Figure 5. Sludge thickness and sedimentation time at various concentration of Moringa seed powder coagulant for Ngomano Sya Ng'ombe Water Pan water sample, Mwingi.

subjected to this experiment. Also, as the clarification time reduced, the thickness of the sludge increased. This was attributed rapid sedimentation at higher moringa coagulant concentration.

For the Bisa Hargeisa Water Pan water sample, both sludge thickness and clarification time increased as *Moringa oleifera* seed coagulant concentration increased (Figure 6). The clarification time was 35 min and the sludge thickness was 0.15 cm for the optimum *M. oleifera* coagulant concentration of 0.10g/l. Differences in the sludge thickness between Bisa Hargeisa Water Pan water sample and Ngomano Sya Ng'ombe water sample was attributed to differences in the total suspended solids concentrations. For the river Tana water sample, at the optimum *M. oleifera* seed coagulant concentration, the sedimentation rate was 27 min and the sludge thickness was 0.18cm (Figure 7).

Although the sedimentation patterns in the river Tana water sample was similar to those at the two water pans located near Mwingi, there are significant differences in the sedimentation times and sludge thickness. These differences were attributed to the differences in the turbidity level and concentration of suspended solids in water. Bisa Hargeisa water sample was more turbid with relatively higher suspended sediment concentration followed by Ngomano Sya Ng'ombe and river Tana water samples in that order (Table 1)

Coagulant effect on physico-chemical parameters of water

The addition of *M. oleifera* seed coagulant in turbid water changes its physico-chemical characteristics. The change was found to be significant as shown in Table 2 and Figures 8 to 10. For all the water sources, there was a tendency for the levels of total dissolved solids (TDS), electrical conductivity and salinity to decrease at Moringa coagulant concentration of 0.20g/l. Conductivity reduction efficiency ranged 2.5 to 33% (mean of 18%) implying a modest but significant reduction. This is consistent with the finding of Hendrawati et al. (2016) who reported that *M. oleifera* reduced conductivity by 10.8%. However, our study shows that above *M. oleifera* coagulant concentration of 0.20 g/l, there was a tendency for the levels of total dissolved solids (TDS), electrical conductivity and salinity to increase exponentially as *M. oleifera* coagulant concentration increased (Figures 7 to 9). The greatest increases were for electrical conductivity and total dissolved solids. These increases imparted objectionable taste in water. The patterns in a perennial river Tana were similar to those observed for the water pans at Bisa Hargeisa and Ngomano Sya Ng'ombe. Therefore, it can be argued that turbid waters found in arid and semi-arid lands of Kenya exhibits similar patterns in terms of an increase in electrical conductivity,

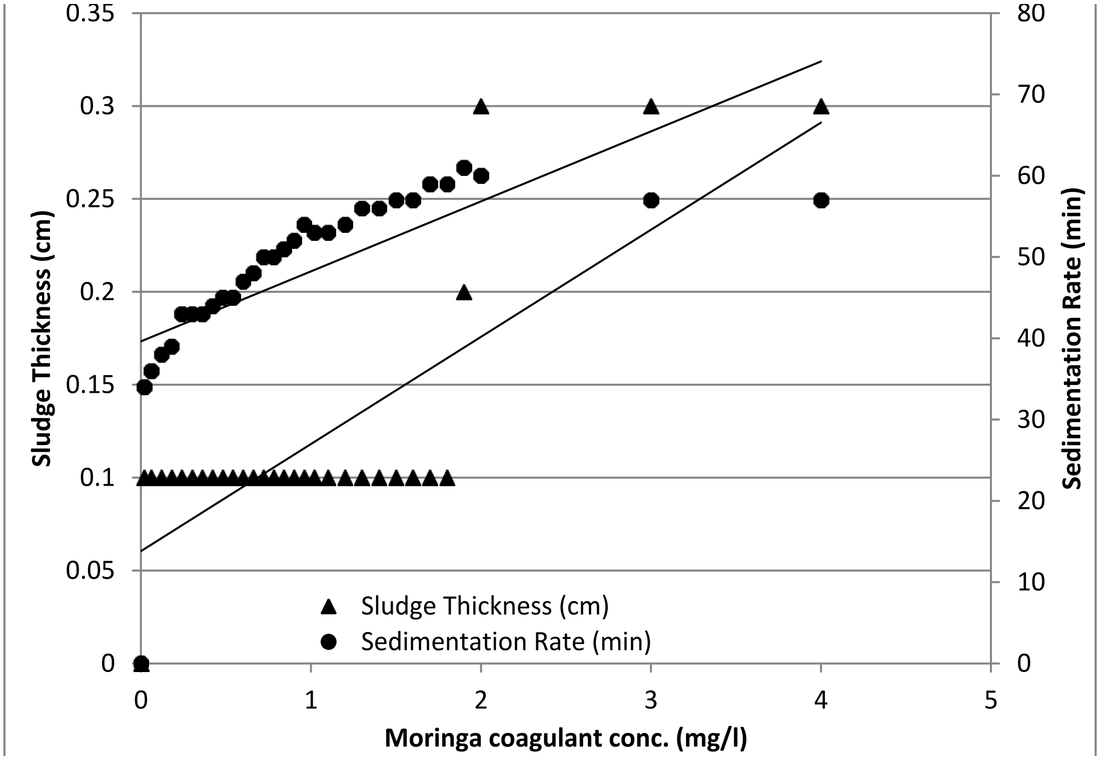

Figure 6. Sludge thickness and sedimentation time at various concentration of *Moringa oleifera* seed powder coagulant for Bisa Hargeisa water Pan water sample.

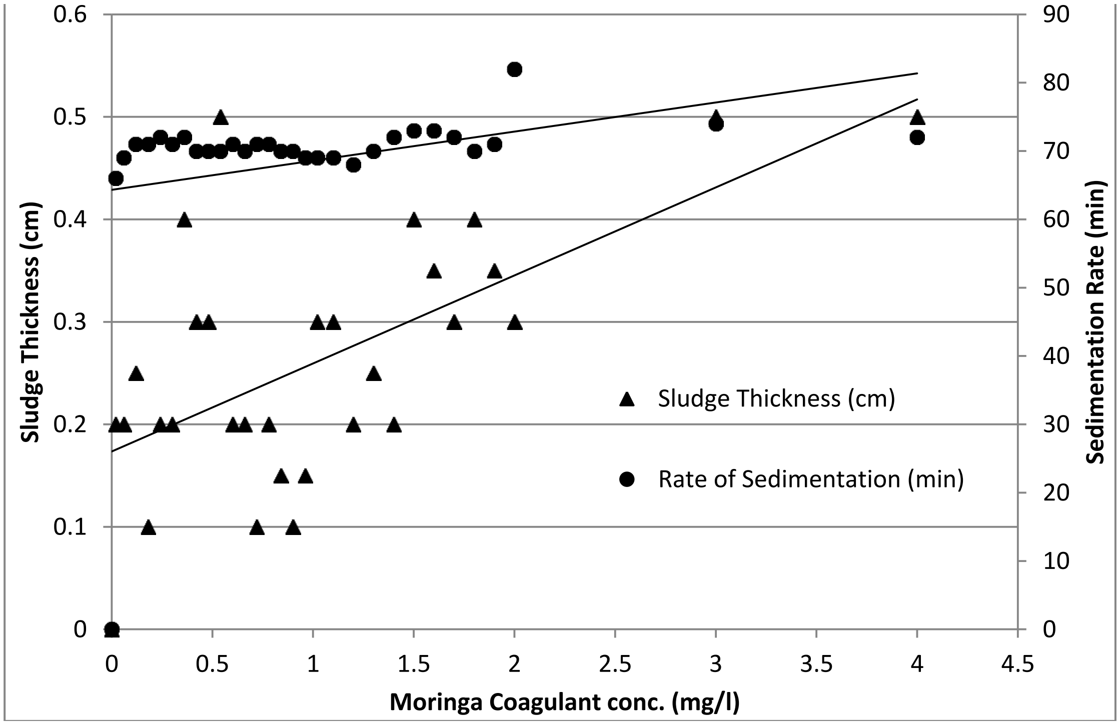

Figure 7. Sludge thickness and sedimentation time at various concentration of *M. oleifera* seed powder coagulant for river Tana water sample at Usueni.

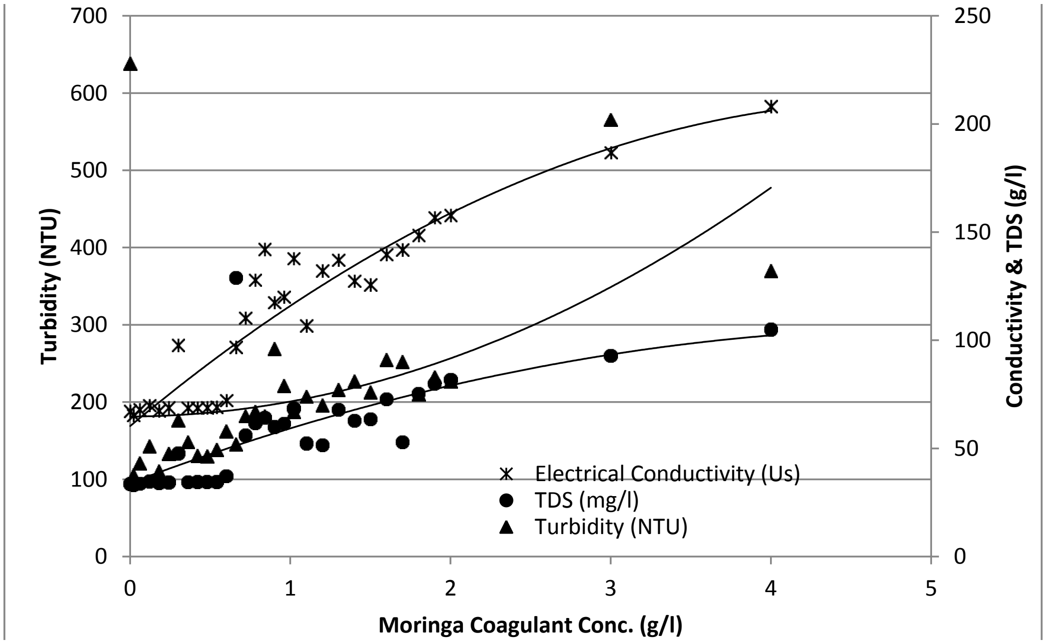

Figure 8. Variations of physico-chemical parameters at various concentration of *M. oleifera* seed coagulant for Ngomano Sya Ng'ombe Water Pan water sample.

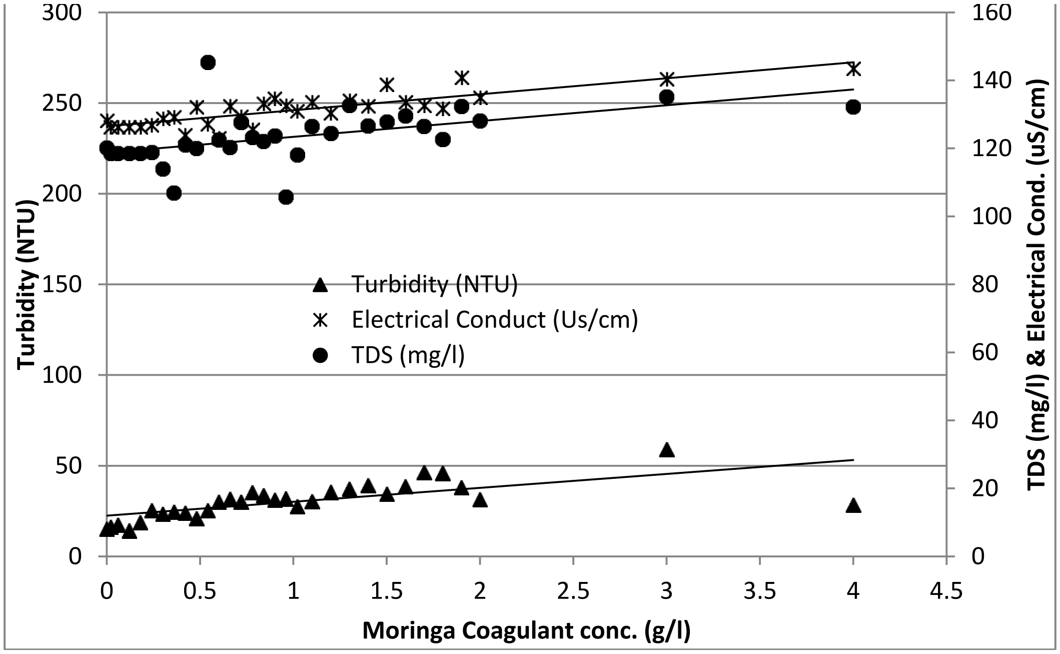

Figure 9. Variations of physico-chemical parameters at various concentration of *M. oleifera* seed coagulant for Bisa Hargeisa water pan water sample.

total dissolved solids and salinity of treated water at higher doses of *M. oleifera* seed coagulant.

For the relationship between *M. oleifera* seed coagulant concentrations and total dissolved solids (TDS) concentrations for water samples obtained at Ngomano Sya Ng'ombe, Bisa Hargeisa and river Tana, the

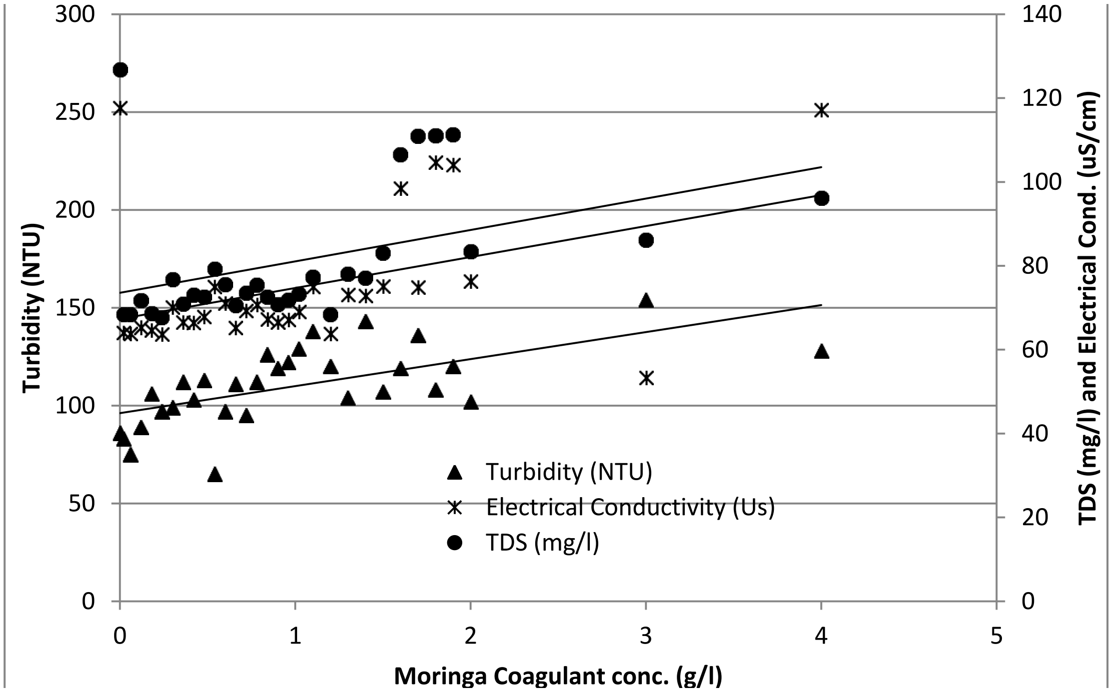

Figure 10. Variations of physico-chemical parameters at various concentration of *M. oleifera* seed coagulant for river Tana water sample.

coefficients of determination R^2 were 0.53, 0.28, and 0.38, respectively. The respective correlation coefficients *r* were 0.73, 0.53 and 0.62 indicating existence of strong positive relationship between Moringa seed coagulant concentrations and TDS concentrations. Therefore, variations in the coagulant concentration explained 28-53% of the variations in TDS in the water samples. Therefore variation in the *M. oleifera* seed coagulant concentration only explains part of the processes causing an increase of TDS concentration in treated water. Other physical chemical processes are also important in controlling the increase of TDS concentration in treated water.

For the relationship between variations in *M. oleifera* seed coagulant concentrations and variations in electrical conductivity for Ngomano Sya Ng'ombe, Bisa Hargeisa and Tana river water samples, the coefficients of determination R^2 were 0.26, 0.70 and 0.18, respectively. The respective correlation coefficients *r* were 0.51, 0.83 and 042 indicating relatively strong positive relationship between Moringa seed coagulant concentration and electrical conductivity of water samples. Therefore, variations in the *M. oleifera* seed coagulant concentration explained 26-70% of the variations in electrical conductivity in the water samples.

The ideal *M. oleifera* seed coagulant concentration for turbid waters ranged 0.02 to 0.50 g/l with a mean of 0.20g/l. At this concentration range, there is attainment of maximum water clarity at the shortest time possible. The quantity of sludge that is formed is minimal at this range of *M. oleifera* seed coagulant concentration. The levels of electrical conductivity and total dissolved solids (TDS) were also the lowest at this concentration. Above *M. oleifera* seed coagulant concentration of 0.20g/l, there was an exponential increase in water turbidity, quantity of sludge, total dissolved solids (TDS) concentration and electrical conductivity. In other words, the quality of water deteriorates at high Moringa seed coagulant concentrations >0.20g/l. These results point to the fact that care has to be exercised so as not add Moringa seed coagulant in turbid water beyond the optimum level as this would be counter-productive in as far as water quality is concerned.

Determination of effectiveness of coagulants derived from *M. oleifera* provenances

There are various *Moringa oleifera* provenances in Kenya and seed coagulant derived from various provenances exhibited significant differences as is illustrated in the following sections. The results of this study showed that seed coagulants derived from *M. oleifera* provenances at Kibwezi, Maungu and Gede areas exhibited significant differences in terms of the effectiveness of reducing turbidity. Figure 11 shows the effectiveness of Maungu

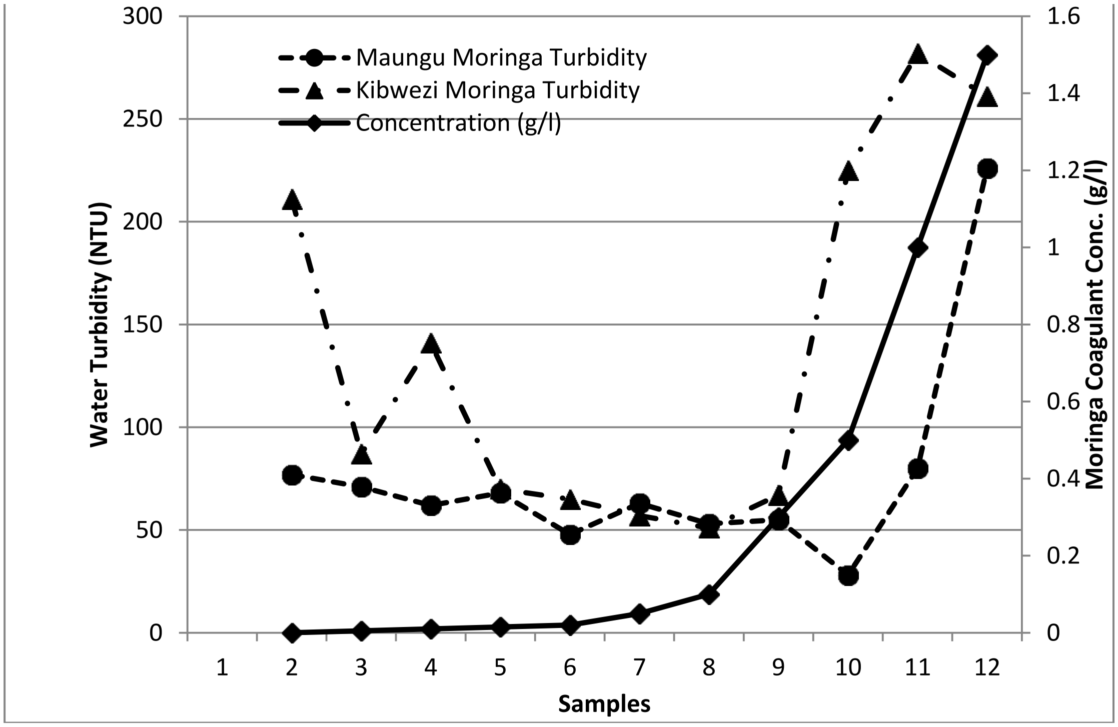

Figure 11. Effectiveness of Moringa seed coagulants on water turbidity based on *M. oleifera* seeds derived from Maungu and Kibwezi provenances.

and Kibwezi provenances seed coagulants on water turbidity. The patterns of turbidity reduction for the coagulant derived from moringa seeds obtained from the two provenances were different. There was a rapid decrease in water turbidity for Maungu seeds and gentle decrease for Kibwezi seeds as the *M. oleifera* seed coagulant concentration decreased up to 0.50g/l. For the three Moringa provenances, there was in general a decrease in water turbidity up to a *M. oleifera* seed coagulant concentration of 0.10 to 0.50 g/l. It was observed that above this range of *M. oleifera* seed coagulant concentration, there was a rapid increase in the turbidity of treated water. Therefore, the optimum *M. oleifera* seed coagulant concentration for all the three provenances (Maungu, Gede and Kibwezi) is the range 0.10 – 0.50g/l with a mean of 0.35 g/l (Table 2). At this range, a significant reduction in water turbidity occurs and there is no significant increase in turbidity, TDS concentration and salinity of treated water. Above this range, the physico-chemical characteristics of treated water changes as demonstrated in earlier sections.

Attempt was made to determine how long it takes for the water turbidity to be reduced significantly following addition of *M. oleifera* seed coagulants at various concentrations for various *M. oleifera* seed provenances. Figure 12 shows the rate of water clarification times for Maungu and Kibwezi *M. oleifera* provenances seed coagulants. The results showed that water turbidity reduced rapidly for Kibwezi provenance as compared to Maungu moringa provenance. For Kibwezi moringa provenance, water cleared rapidly with time up to coagulant concentration of 0.30 g/l. This was followed by a gentle reduction up to coagulant concentration of 0.20-0.30g/l. Above this concentration, there was a tendency for water clarification time to increase rapidly meaning that it takes much longer for turbid water to clear for both Kibwezi and Maungu provenances.

The determination of the effectiveness of *M. oleifera* seed coagulant concentrations for different *M. oleifera* provenances on water turbidity showed that the relationship is quite complex and non-linear. *M. oleifera* seed coagulant derived from different provenances behaved differently. Figure 12 shows that the relationship between Maungu *M. oleifera* provenance seed coagulant concentration and water turbidity is positive with a coefficient of determination R^2 of 0.97. That for Kibwezi provenance had a R^2 of 0.45. Therefore, it can be stated that in general the R^2 ranges 0.45- 0.97. This indicates 45-97% variations in the effectiveness of *M. oleifera* can be attributed to provenance differences. These results points to the possibility that there are wide differences in the effectiveness of various *M. oleifera* seed coagulants derived from various provenances found in Kenya. This is an area that should be subjected to further investigation

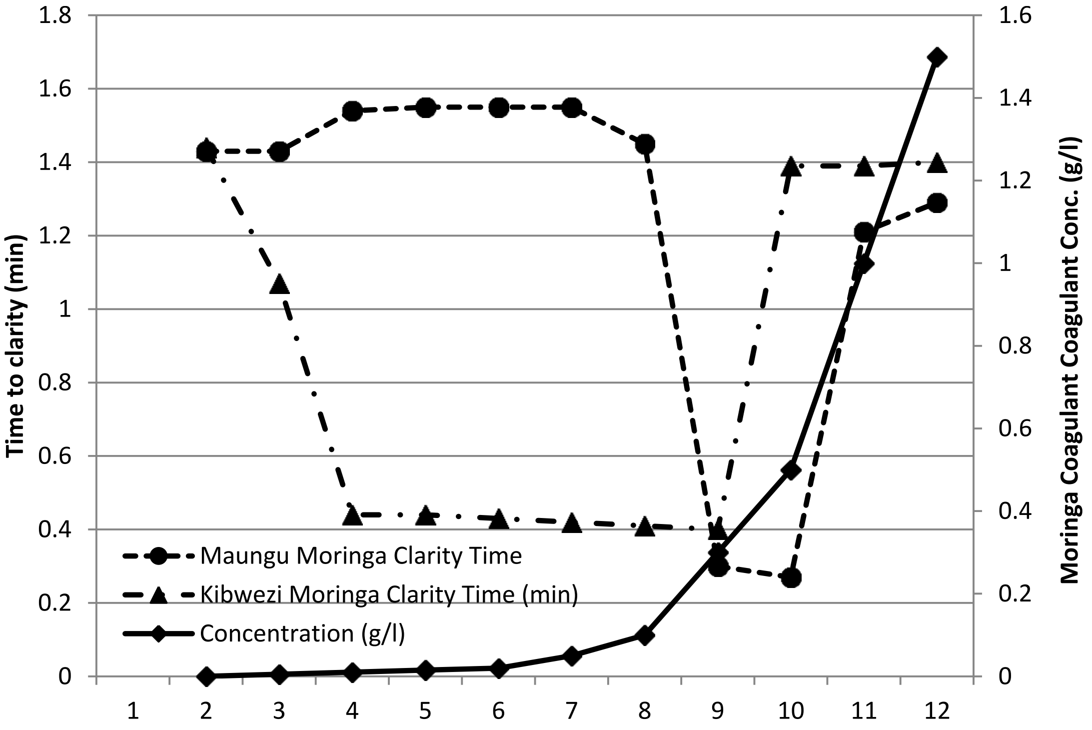

Figure 12. Rate of water clarification based on *M. oleifera* seed powder coagulant derived from Maungu and Kibwezi provenances.

since we only dealt with samples derived from three *M. oleifera* provenances in Kenya.

Attempt was made to determine the relationship between Kibwezi and Maungu *M. oleifera* seed coagulants in terms of time taken for water turbidity to be reduced significantly. Figure 13 shows the relationship between Maungu and Kibwezi provenances *M. oleifera* seed coagulant concentrations and water clarification time. The relationship between Kibwezi *M. oleifera* seed coagulant concentration and water clarity time was generally weak with R^2 of 0.33. For Maungu *M. oleifera*, R^2 was 0.16. Therefore, the relationship between moringa seed coagulant concentration and water clarification time is weak for the two provenances.

Attempt was also made to determine the relationship between Kibwezi and Maungu *M. oleifera* provenances in terms of water clarification time. The results yielded a coefficient of determination R^2 of 0.053 showing there is a very weak relationship between the two. In case of their influence on water turbidity, results showed a weak positive relationship with R^2 of 0.23. In other words, the two *M. oleifera* provenances yield seed coagulants that have different effects on water turbidity (Table 3).

There is a significant relationship between Gede *M. oleifera* provenance seed coagulant concentration and water turbidity reduction. Figure 14 shows the changes in water turbidity under varying Gede moringa provenance seed coagulant concentration. The relationship is complex with the coefficient of determination R^2 of 0.53. Water turbidity reduced as *M. oleifera* seed coagulant concentration increased up to concentration of 0.25-0.30g/l. Above the concentration of 0.30g/l, there was a rapid increase in water turbidity (Figures 15 and 16).

DISCUSSION

Turbidity reduction efficiency and sedimentation time

The results of this study show that *M. oleifera* seed powder can be used a water coagulant as it leads to rapid flocculation of suspended solids in water leading to a significant reduction in turbidity. This is in agreement with the study by Jahn (1984), Jahn et al. (1986) and Jahn (1991) who argued that *M. oleifera* seeds can be used to clear different types of turbid surface waters with low, medium and high turbidities to tap water quality. The study established that following addition of *M. oleifera* seed coagulant, the water turbidity reduced from as high as 461 NTU to15NTU within a period of about 30 to 69 min. Water with turbidity of 15NTU is clear enough to allow for various uses at domestic level. However, studies conducted elsewhere have reported that it takes

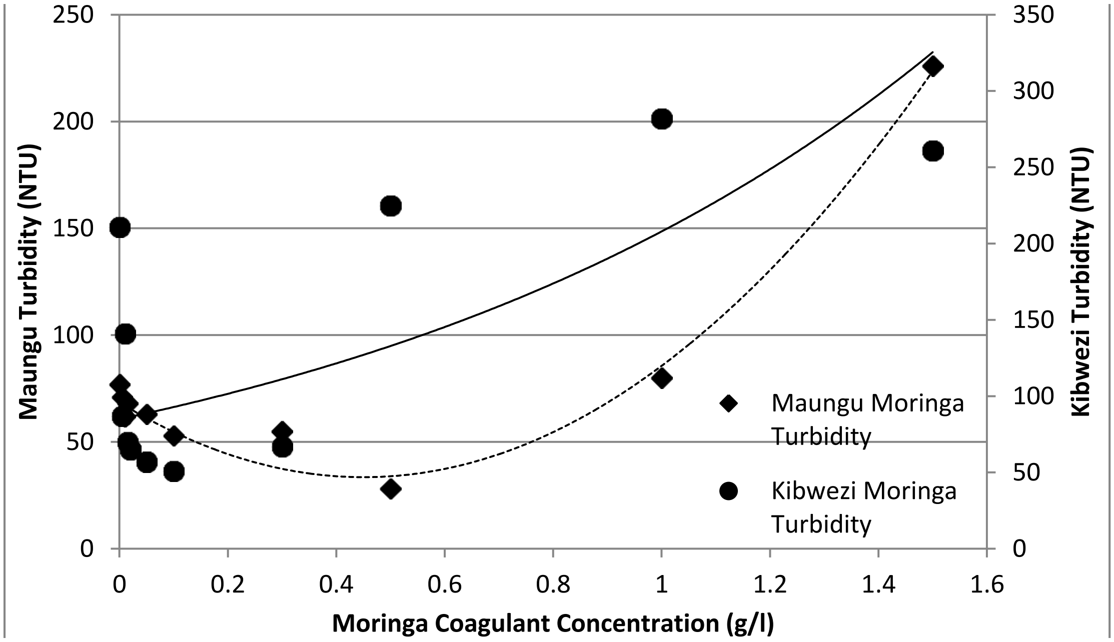

Figure 13. Relationship between Maungu and Kibwezi provenances *M. oleifera* seed powder coagulant concentration and water turbidity.

Table 3. Values of sludge thickness, turbidity and water clarification times for various provenances of *Moringa oleifera* seeds.

	Gede Moringa	Maungu Moringa	Kibwezi Moringa	All provenances means
Sludge thickness (cm)	0.64	0.45	0.53	0.54
Turbidity (NTU)	199	75	137	137
Clarification time (h)	1.06	0.30	0.40	0.59
Optimal Moringa coagulant conc. (g/l)	1.50	0.30	0.3	0.9

60-120 min for the turbid water to be clarified to tap water quality (Jahn, 1984; Sotheeswaran, et al., 2011). This study established that the turbidity reduction efficiency of *M. oleifera* seed coagulant concentration ranged from 64 to 95% with a mean of 74.34%. This result compares well with that of Hendrawati et al. (2016) who reported that *M. oleifera* turbidity reduction efficiency of 98.6% for wastewater. Tunggolou and Payus (2017) reported *M. oleifera* seed powder has 91.17% treatment efficiency.

Our results and those of other studies show that *M. Oleifera* causes a significant improvement in water quality in terms of turbidity reduction. Thus, for turbid water obtained from arid and semi-arid lands of Eastern Kenya, it takes an average of 30-69 min for the complete clarification of turbid water to occur at optimum *M. oleifera* seed coagulant concentration ranging from 0.01g/l to 0.50g/l. The differences between our results and those of previous studies undertaken elsewhere could be due to differences in the concentration of suspended solids in water samples used in those experiments. It is possible that TSSC for water used in other studies was much higher than that in our water samples.

Effectiveness of *M. oleifera* seed coagulant differs among various provenances. Among different provenances, it was observed that the effective *M. oleifera* seed coagulant concentration varied from 0.10 to 0.5g/l with the mean of 0.35 g/l. This concentration range provided the lowest water turbidity ranging from 28 to 61 NTU with water clarification time ranging from 27-68 min. The potency of *M. oleifera* seed coagulant differed among various *M. oleifera* provenances. This could be due to many other genetic, physiological and environmental factors that were not subject of investigation in this study. However, our results showed that Kibwezi *M. oleifera* provenance provided faster clarification times as compared to Gede and Maungu *M. oleifera* provenances. For instance, Kibwezi *M. oleifera* provenance seed coagulant concentration of 0.1g/l provided the lowest turbidity of 51NTU within 41 min.

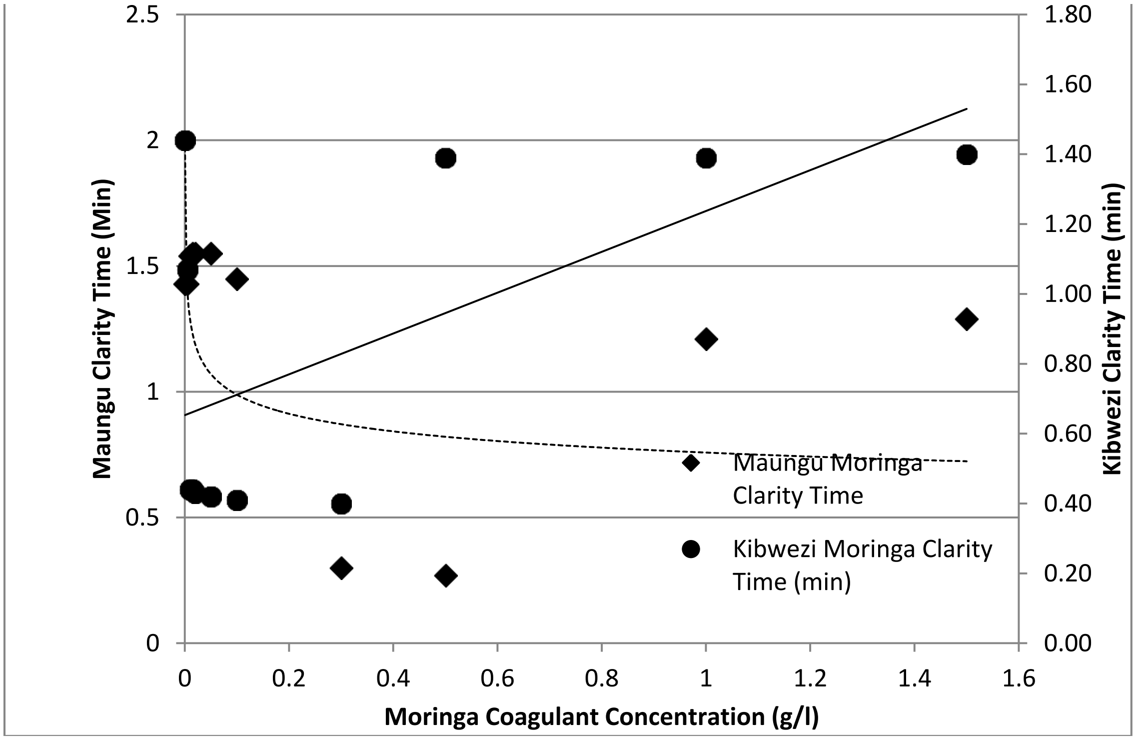

Figure 14. Relationship between Maungu and Kibwezi provenances *M.oleifera* seed coagulant concentration and water clarity time.

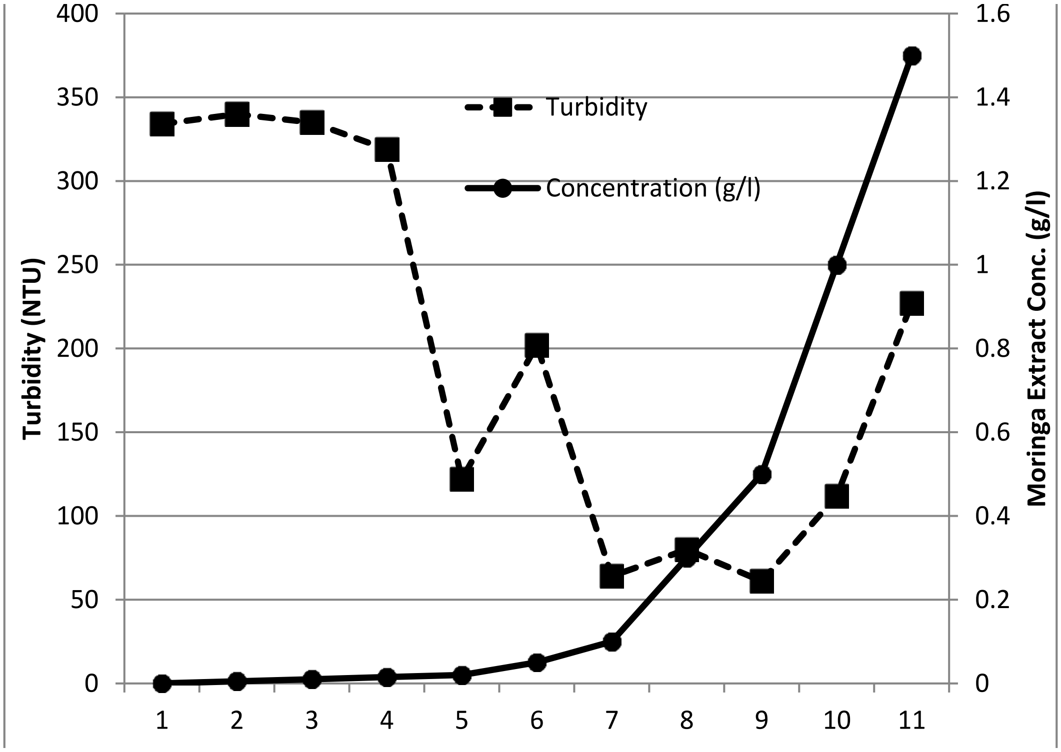

Figure 15. Changes in water turbidity under varying Gede *M. oleifera* provenance seed coagulant concentration.

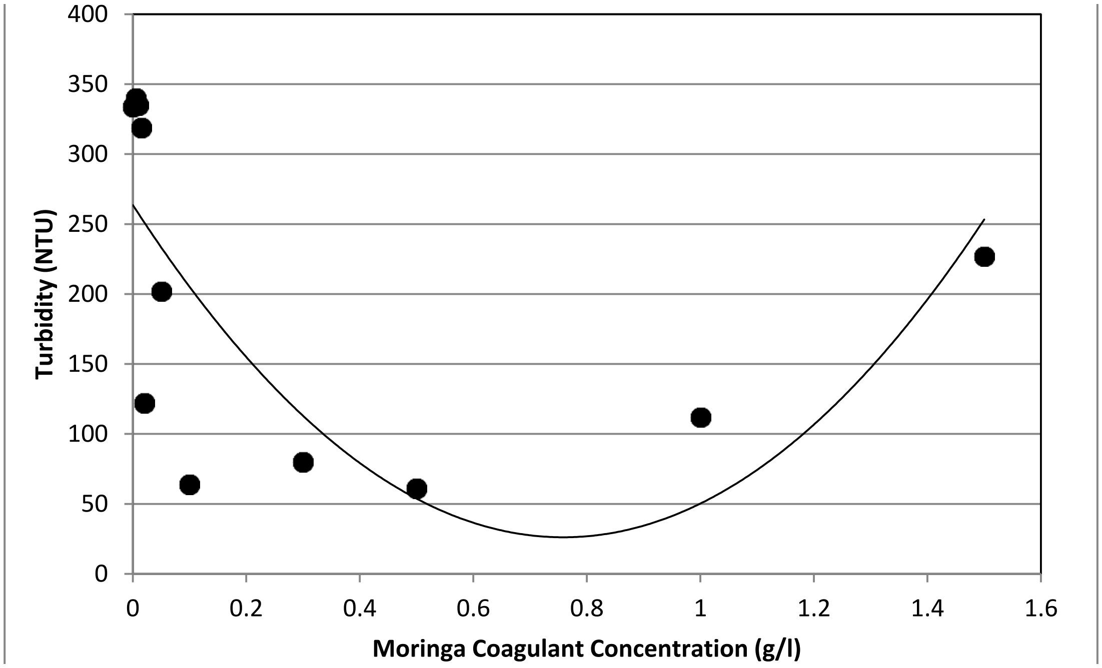

Figure 16. Changes in water turbidity under varying Gede *M. oleifera* provenance seed powder coagulant concentration.

Optimum Moringa seed coagulant concentration

The study showed that ideal concentration of the *M. oleifera* seed powder coagulant for turbid waters drawn from arid and semi arid lands of Eastern Kenya ranges 0.02-0.50g/l. The mean optimum coagulant concentration is 0.20 g/l with the minimum and maximum coagulant concentrations being 0.02 and 0.50 g/l, respectively. These minimum and maximum *M. oleifera* coagulants concentrations would be applicable for low turbidity and high turbidity waters, respectively. For low turbidity waters (<100 NTU), the minimum coagulant concentration of 0.02 g/l would suffice. For moderately highly turbid waters (>350 NTU), the maximum coagulant concentration of 0.50g/l would be ideal. The mean coagulant concentration of 0.20g/l would be ideal for waters with modest turbidity levels (100-350 NTU). Within the range of optimum coagulant concentrations indicated above, water with turbidity values that are acceptable for safe drinking water can be obtained. Our optimum coagulant concentrations values are comparable to concentrations of 0.03-0.20g/l reported by John (1984). A study by Amagloh (2009) reported an optimum *M. oleifera* coagulant concentration of 12 g/l which is on the higher side when compared to our mean Moringa coagulant concentration of 0.20g/l. Tunggolou and Payus (2017) reported an optimum *M. oleifera* coagulant concentration of 0.15g/l which is comparable to that reported in our study. Therefore, it seems there is a wide variation in terms of optimum concentration for *M. oleifera* seed powder coagulant. Different water sources require different optimum dosage for significant reduction in turbidity to be noticed. Other studies seems to have used water with relatively low turbidity <10 NTU while in our case turbidity was relatively higher ranging from 51-461 NTU.

Effects of treatment above optimum coagulant concentration

The use of *M. olefeira* seed coagulant concentrations above the optimum range causes significant increase in the levels of turbidity, salinity, total dissolved solids (TDS) concentration and electrical conductivity. However, a study by Tunggolou and Payus (2017) reported no change in conductivity following addition of *M. olefeira* seed powder coagulant in turbid water. Our study showed that increasing higher dosages of *M. olefeira* seed coagulant leads to an increase in not only conductivity but also salinity, TDS and turbidity of the water. The increase in salinity and TDS imparts unpalatable and objectionable taste to water. This may discourage local communities from using the *M. olefeira* seed powder as a water coagulant. Therefore, it is important to maintain the coagulant concentration in the range 0.02-0.50 g/l so that the levels of the physico-chemical parameters would not be so high to cause objectionable taste to water. It would be important to create awareness among the local community users on the need to only use the right quantity of *M. olefeira* powder when treating water for domestic consumption. This is also important from economic point of view as using large quantity of the coagulant could be uneconomical due to other more equally important uses of Moringa powder such as medicinal and nutritional uses (Caceres and Lopez, 1991; Makkar and Becker, 1997). In terms of the use of *M. oleifera* coagulant for water treatment, it is suggested in this study that water treated using this coagulant be used immediately. This is due to the fact that Moringa seed coagulant is biodegradable (Ndabigengesere et al., 1995, Ndabigengesere and Narasiah, 1996) and the decomposition of the coagulant in water may therefore exert bio-chemical oxygen demand (BOD), causing anoxic conditions that may lead to objectionable smell in water. In this regard, water treated using *M. oleifera* seed coagulant should not be stored without use for more than 5 days. This however is another area that requires further research.

Sludge formation during water treatment

The results show that the sludge that is formed as a result of treatment of turbid water using *M. olefeira* seed coagulant is of the order 1 cm thick (in 0.5 L bottle). This is equivalent to about 10% of the total volume of water under treatment. The volume of sludge produced is a function of the original suspended sediments concentration and hence turbidity of water and also the quantity of the coagulant added in water during the treatment process. The higher concentration of suspended sediments leads to a relatively higher volume of sludge. For treatment of a large volume of water, the sludge would settle at the bottom of the tank and can be removed by opening the tap placed at the bottom of the tank.

Active agents in *M. Oleifera* seed coagulant

Previous studies have shown that the active agents in *M. oleifera* seed coagulants are water soluble, highly cationic polypeptides (Gassenschmidt et al., 1995). It has been shown that water clarification by *M. oleifera* seed coagulant is primarily due to the action of seed's proteins (Jahn, 1988, 1991). The *M. oleifera* seed kernel contains about 37% of proteins (Ndabigengesere and Narasiah, 1998). The basic polypeptides with molecular weights ranging from 6,000 to 16,000 Daltons are the main causes of flocculation. The functional groups in the side chain amino acids of the *M. oleifera* seed proteins are thought to contribute to the water clarification (Ndabigengesere and Narasiah, 1998). The mechanism of coagulation is adsorption and charge neutralization of the colloidal positive charges that attract the negatively charged impurities in water (Ndabigengesere et al., 1995). At a pH below 10, the *M. oleifera* seed proteins are positively charged and thus the seeds powder coagulant when added to turbid water binds to the negatively charged particles (Ndabigengesere and Narasiah, 1998). Previous studies have also shown that the addition of *M. oleifera* seeds coagulant does not have any effect on the pH of the water (Sotheeswaran et al., 2011). Therefore, as opposed to aluminum sulphate, *M. oleifera* seed coagulant requires no pH adjustment and leads to relatively low values of sludge volume and the products are organic and bio-degradable (Ndabigengesere et al., 1995, Ndabigengesere and Narasiah, 1996).

M. Oleifera provenance and variation of coagulant concentration

The effectiveness of *M. oleifera* seed coagulant on water turbidity seems to vary among the *M oleifera* provenance found in Eastern and Coastal regions of Kenya. *M. oleifera* trees grown in different geographical zones shows significant differences in terms of their productivity. It is postulated that some provenances of *M. oleifera* tree produce seeds whose extract is more effective in reducing water turbidity than others. This perhaps is related to the quality of seeds produced and concentration of requisite polypeptides, which in turn could be influenced by environmental conditions and genetic factors of a specific *M. oleifera* genotype. Also, it is possible that the stage at which the seeds are harvested and the way the seeds are stored and for how long, also affects the potency of the seeds. For instance, Kibwezi *M. oleifera* seeds coagulant were noted to be more effective as compared to those obtained from Maungu and Gede. There is however a need for further studies to establish the main causes of the observed differences among different *M. oleifera* provenances.

Conclusion

This study sought to establish the extent to which dry *M. oleifera* seed powder coagulant can be used for reduction of turbidity in raw water drawn from arid and semi arid lands of Eastern Kenya. The study relied on seeds obtained from various *M. oleifera* provenaces in Eastern and Coastal regions of Kenya. The study concludes that *M. oleifera* seed powder can be used a water flocculant as it leads to rapid flocculation of suspended solids in water leading to improved clarity of water. The study established that *M. oleifera* seed powder coagulant reduces water turbidity from as high as 461 NTU to about

15 NTU within a period of about 30 to 69 min. The *M. oleifera* seed coagulant can achieve up to 95% reduction in water turbidity. This leads to a significant improvement in water quality in terms of turbidity reduction.

For the turbid waters drawn from various sources in Eastern Kenya, this study established that the optimum *M. oleifera* seed powder coagulant occur in range 0.02-0.5g/l. The mean optimum coagulant concentration is 0.20g/l. The minimum coagulant concentration is 0.02g/l and maximum is 0.50 g/l. Above this range of optimum coagulant concentrations, the water quality tends to deteriorate due to increased turbidity, electrical conductivity, salinity and total dissolved solids (TDS). The sludge formed following addition of *M. oleifera* coagulant in turbid water is moderate being 10% of the total water volume treated, which is within acceptable limits. However, the volume of sludge is dependent on the initial water turbidity and the level of suspended solids concentration of water.

The study also concludes that various *M. oleifera* provenances show significant differences in terms of the effectiveness of *M. oleifera* seed coagulant in turbidity. The causes of these differences were not subject of investigation in this study. Although further studies are required in this area, there is an indication that certain provenances of *M. oleifera* tree yields seeds that are more effective in reducing turbidity of water.

Recommendations

This study has demonstrated that *M. oleifera* seed powder coagulant is effective in reducing turbidity. In this respect, the following recommendations are put forward:

1) The National Government should approve *M. oleifera* seeds as a coagulant for water turbidity reduction after further tests have been undertaken by the concerned departments.
2) There is a need for the national and county governments to promote *M. oleifera* seed powder coagulant as a marketable item that can be used for water treatment at household level.
3) There is a need for further research on the chemical composition of water following treatment with *M. oleifera* seed coagulant to establish the concentrations of iron and potassium including other chemicals and the extent to which they can affect the potability of treated water.
4) The departments of agriculture at national and county government levels should encourage and provide incentives to farmers in rural areas to cultivate *M. oleifera* in order to enhance sustainable production of the crop for commercial purpose.
5) There is a need for non-governmental organizations and community based organizations to raise awareness among the communities on the use of *M. oleifera* organic coagulants for water treatment at household level.
6) There is a need for further research to establish the effectiveness of various provenances of *M. oleifera* in terms of water treatment and provision of nutritional, health and pharmaceutical benefits.

CONFLICT OF INTERESTS

The authors have not declared any conflict interests.

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Review

Potential of biochar for clean-up of heavy metal contaminated soil and water

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Heavy metals exist in the environment naturally aside those due to anthropogenic impact. These metals are removed from effluents and water using different techniques like adsorption, oxidation/reduction, chemical precipitation, membrane separation, filtration and ion exchange. Biosorption is very effective because it is highly renewed naturally, is cheap, and can remove metals greatly because the pollutant can be recovered either by desorbing or incinerating the biomass. Therefore, this work aims to identify some biochars utilized as adsorbents to remove lead, chromium, mercury and copper in soil and water, according to different researchers. In conclusion adsorption is a very effective method to remove or recover heavy metals from the environment. These biochars can be used in place of commercial activated charcoal because, besides being cheap, they are very effective treatment in removing metal ions based on wastewater discharge standards.

Key words: Biomass, adsorbents, activated carbon, biochar, heavy metals.

INTRODUCTION

Soil and water contamination with significant metals are often attributed to several completely different sources like agricultural, mining activities, industrial and residential activities. A trending environmental downside is contamination of soil and water due to rise of harmful pollutants derived from waste effluents may be. The foremost toxic wastes are significant metals like lead, nickel and others. These might be useful in minute concentrations, but adversely affect aquatic life and human health. The existence of those elements will result in metabolic process issues, immunologic weakness, excretory organ and liver disorders, high blood pressure, genetic mutations, in a worse case death (Zhang et al., 2016). Numerous correction techniques, supported either mobilization or immobilization processes are developed preserving security of human health and also the maintenance of sustainable environment (Souza, 2009). In recent years, it has been found that more soils worldwide are contaminated with toxins, due to waste emissions from various anthropogenic processes and improper use of pesticides and chemicals for agricultural production (Mench et al., 2010). Furthermore, tailings may be characterized by a total absence or low levels of organic matter and macronutrients and will normally have an acidic pH, although some tailings may be alkaline (Krzaklewski and Pietrzykowski 2002; Gbadebo and Ekwue 2014). Aside from that, tailings are also said to be devoid of normal soil structure and support a highly

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stressed heterotrophic microbial community (Mendez et al., 2007). Further pollution of soil and tailings can be curbed by deploying pollution by employing environmentally sound technologies as alternatives (Beesley et al., 2011). For instance use of compost as soil amendment has been embraced by rural farmers due to its cost effectiveness (Umeobika and Onmonya, 2020). Many disadvantages of widespread use of chemical fertilizers include increase in soil acidity, mineral imbalance and soil degradation (Ayoola and Makinde, 2008). Also, in Europe Petruzzelli (2012) has reported that soil contamination has been known as a vital point for action within the European Economic Community, because it affects a large expanse of the available land. The economy in China has experienced progressive growth within the past few years; this has led to increased environmental problems (Xi et al., 2011). Standard strategies are enforced to reduce major metals from contaminated water. However, most of the main strategies are ineffective and undesirable due to high costs, high sludge production, and incomplete removal (Lara et al., 2016). Several studies aiming at reducing operating costs and increasing efficiency in water treatment have been conducted. Some of the biomass already worked on include: shells of aquatic animals and egg, fruit peels, vegetable oil and its residues, nuts, zeolites and husks of some roots and tuber crops cocoa and corn cobs. The efficiency of the process is hinged on the nature of the biomass used (Tejada-Tovar et al., 2016). Biochar is produced by thermochemical breakdown of biomass under restricted environments (Cha et al., 2016; Gondim et al., 2018). Temperature, type of biomass and atmosphere (often slowly oxidizing) are the most critical variables considered in this process (Kim et al., 2012). Water correction Contamination of aquatic systems may be a serious environmental issue and so the event of associate economical and appropriate technology to get rid of significant metals from binary compound solutions is important. Many strategies are often employed to remove significant metals from contaminated water. They include chemical precipitation, action, adsorption, membrane filtration; reverse diffusion, solvent extraction, and chemistry treatment with several of those strategies suffering from high capital and operational prices (Khatri et al., 2017).

Soil correction was done by removal of significant metal by screening followed by Soil washing from Contaminated Soil. In this technique the contaminated soil is removed from contaminated sites (ex-situ) and washed, the limitation of this method; the operation cannot be performed for a really massive volume of soil. Benefits of excavation involve the entire removal of the contaminants and also the comparatively fast cleanup of a contaminated site. Disadvantages embrace the actual fact that the contaminants square measure merely affected to a special place, wherever they need to be monitored; the danger of spreading contaminated soil and dirt particles throughout removal and transport of contaminated soil; and also the comparatively high value. Excavation is often the foremost high-ticket choice once massive amounts of soil should be removed or disposal as risky or toxic industrial waste is needed (Khatri et al., 2017). Stabilizing metals within the soil, significant metals are often left on the site and treated during a means that reduces or eliminates their ability to adversely have an effect on human health and also the environment. This method is usually referred to as stabilization. Eliminating the bioavailability of significant metals on the site has several benefits over excavation. A technique of stabilising significant metals consists of adding chemicals to the soil that cause the chelation of minerals that contain the significant metals during a form that's not simply absorbed by plants, animals, or people. This technique is termed in-place fixation or stabilization. This method doesn't disrupt the setting or generate dangerous wastes. Instead, the significant metal combines with the additional chemical to make a less harmful compound. The significant metal remains within the soil, however in a form that is abundant and less harmful, the disadvantages is that it permits incomplete neutralization of metals (Khatri et al., 2017). Uses of plants growing plants will facilitate contain or scale back significant metal pollution often referred to as phytoremediation. It has the advantage of comparatively low value and wide public acceptance. It is often but 1 / 4 of the price of excavation or in-place fixation. Phytoremediation has the disadvantage of taking longer to accomplish than different treatments. Plants are often utilized in other ways. Generally, a contaminated site is just revegetated during a method referred to as phytostabilization (Liu et al., 2017).

EFFICIENT REMOVAL OF METALS FROM WATER BY BIOCHAR

A great number of solid substances can serve as adsorbents. Adsorbents are very important because their porous structure is suitable; it affects diffusion directly. This is seen on the surface area of solids, affecting total adsorption capacity and the values of adsorption velocity (Souza, 2009). Some works have evaluated the capacity and efficiency of adsorption to remove chromium, copper, mercury ions and lead in marine environments (Santhosh et al., 2020). Some of them are given below (Table 1), which show the biomass mostly utilized to produce biocarbons to be adsorbed to heavy metal ions.

BIOCHAR USED TO REMEDY METAL POLLUTED SOILS

Heavy metals stay for years and not easily biodegradable in soils that are polluted. For heavy metals to be removed from polluted soils it is expensive and takes a lot of time

Table 1. Copper and lead removal in aqueous environment using various adsorbents with copper activator.

Adsorbent	Dosage*	Activator	Efficiency (%)	Adsorption capacity (mg g $^{-1}$)	Reference
Conventional	0.1 g/50 ml	Nd**	99.87	4.84	Rocha et al. (2006)
Guava seed	0.1 g/50 ml	N_2	93.04	1.23	Rocha et al. (2006)
Macadamia nut	0.1 g/50 ml	N_2	99.01	3.48	Rocha et al. (2006)
Taioba-brava	0.5 g/250 ml	Physical	99.88	4.47	Lucena et al. (2012)
Saltbush	0.5 g/250 ml	Physical	98.82	8.89	Lucena et al. (2012)
Buriti lumps	1.0 g/100 ml	Physical	99.21	4.96	Pinto et al. (2013)
Sugarcane	40 mg/20 ml	HCl	99.53	3.56	Ferreira et al. (2015)
Rice husk	0.2 g/20 ml	H_3PO_4	92.9	2.20	Miguel (2017)
Rice husk	0.2 g/20 ml	KOH	99.6	3.20	Miguel (2017)
Sugarcane	0.25 g/25 ml	H_3PO_4	99.79	Nd**	Silva (2017)
Water hyacinth	100 mg/10 ml	N_2	90.8	6.31	Lima (2018)
Coffee straw	1.5 g/50 ml	N_2	85	Nd**	Oliveira (2018)

•Dosage: Refers to the amount of adsorbent / amount of adsorbate. ** Nd: parameter not determined in the study.
Source: www.revistas.ufcg.edu.br.

(Cui and Zhang, 2004). Heavy metals are stabilized *in situ* by amending the soil with organic additives; this is mostly done to decrease the mineralization of metals and reduce absorption by plants (Komárek et al*.,* 2013). Heavy metals can be stabilized in polluted soils by biochar. Biochar can lead to the improvement of polluted soil (Ippolito et al*.,* 2012) and can greatly reduce the adsorption of heavy metals by crops. Thus, biochar has the potential of providing a novel remedy for soils polluted with heavy metals. There could be possible a large number of mechanisms involved in stabilizing heavy metals in soils using biochar. Using Pb^{2+} for instance, the research suggested different mechanisms for Pb^{2+} sorption with sludge-derived biochar as follows:

1. Heavy metal exchange with Ca^{2+}, Mg^{2+}, and other cations connected to biochar, due to co-precipitation and inner sphere complexation with complexed humic matter and biochar mineral oxides.
2. Surface complexation of heavy metals with various functional groups, and inner sphere complexation with the free hydroxyl of mineral oxides and other surface precipitation.
3. Physical adsorption and surface precipitation contributing to make Pb^{2+} stable (Lu et al., 2012).

Soils polluted with acids due to kind of biochar and levels of cation could facilitate discharge of same through sorption thus enhancing soil stabilization. Lu et al. (2012) showed that major cations often present in the sludge-derived biochar aide heavy metal exchange. However, contribution of cations with a valency of one (such as Na^+ and K^+) contributed little for heavy metal exchange. Thus, it is possible that under field condition, biochar adsorption mechanism for metal polluted soils is based on the soil types and cations in both soils and biochar; therefore results for using biochar for remedying soils polluted with metals might differ.

MERITS OF APPLYING BIOCHAR TO REMEDY SOIL AND WATER

Cheap source and waste management

Biochars are normally produced from inexpensive and abundantly existing waste biomaterials. Precisely, biochar feedstocks are mainly manufactured from the biomasses and solid wastes of agricultural works. Agricultural remains are seen in large amounts and are often difficult to dispose. For example, producing biochar from invasive plant can solve disposal problems and waste management. Also, aquatic algae are normally many and can block waterways; thus, other uses like the synthesis of biochar can benefit local people.

Nutrient

Pyrolysis of feedstock, leads to concentration of elements such as P, K, Ca, and Mg in biochar. Soluble organic substances are also formed during the pyrolysis process. Currently, using chemical fertilizers to improve soil is costly and out of reach for small farmers. Some disadvantages of the widespread use of chemical fertilizers are the soil acidity increase, mineral imbalance, and soil degradation (Ayoola and Makinde, 2008; Onmonya and Umeobika, 2020). Research has also shown that soils and residues can be characterized by total deficiency or low levels of organic matter and macronutrients and usually have an acidic pH, although some soil residues can be alkaline (Krzaklewski and Pietrzykowski, 2002; Gbadebo and Ekwue, 2014). In addition, tailings should also be without a normal soil structure and support a highly stressed heterotrophic microbial community (Mendez et al., 2007; Southam and Beveridge, 1992). The addition of biochar can provide plants and microrganisms with bioavailable nutrients. However, the nature of the starting materials and the conditions of pyrolysis determines the quality of biochar produced. The levels of C and N differed significantly in biochar when made from chicken droppings, pine and groundnut shells at 400 against 500°C. In addition, pyrolysis at 500°C yielded higher level of P, K, Ca, and Mg in biochar than at 400°C. This was due to the higher pyrolysis temperature, which decreased the CEC but enhanced mineralization of the feedstocks. In this context the goal is to maintain high quality of biomass, as well as the biochar given the right conditions for the process. In general, the nutrient content of plant derived vegetable biochar is comparatively lower than that of manure (Woolf et al*.,* 2010). In line with this, Onmonya and Umeobika (2020) recommended that researchers do more research on processed cow dung to improve soil quality.

Soil stability

Erosion effects in Nigeria is huge, especially gully erosion in the south and southeast of the country. The high water flow with the undulating topography creates a high water flow. The lack of drainage channels to control fluid flow and soil structure has contributed to the severe effects of erosion in this area (Hillili et al., 2011). Moreso, wind erosion predominates in some parts of the northern states. In 1995 it was estimated that over 700 million kg of metals were dumped in land mine debris each year (Warhurst, 2000). The global impact of such tailings dumps is enormous, since unused tailings piles typically lie fallow for several decades and exposed tailings piles can spread over several tens of hectares due to aeolian dispersion and water erosion (González and González-Chavez, 2006). This has the potential to contaminate nearby communities and ecologically sensitive areas (Gbadebo and Ekwue, 2014). It is therefore imperative to research for alternatives such as biochar for promotion of stable soils (Trazzi et al., 2018). Biochar acts as an isolated particle, distinct from other stable organic matter that trapped in aggregates, soil pores or adsorbed on mineral surfaces. Biochar makes it easier for carbon to be sequestrated in the soil, because it is highly stable in its organic form. Sun et al. (2018) reported a half-live of 102 – 107 years for carbon in biochar and stated that biochar mineralizes very slowly. Woolf et al. (2010) also reported that fine particles of biochar have been in soils in climates with low heat levels, like Amazon.

Effect of biochar on heavy metal mobility

Biochar can reduce the movement of heavy metals in polluted soils, resulting in a low risk uptake by plants. Research has shown that bamboo-derived biochar can absorb Cu, Hg, Ni and Cr from soil and water and Cd in contaminated soils. Cao et al. (2009) reported that biochar derived from dairy manure at 200 °C pyrolyzes Pb more effectively than biochar produced at 350°C due to the higher concentration of soluble phosphate in the biochar at 200°C. A remediation process can utilize different biochar and mechanism for multi-element polluted soils.Therefore, when using biochar to improve soils polluted with heavy metals, the types of heavy metals in the polluted soil and the temperature used in the production of biochar must be considered because their properties depend on the pyrolysis conditions such as the water content of the feedstock, highest treatment temperature, type of starting material used and residence time. The influence of biochar on the bioavailability of metals varies depending on the type of biochar products and heavy metals. The ratio of Cd and Zn in pore water of contaminated soil was reduced when biochar from hardwood was applied (Beesley et al., 2010). Similarly, addition of biochar to contaminated soil reduced the concentrations of Cd and Zn in the pore water by 300 and 45-fold in a column leaching experiment (Beesley et al., 2011). Namgay et al. (2010) showed that the ratios of As and Zn that can be extracted in soil became high with the application of biochar; extractable Pb reduced; Cu was unchanged and Cd was not constant. They also described that there was sorption of trace elements on biochar with initial loadings up to 200 mol at pH 7 in the order: Pb > Cu > Cd > Zn > As. Biochar can decrease the leakage of metals via its effect of redox reactions of metals (Choppala et al., 2012). The significant reduction in the leaching of Cr(III) is due to the uptake of Cr(III) onto cation exchange sites and precipitation as Cr(OH)3 resulting from the discharge of OH ions during the process of Cr(VI) reduction (Bolan et al*.,* 2013) as illustrated in Figure 1.

Biochar production and identification of the main biomasses used in this process

The two main techniques for converting biomass are: the use of enzymes and microorganisms (biochemical conversion) which is less expensive and environmentally friendly, although has a lower yield (Tripathi et al., 2016); and break down of biomass using heat (thermochemical conversion) (Kubilay et al., 2014). The thermochemical process includes conventional carbonization or pyrolysis, hydrothermal carbonization, incineration and gasification (Kubilay et al., 2014). The processes in this type of biochar production are mainly determined by the pyrolysis temperature, the residence time of the material in the reactor and the heating rate (Trazzi et al., 2018). Using biomass in combination with thermochemical synthesis has advantages in obtaining new carbonaceous

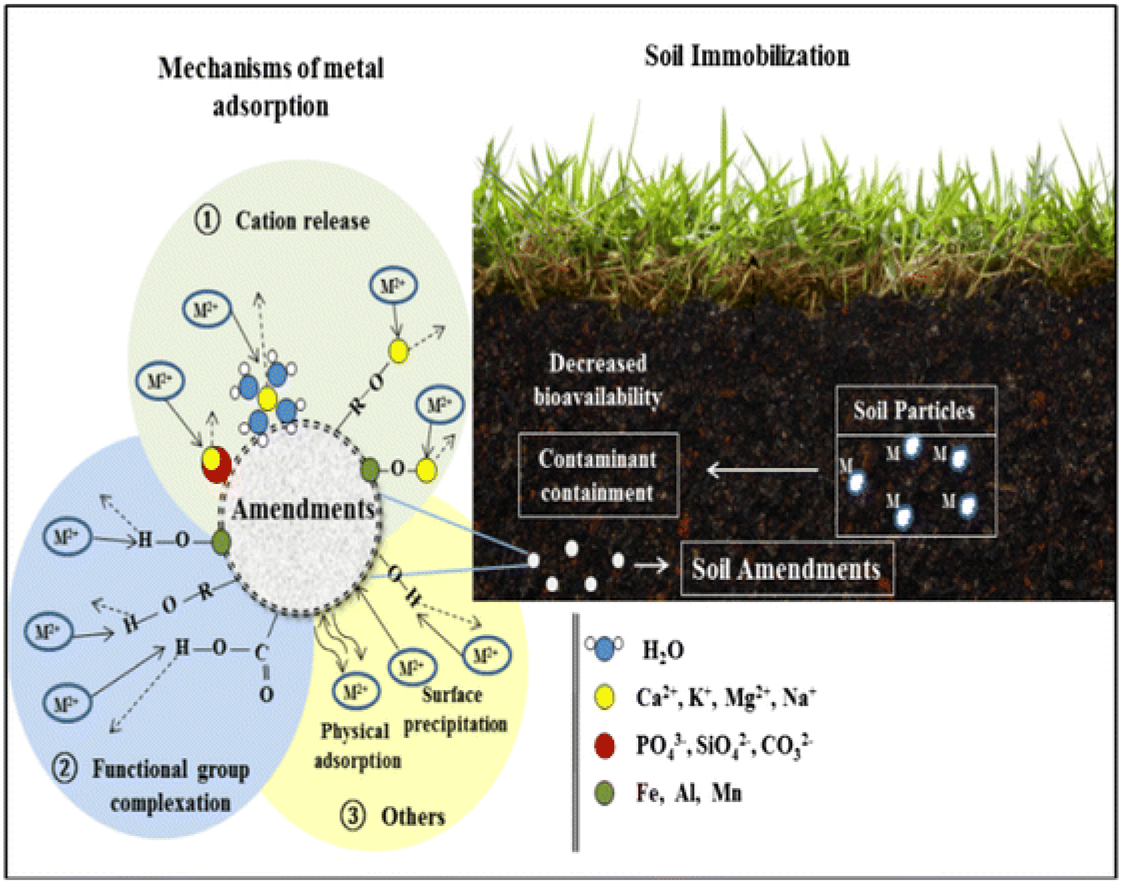

Figure 1. Mechanisms of metal Adsorption in Soil.

Table 2. Copper and lead removal in aqueous environment using various adsorbents chromium activator.

Adsorbent	Dosage*	Activator	Efficiency (%)	Adsorption capacity (mg g $^{-1}$)	Reference
Conventional	0.35 g/50 ml	Nd**	98	0.54	Souza et al. (2009)
Water hyacinth	7 g/L	Physical	92.24	36.34	Giri et al. (2012)
Acerola seeds	1 g/50 ml	Nd**	66	Nd**	Resende et al. (2014)
Sugarcane	10 mg/20 ml	HCl	99.97	5.26	Ferreira et al. (2015)
Yam peel	40 mg/200 ml	$C_6H_8O_7$	88.7	25.01	Tejada-Tovar et al. (2015)
African palm bagasse	40 mg/200 ml	$C_6H_8O_7$	58.8	41.57	Tejada-Tovar et al. (2015)
Walnut shells	Nd**	Physical	80.47	36.55	Altun and Kar (2016)
Rice residues	3 g/20 ml	H_3PO_4	72	6.67	Miguel (2017)
Sugarcane	0.5 mg/100 ml	H_2SO_4	29.13	0.2884	Ferreira (2018)
Corn cob	10 g/50 ml	H_3PO_4	93	25.69	Gupta et al. (2018)

•Dosage: refers to the amount of adsorbent / amount of adsorbate. ** Nd: parameter not determined in the study.
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materials with different applications, low cost, high availability in nature and fast regeneration (Santos, 2016). For (Novotny et al., 2015) various organic materials are suitable as raw materials in thermal processing, from agricultural and wood biomass to all available agricultural and industrial waste (husks, straw, seeds, bagasse, nut shells, wood chips, etc.) and even municipal waste (Table 2). The biochar produced in the

Table 3. Copper and lead removal in aqueous environment using various adsorbents mercury activator.

Adsorbent	Dosage*	Activator	Efficiency (%)	Adsorption capacity (mg g $^{-1}$)	Reference
Conventional	0.3 g/50 ml	Nd**	99.9	4.77	Tan et al. (2016)
Apricot	10 mg/50 ml	HCl	99.6	153	Ekinci et al. (2002)
Soybean stem	0.01 g/35 ml	Physical	74.5	86.4	Kong et al. (2011)
Bamboo	0.6 g/L	H_2O	99.13	248.05	González and Pliego-Cuervo (2014)
Cocoa husk	0.05 mg/50 ml	$ZnCl_2$	99.8	10	Kede et al. (2015)
Wheat straw	5 g/50 ml	N_2	98.1	10.47	Tang et al. (2015)
Hops	0.8 g/200 ml	Physical	>95%	Nd**	Liu et al. (2016)
Corn cob	0.8 g/200 ml	Physical	>95%	Nd**	Liu et al. (2016)
Cotton seed	0.8 g/200 ml	Physical	>95%	Nd**	Liu et al. (2016)
Corn cob	0.3 g/50 ml	N_2	99.8	3.23	Tan et al. (2016)

•Dosage: refers to the amount of adsorbent / amount of adsorbate. ** Nd: parameter not determined in the study.

Table 4. Copper and lead removal in aqueous environment using various adsorbents lead activator.

Adsorbent	Dosage*	Activator	Efficiency (%)	Adsorption capacity (mg g $^{-1}$)	Reference
Commercial	1 g/100 ml	Nd**	98.69	4.32	Nogueira (2010)
Babassu coconut shell	0.1 g/200 ml	H_2O	98.87	30.3	Golin (2007)
Moringa seed husk	1 g/100 ml	H_2O	98.21	136.98	Nogueira (2010)
Moringa seed husk	1 g/100 ml	CO_2	99.14	15.22	Nogueira (2010)
Green coconut	17 g/1 L	NaOH	98.79	Nd**	Ferreira et al. (2012)
Sugarcane	1 g/20 ml	HNO_3	96	20.77	Figueredo et al. (2017)
Pine nut shell	90 mg/30 ml	N_2	98.5	73.99	Lage Junior (2016)
Cocoa husk	8 g/8 L	Physical	91.32	0.07	Lara et al. (2016)
Yam peel	40 mg/200 ml	$C_6H_8O_7$	98.04	98.36	Tejada-Tovar et al. (2016)
Cassava peel	40 mg/200 ml	$C_6H_8O_7$	95.57	52.34	Tejada-Tovar et al. (2016)
Orange peel	1 g/100 ml	$ZnCl_2$	96	Nd**	Ali and Abdel-Satar (2017)
Sugarcane	0.5 mg/100 ml	H_2SO_4	54.74	0.4486	Ferreira (2018)

*Dosage: refers to the amount of adsorbent / amount of adsorbate. ** Nd: parameter not determined in the study.

pyrolysis process is high in energy comparable to the coal used in industry, owing to its microporous structure and high carbon content. In agriculture, it is used to improve soil quality and increase carbon storage. It slows down nutrient degradation and consequently improves soil quality. In the adsorption industry it is used to remove heavy metals such as Cr, Cd, Ni, Hg, Pb and organic compounds (Tripathi et al., 2016). Accordingly, low-cost alternative sources for the production of biochar are being researched into. Sofar agricultural residues such as rice husk (Doria et al., 2016), orange peel (Tejada-Tovar et al., 2015), corn cobs (Lopes et al., 2013), sugar cane bagasse (Ferreira et al., 2015) (Table 3) orange peel (Tejada-Tovar et al., 2015) (Table) 4 and the coir-chitosan composite (Costa et al., 2017) have shown great potentials for adsorption of pollutants.

HOW BIOCHAR AFFECT HEAVY METAL BIOAVAILABILITY

Heavy metals are generally found in small amounts in agricultural soils. However, due to their cumulative behavior and toxicity, they not only have a potentially harmful effect on crops but also on human health (Ekwue et al., 2012; Das et al., 1997). Heavy metal contamination of soil, water and crops and its health impact on local residents is an ongoing social problem, and several studies have identified health risks for local residents living near abandoned mines (Chung et al., 2005). Man-made pollutants can threaten human health and harm the natural ecosystem and environment (Hilli et al., 2021). The bioavailability of heavy metals determines toxicity in soil and potential risk upon entry into the environment. Fellet et al. (2011) reported that increased application of biochar resulted in increased pH, cation exchange capacity, and water-holding capacity and decreased bioavailability of some metals in mine tailings. In a study Zhou et al. (2008), used biochar derived from cotton stalks to improve Cd-contaminated soil, the biochar decreased the bioavailability of Cd in the soil. Mendez et al. (2012) also reported that biochar treatments reduced the plant availability of Ni, Zn, Cd and Pb compared to sewage sludge treatments in a Mediterranean agricultural soil. A reduced Cd, Cu and Pb uptake by Indian mustard was reported by Park et al. (2011) when they applied chicken manure and green waste derived biochar. The study also recorded reduced metal concentrations in plant except for Cu, with increased biochar application. Furthermore, biochar is highly effective in adsorption of many natural and anthropogenic sourced organic compounds (Sarmah et al*.,* 2010). Owing to its highly aromatic nature, large surface area, micropore volume and abundant polar functional groups, biochar is effective in absorbing a wide range of organic chemicals including pesticides, PAHs and new emerging contaminants such as steroid hormones (Kookana et al., 2011). The level of aromaticity, type of biochar and organic carbon play a major role for effective removal of contaminants (irrespective of the other properties of the biochar) (Sarmah et al., 2010).

CONCLUSION

Bioremediation supplemented with biochar is one of the most important remediation technologies for the remediation of soil and water bodies contaminated with heavy metals. Biochar-enhanced remediation has great potential for immobilizing cationic heavy metals in mining tailings, tailings piles and water bodies, especially those with high acidity. Biochar can reduce the bioavailability and leachability of cationic heavy metals in soil and water, improve soil fertility and greening, and create a suitable environment for soil microbial diversity. To reduce the bioavailability of the organic pollutants and the risk of the pollutants entering the human food chain or leaching into groundwater, biochar could be of immense benefit. However, the long-term environmental fate of the deposited pollutants is still unknown and further research is warranted to fill this gap, especially under realistic field conditions through biochar-mediated remediation trials. Furthermore, it is important to select appropriate biochar to develop an effective strategy to immobilize anionic metals in situ. Future research should focus on: biochar stability and its impact on the fate and transport of metals in mining tailings and large-scale soils and waters; and understand the mechanisms of biochar-assisted bioremediation.

CONFLICT OF INTEREST

The authors have not declared any conflict of interest.

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