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Performance evaluation of open air burnt sorghum and wheat straw ashes in hard water treatment

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Abstract The average values for the physiochemical parameters of raw water samples were 1.45 NTU, 5.42, 355 µS/cm, 8 Pt-Co, 60 mg/l and 740 mg/l respectively for turbidity, pH, EC, color, TDS and hardness. This measured hardness value of 740 mg/l was higher by 140 mg/l than the recommended standard for natural potable of 600 mg/l. In the course of hardness treatment, optimum dosages were obtained to be 20.0 g/l for WSA and 22.5 g/l for SSA, with hardness removal efficiencies of 53% and 42% respectively. At optimum dosages of the ashes, other physiochemical parameters of treated water samples were measured. Studies revealed that properties such as turbidity, pH, color and TDS of the treated water increased with respect to raw water samples but still remained within the acceptable limits except for alkalinity that was initially higher than the standard while EC and hardness reduced in percentages. The pH of raw water samples initially above the acceptable standards were found to be within the standards after being treated. The study revealed that WSA and SSA were good for hardness treatment and additives for raising the pH level. The ashes are recommended for hardness treatment being abundantly available and inexpensive for small scale hardness treatments in rural communities.

Keywords: Hardness treatment, SSA, SWA, Water quality parameters

Introduction

Water is the most important natural resource for human survival and sustainable socioeconomic development of all countries. It is an everlasting free resource that is vital for life (Rahman *et al*., 2014). Yet, its spatial and temporal distributions is highly uneven both in quantity and quality. Access to water supply is essential to good life and health. It is crucial and pivotal to many other goals highlighted in the United Nation's Sustainable Development Goals (SDGs). Sustainable access to water for potable and non-potable uses continues to pose enormous challenges in developing countries. The challenge of achieving

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water security in Africa is contingent on the hydrological variability and its extremes (Stakhiv and Stewart, 2010). However, the availability of freshwater resources has become a major challenge facing humanity worldwide especially in developing countries like Uganda. This situation has further been aggravated by high rate of urbanization, population growth, rising water demand, continuous depletion of fresh surface and groundwater, climate change, water governance, extreme social inequality and pollution (Karolinczak *et al*., 2020). These situations require that water resources be satisfactorily managed in terms of quantity and quality to meet the current demands and attain future sustainability.

According to UNDP (2006), some countries' child deaths is about 44 per cent, which are primarily caused by diarrhoea. It's been established that over 90 per cent of diarrheal deaths are attributable to poor hygiene, and unsafe drinking water. Despite this fact, about 1.1 billion people do not have access to safe drinking water. On a global scale, most of the rural communities have limited access to safe drinking water. Joint United Nations and World Health Organization reported that about 19% of the Ugandan population depend on unimproved water to meet their daily requirement. By this, more than 8 million people source their water from streams, hand dug wells, boreholes and ponds (Lifewater, 2020). It is imperative that water is thoroughly treated such that water-borne diseases like cholera, typhoid and others are avoided. Megersa *et al.* (2014) reported that waterborne infections are responsible for more than 80% of the diseases all over the world. Thus, water quality assessment and treatment are of concern to everyone.

It is reported that most rural communities in Republic of Uganda depend largely on rainwater harvesting and groundwater from boreholes, springs and shallow wells for domestic uses (Lukubye and Andama, 2017). This groundwater might have been contaminated by the parent aquifer and anthropogenic activities within and around the wells. Thus, having significant levels of hardness due to the dissolved polyvalent metallic ions from sedimentary rocks, and seepage from soils. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are the two principal ions present in many sedimentary rocks that contribute to the total hardness of water (WHO, 2017). Several studies have highlighted the health benefits of presence of Ca^{2+} in water (Bellizzi *et al*., 1999; Nerbrand *et al*., 2003; Miyake *et al*., 2004; Sengupta, 2013). However, very high content of Ca^{2+} and Mg^{2+} may lessen water acceptability due to taste and high total dissolved solids (TDS) which could lead to high risk of renal and arthritis problems (Sengupta, 2013; Frantisek, 2020). There have been reported techniques for water hardness removal like ion exchange, reverse osmosis, electro-coagulation, among others. Conversely, these techniques are not readily available and expensive for rural communities' application for hardness treatments. This study applies open air burnt wheat and sorghum straw ashes in softening hard water.

Wheat is one of the primary sources of food. Over 500 million tonnes of Wheat straw are produced and about 62 million metric tons of sorghum produced per year (Shahbaneh, 2022). In Uganda, Sorghum is the most important cereal crop after maize, rice and wheat. Uganda is the second largest producer of Sorghum in East Africa region after Tanzania (Tenywa *et al*., 2018). Kigezi sub-region of Uganda produces about 24,900 million tons in the year 2018 (UBoS, 2020). Pan and Sano (2005) highlighted that the average yield of straw is around 1.3 to 1.4 kg per kg of grain. The current use of wheat and sorghum straws are animal feeds, decomposition for manure, roofing small mud houses, among others. In Uganda and Kigezi in particular, these straws are burnt in an open field causing environmental issues and health problems.

After the burning process, ash is produced which is the solid residue, somewhat powdery substance that is left over after combustion. Although, ash is created during the process of incomplete combustion. This combustion can lead to generation of soot, smoke and ash. Due to chemical composition of the materials, the appearance of ashes can vary significantly. However, the chief chemical composition of ash is carbon, calcium, phosphorus, potassium, magnesium, etc. Ashes from burning of agricultural wastes contain compounds like potassium oxide and other metal oxides favourable for precipitation of Ca^{2+} and Mg^{2+}. Piekarczyk *et al*. (2011) opined that most of the agricultural wastes like straws contain about 155.7 grams of potassium per kilogram of straw ash. The potassium oxide has the potential to remove Ca^{2+} and Mg^{2+} ions that are responsible for hardness (WHO, 2017). Kharel *et al*. (2016) obtained concentration of potassium in wheat straw ash (WSA) as 32.2 g/kg of the ash while Food and agriculture organization -FAO (2020) reported 12.9 g/kg for sorghum straw ash (SSA). Thus, these are potential water softeners. However, extensive literature survey revealed that there is scarce research that applied WSA and SSA for hard water treatment. Kharel *et al*. (2016) conducted a study on water hardness removal using rice husk ash (RHA) and wheat straw ash (WSA) produced in a furnace with limited oxygen supply. Both ashes were effective for hardness removal with WSA outperformed RHA. Studies have shown that difference in chemical composition of ash depend on the type of combustion used for its production (Neina *et al*., 2020). Dodson *et al*. (2011) studied the effect of combustion time and temperature on the wheat straws and concluded that for all temperatures below 500ºC, potassium content remains constant irrespective of the extent of combustion and cooling condition. Furthermore, at 600ºC, the availability of potassium for extraction decreases with increase in temperature and combustion time.

Hettiarachchi *et al*. (2017) applied phosphoric acid activated coconut coir (ACC) as low-cost filter material for the removal of total hardness, Ca and Mg hardness from both artificial and natural hard water. Their studies revealed that at optimum dosage of 80.00 g/*l*, 30 minutes stirring and 2 hours settling time, removal efficiencies of total, Ca and Mg hardness, were approximately 46%, 66% and 30%, respectively from artificial hard water. In another study, Rolence *et al*. (2014), treated hard water by adsorption of hardness ions onto coconut shell activated carbons under various adsorbent conditions like adsorbent dose, initial pH, contact time, and temperature. The removal efficiency achieved were 60% and 55% respectively for the synthetic and field collected water samples. Mwakobe (2020) applied cashew nut shell activated carbon in a column for the removal of hardness from groundwater. It was concluded that it may be used to sufficiently remove total hardness from groundwater. Hence, the study investigated and evaluated the performance of open air burnt sorghum and wheat straw ashes in hard water treatment.

Materials and methods

Raw water sample and preparation of ashes

Sorghum straws and wheat straws were obtained respectively from Rubuguri town council, Kisoro district and Kanungu district, Uganda. Each sample was sorted to remove any other grasses or external unwanted materials. These straw samples were burnt separately in open air on clean trays to obtain uncontaminated ash samples. The ashes were then sieved to obtain the finer particles with a maximum size of 300 μ. This was aimed at increasing the specific surface area of the ash particles. The water samples were obtained from Koranorya Borehole in Rukungiri District, Uganda on the 25th January 2022.

Laboratory testing of water samples

Raw water samples were tested for hardness, color, pH, turbidity, electrical conductivity (EC), alkalinity and total suspended solid (TSS). The tests were conducted in accordance with the standard operating procedures by the National Water and Sewerage Corporation (NWSC, 2015) water quality handbook of Uganda. The water quality parameters considered, equipment used, and methods of tests adopted in this study are presented in Table 1.

Table 1. List of water quality parameters, equipment and methods of test

Parameters	Equipment/Apparatus used	Method of test
Hardness	Complexometric titration	ISO 6059
Colour	Spectrophotometer	ISO 7887
EC	Electrical conductivity meter	ISO 7888
pH	pH Meter	ISO 10523
Turbidity	Spectrophotometer	ISO 7027
TSS	DR 2010 Spectrophotometer	ISO 11923
TDS	Spectrophotometer	ISO 11923
Alkalinity	pH meter	ISO 10523

Hardness removal experiment

The hard water samples were treated with the ashes and the degrees of the hardness were measured after the treatment. The ashes (SSA and WSA) were applied separately for hardness treatment. For the first experiment, 2.5 g of SSA were measured using an electronic weighing balance and put in a 1 litre bottle. A 200 ml of water was added and then vigorously shaken to ensure that the ash mixes completely with the water. Another 200 ml of water was added and the vigorously shaken until the 2.5 g of SSA was fully mixed with the water. The mixture was then allowed to settle for 1 hour for the heavier particles to settle at the bottom and the light flocks remained on top. The light flocks were filtered before measuring the hardness and other physiochemical properties. The residual hardness and other physiochemical properties of treated water samples were then measured using standard methods (NWSC, 2015).

The procedures above were repeated by increasing the ash content of SSA and WSA at regular increments of 2.5 g until optimum dosage was achieved. Total hardness was measured by titrating the water samples against EDTA acid or its sodium salt so as to form a stable complex ion with Ca^{2+} or Mg^{2+} with Eriochrome Black T as an indicator. At start, 50 ml of hard water sample was taken in a 250 ml titration flask, and then 2 ml of NH_3-NH_4Cl buffer and three drops of indicator were added, which changed the colour of solution to wine red during titration. The experiment described above was repeated using SWA for water hardness treatment.

Determination of other physiochemical properties of water

At optimum dosage of SWA and SSA for hardness treatment, parameters such as colour, EC, pH, turbidity, TSS and alkalinity were measured to determine the effect of the ashes on other physiochemical properties of water. Thereafter, hardness values and ashes dosages were modelled (using linear, polynomial and exponential functions) to establish relationships. Standard equipment used and methods of testing were adopted for measuring the physiochemical properties of water.

Results

Analysis of raw water sample

The physiochemical properties such as turbidity, pH, EC, color, Alkalinity, TDS and hardness of raw water samples were tested using standard methods and equipment. The average values for each of the physiochemical parameters were obtained to be 1.45 NTU, 5.42, 355 μS/cm, 8 Pt-Co, 60 mg/l and 740mg/l respectively for turbidity, pH, EC, color, TDS and hardness as presented in Table 2.

Table 2. Physiochemical properties of raw water sample and US EAS standards

Parameters	**Raw water Sample**	**Max. Recommended Standard by US EAS (2014)**	
		Treated portable water	**Natural portable water**
Turbidity (NTU), max	1.45	5	25
pH	5.42	6.5 - 8.5	5.5 - 9.5
E.C. (μS/cm), max	355	1500	2500
Color (Pt-Co), max	8	15	50
Alkalinity (mg/l)	576	500	500
TDS (mg/l)	60	700	1500
Hardness (mg/l)	740	300	600

Analysis of hardness removal with wheat straw ash

The hardness values were measured for 0, 2.5, 5.0, up to 25.0 mg of added WSA in a litre of water as described in the hardness removal experiment. Then, the average hardness values were evaluated. The plot of average hardness (y) against the dosage of WSA (x) applied for the hardness treatment is presented in Figure 1.

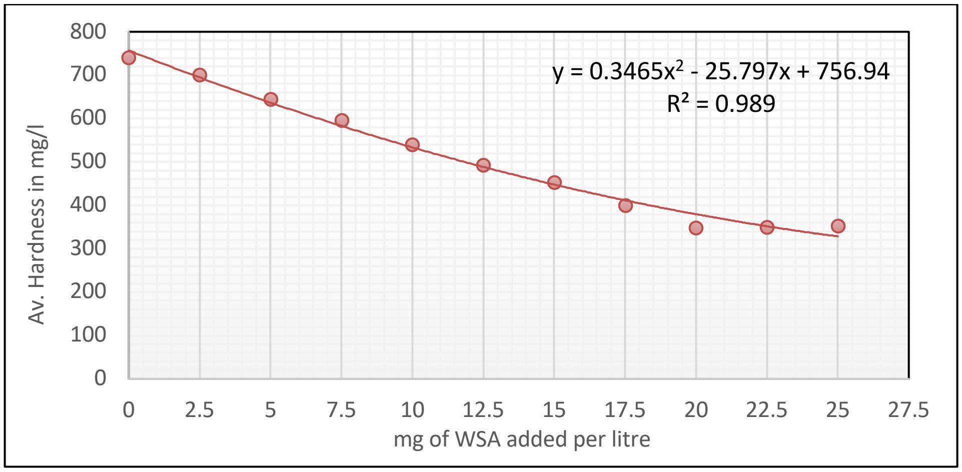

Figure 1. Dosage of WSA mg per litre of water sample

It was observed that the addition of WSA beyond 20 g/l did not significantly reduce the hardness. Hence, 20 g/l of WSA was taken as the optimum dosage of the ash. The water sample after addition of 20 g of WSA, was then tested to ascertain if the addition of WSA increases or decreases the physiochemical parameters of water sample. The turbidity, pH, color, alkalinity and TDS increased by 55.2%, 27.5%, 75.0%, 12.0% and 296.7% respectively while EC and hardness reduced by 17.2% and 53.0% respectively as presented in Table 3.

The trend analysis using linear, exponential and polynomial functions for WSA and SSA hardness treatments analyzed and results are presented in Table 4. Analysis showed that polynomial function had the highest correlection coefficient than others for both SSA and WSA.

Table 3. Impact of 20 g/l dosage of WSA on other physiochemical properties of water

Parameters	Before addition of WSA	After addition of WSA	% Change
Turbidity NTU	1.45	2.25	55.2
pH	5.42	6.91	27.5
EC (µS/cm)	355	294	-17.2
Color (Pt-Co)	8	14	75.0
Hardness (mg/l)	740	348	-53.0
Alkalinity (mg/l)	576	645	12.0
TDS (mg/l)	60	238	296.7

Table 4. Trend analysis for WSA and SSA hardness treatments

S/No	Functions	Coefficient of correlation (R^2) for WSA	Coefficient of correlation (R^2) for SSA
1	Linear	0.9696	0.9769
2	Exponential	0.9765	0.9713
3	Polynomial	0.9890	0.9968

Analysis of hardness removal with sorghum straw ash

The plot of average hardness against the dosage of SSA applied for the hardness treatment is presented in Figure 2. Similar to the results of WSA, a decreasing trend in the average hardness values was observed as the dosage of SSA increased. Contrarily, at a dosage of 12.5 g of SSA, the average hardness value of 578 mg/l satisfied the hardness value (i.e., less than the maximum permissible of 600 mg/l) for natural potable water.

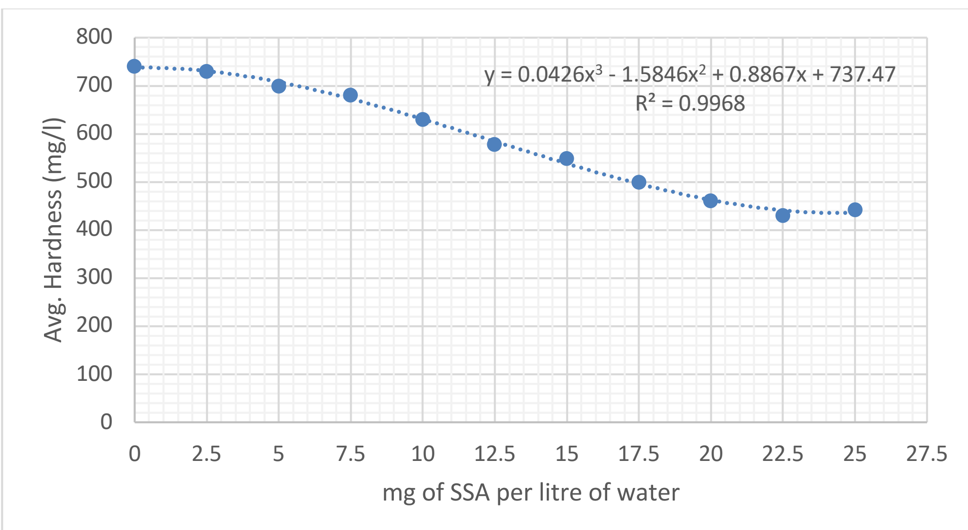

Figure 2. Dosage of SSA mg per litre of water sample

The impact of SSA on other physiochemical parameters of the sample before and after addition of 22.5g at optimum dosage are presented in Table 5. This elucidated the extent of changes in other physiochemical parameters at 22.5 g/l dosage of hardness treatment with SSA. Turbidity, pH, color, alkalinity and TDS increased by 62.1%, 29.5%, 75%, 17.0% and 306.7% respectively after addition of 22.5g/l of SSA while EC and hardness reduced by 12.1% and 41.9% respectively.

Table 5. Impact of 22.5 g/l dosage of SSA on physiochemical properties of water

Parameter	Before addition of SSA	After addition of SSA	% Change
Turbidity NTU	1.45	2.35	62.1
pH	5.42	7.02	29.5
EC (μS/cm)	355	312	-12.1
Color (Pt-Co)	8	14	75.0
Hardness (mg/l)	740	430	-41.9
Alkalinity (mg/l)	576	674	17.0
TDS (mg/l)	60	244	306.7

Discussion

High water hardness is often attributed to groundwater resources which is required to be treated in order to fix it within permissible limits. Various techniques like ion-exchange, distillation reverse osmosis, etc., have been in used for hardness removal. Due to high cost, energy requirement and rigorous processes in these techniques, it is imperative to find an alternative techniques of hardness removal most especially for rural communities of developing countries. Hence, this study applied locally available agricultural waste ashes, i.e., WSA and SSA openly burnt for water hardness treatment. In this study, the performances of WSA and SSA were evaluated and compared for their hardness removal efficiency from water. The physiochemical properties of raw water samples were compared with the Uganda Standard, US EAS (2014) by National Standards Council of Uganda, for the treated and natural potable waters specifications reproduced from the East African Standard, EAS 12: 2014. The results showed a decreasing trend in the average hardness values as the dosage of WSA increases. At a dosage of 7.5 g of WSA, the average hardness value of 596 mg/l has satisfied the hardness value (maximum of 600 mg/l) for natural potable water recommended by Uganda Standard, US EAS (2014). From Table 2, the maximum allowable water hardness ranges from 300 to 600 mg/l (US EAS, 2014). However, the average hardness value of raw water measured was 740 mg/l which is above the recommended standard for natural potable of 600 mg/l by 140 mg/l. Furthermore, the average alkalinity value of 576 mg/l obtained for the raw sample is higher than the maximum (max.) recommended for natural potable water, while, EC is far less. It imperative to note that the public acceptability of the degree of hardness of water may vary considerably from one community to another. According to WHO (2017), consumers may tolerate water hardness in excess of 500 mg/l.

Depending on the interaction of other factors, such as pH and alkalinity, water with hardness exceeding 200 mg/l may cause scale deposition in the treatment equipment, distribution network and tanks within the buildings (WHO, 2017). This scale build up may also lead to low water pressures from the showers due to clogged pipes (Byjus, 2021). It was observed that the hardness and EC reduced respectively by 53.0% and 17.2% at 20 g/l of WSA. The hardness removal efficiency of 53% was achieved at 20 g/l dosage. Conversely, Kharel *et al*. (2016) obtained an average hardness removal efficiency of 76%. Further analysis showed that other physiochemical parameters like color, TDS, turbidity and alkalinity increased by 75.0%, 296.7%, 55.2% and 12.0% respectively. Although, they still remained within the acceptable limits for potable water (Uganda National Bureau of Standards, 2014) except for alkalinity that even fell outside the range of raw water sample. Furthermore, the initial pH of 5.42 which was below the 5.5 minimum in the standards increased to 6.91 that is within the range for natural potable water (Uganda National Bureau of Standards, 2014). This was in disagreement with the results of Kharel *et al*. (2016) in which the pH obtained after use of WSA and Rice Husk Ash (RHA) go far beyond the limit for natural and treated potable waters. The average hardness values and dosages for WSA and SSA were modeled using linear, polynomial and exponential functions. The correlation between hardness and WSA dosage, and predictive models are developed. The results showed that all the functions fitted excellently for hardness treatment. However, polynomial function of second order is the best fit having the highest coefficient of correlation (R^2) of 0.9890. Similar to SWA, the results for correlation between hardness and SSA dosage showed that all the functions fitted excellently. However, polynomial function of third order is the best fit having the highest coefficient of correlation (R^2) of 0.9968 for SSA.

It is observed that further addition of the ash after the 22.5 g/l did not reduce the hardness. Hence, 22.5 g per litre was taken as the optimum dosage of SSA that reduced the hardness by 42%. Thus, water sample at 22.5 g dosage of SSA was then tested to ascertain the impacts of SSA on the other physiochemical parameters of water sample. Result showed 41.9% reduction in hardness at 22.5 g/l of SSA which is the hardness removal efficiency. Similarly, EC also reduced by 12.1% while other physiochemical parameters such as pH, color, TDS, turbidity and alkalinity increased by 29.5%, 75.0%, 306.7%, 62.1% and 17.0% respectively at 22.5 g/l dosage. Similar to WSA, all these parameters are still within the limits except for alkalinity which still increased to go beyond the maximum as per the (Uganda National Bureau of Standards, 2014).

In conclusion, the WSA and SSA hardness removal efficiencies were obtained to be about 53% and 42% at optimum dosages of 20.0 g/l and 22.5 g/l respectively. At these optimum dosages, WSA and SSA increased other physiochemical parameters of water such as pH, color, TDS, turbidity and alkalinity but still remained within the acceptable limits except for alkalinity that was initially higher than the standard. Moreover, the water samples had a pH that was outside the acceptable standards. Applying both ashes for hardness treatment raised it to fall within the limits for natural potable water. In modeling the hardness removal against the dosages, all functions: linear, exponential and polynomial functions excellently fitted the relationships. However, polynomial function is the best fit with second and third orders for WSA and SSA respectively. Thus, WSA and SSA are relatively good additives for raising the pH of hard water sources. These ashes are available and cost effective for small scale household water hardness treatments especially in rural communities of developing countries.

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