Journal of Environmental Science and Technology

ISSN 1994-7887

science alert

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS Journal of Environmental Science and Technology

ISSN 1994-7887
DOI: 10.3923/jest.2017.268.275

Research Article
Application of *Moringa oleifera* Plant as Water Purifier for Drinking Water Purposes

[1]Jessica Tunggolou and [2]Carolyn Payus

[1]Natural Disaster Research Centre (NDRC), Faculty of Science and Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia
[2]Water Research Unit (WRU), Faculty of Science and Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia

Abstract

Background and Objective: Drinking water needs to be treated in order to remove impurities and bacteria to meet the quality guidelines which satisfy 5 nephelometric turbidity unit (NTU) for drinking water requirement according to World Health Organization. This project is aimed to compare the treatment efficiency of *Moringa oleifera* Lam. to that of aluminum sulphate, regarding both treatment efficiency and their effects on water quality in terms of turbidity removal. **Methodology:** The study is conducted using Jar tests. Data obtained from the experiments are analyzed using microsoft excel office professional plus 2013 and pearson correlation. **Results:** *Moringa oleifera* as coagulant reduced the initial turbidity reading of 35.9±1.65 NTU to 3.17±0.3 NTU at optimum dosage of 15 mg L^{-1} while aluminum sulphate to 7.26±2.13 NTU at dosage of 55 mg L^{-1}. The treatment efficiency of both coagulants are as follows, *Moringa oleifera* with 91.17% and aluminum sulphate 78.72%. At initial acidic reading 5.67±0.23 of the water sample, *Moringa oleifera* final pH reading increases to 6.05±0.03 while aluminum sulphate decreases to higher acidity level of 3.43±0.05. The initial conductivity reading 86.67±5.77 μS increased significantly to 1120±10.0 μS for aluminum sulphate while for *Moringa oleifera* remains fairly constant at 113.33±5.77 μS. The final temperature recorded for both coagulants are still at room temperature range of 22.07-24.97°C. **Conclusion:** Thus, in the light of this study, an establishment of a cheaper and safer coagulant to treat the problems that rises due to the usage of aluminum sulphate such as health implications for rural areas usage can be established.

Key words: *Moringa oleifera*, aluminum sulphate, coagulation process, turbidity, conductivity

Citation: Jessica Tunggolou and Carolyn Payus, 2017. Application of *Moringa oleifera* plant as water purifier for drinking water purposes. J. Environ. Sci. Technol., 10: 268-275.

Corresponding Author: Jessica Tunggolou, Natural Disaster Research Centre (NDRC), Faculty of Science and Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia Tel: +6-014-3513572

Copyright: © 2017 Jessica Tunggolou and Carolyn Payus. This is an open access article distributed under the terms of the creative commons attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The number of current world population that is living in developing country was estimated to be 75% out of the total and the number of people still lacking safe drinking water was 1.2 billion. In developing country, more than 6 million children die from diarrhoea each year[1]. This data shows that not getting clean drinking water supply is a major concern that should be solved in developing countries. Numerous nations that are as yet inadequate with regards to water treatment system can't appear to provide their residents with an adequate quality that follow the minimum requirement of a drinking water which resulted in the image of an ideal country where all citizens receive clean water supply has totally vanished.

It was known that poorly treated water resulting from lacking water treatment facilities has been said to cause waterborne diseases that kills people every day while others suffers from the side effects[1]. Waterborne diseases are known as the diseases that arise due to the directly transmitted pathogenic micro organisms when the contaminated drinking water is consumed. It was caused by multiple and various kinds of microorganisms such as protozoa, viruses, bacteria and intestinal parasites. Due to this waterborne disease outbreaks, water that is to be consumed for drinking must undergo purification process before they can be considered as safe. Since disease causing agents and toxic chemicals might be present in the drinking water, systematic water quality monitoring and surveillance are required to control the risks to public health[2]. Therefore it is necessary to treat the drinking water to remove impurities and bacteria in the water in order to meet the quality guidelines which satisfy 5 NTU for drinking water requirement according to WHO[3].

As stated by Ali *et al.*[1], among the most used water treatment method in the water treatment industry before distributing them to the consumers in the past is coagulation-flocculation that is followed by sedimentation, filtration and disinfection, which is usually done using chlorine. But nowadays, in the water treatment latest technology, they are using chemicals such as aluminum sulphate which is a synthetic coagulant to enhance the water purification. Drinking water source for majority of the expanding and growing countries was limited mostly to river water and the treatment processes is heavily depended on the chemicals that is used as water treatment agents such as aluminum sulphate but however, even those chemicals are mostly imported and are expensive[4].

On top of that, the usage of aluminum sulphate as coagulant also causes the water to be acidic and hence to neutralize the water, lime will be needed to balance the pH of the water. This is known as pH adjustment where it is added to the water during treatment process and is regarded as another added cost for water treatment companies[1]. Other than its cost, among the reasons why there should be a plant based coagulant to replace synthetic coagulants is due to aluminum sulphate threatening properties in drinking water. Coagulants that occurred naturally are regarded as safe in terms of health for human while synthetic coagulants, especially aluminum salt, has probability inducing Alzheimer's disease[5]. This is supported by other studies where rising health risks was mentioned from drinking the water with residual aluminum left in it such as neurodegenerative illness[6].

Other than proposed to own better properties in terms of water turbidity removal compared to aluminum sulphate, *Moringa oleifera* also possessed numerous health benefits. Among other great properties of *Moringa oleifera* are such as anti-ulcer, hepatoprotective, anti-bacterial, anti-fungal, anti-hypertensive, anti-tumor, anti-cancer activities and last but not least, diuretic and cholesterol lowering activities[7]. Thus as a solution to the problem that has been stated, *Moringa oleifera* can be used as an alternative to replace synthetic aluminum to reduce the turbidity of the water and make it more suitable and safe to be consumed by humans. This study thus, was aimed to compare the efficiency of seed extracts of *Moringa oleifera* and aluminum sulphate in treating water that is used for drinking purposes and also to look into a deeper depth of how the water quality factors (turbidity, pH, conductivity and temperature) affects the efficiency of aluminum sulphate and *Moringa oleifera* dosage when it is used for the groundwater sample.

MATERIALS AND METHODS

This study was conducted from May, 2016-May, 2017 at Universiti Malaysia Sabah (UMS) Environmental Science laboratory.

Preparation of coagulants: There were two types of coagulants used in this study, a naturally occurring coagulant, which is *Moringa oleifera* and a synthetic type of coagulant that is aluminum sulphate (laboratory grade).

Moringa oleifera pods was first collected from the tree and only *Moringa oleifera* of the best and matured quality were obtained. Removal of the seeds from the plant was done manually. Throughout the whole experiment, only the seeds that are brown in colour are used due to their higher coagulation activity as compared to the green pods which has no coagulation properties. The seeds were air-dried at 40°C for

2 days. The seeds were then removed from the seed coats manually and the remaining seeds kernel is grounded using basic pestle and mortar (PPM125) soon afterwards to convert them into powder.

The aluminum sulphate which acts as synthetic coagulant was used for comparison in terms of treatment efficiency with *Moringa oleifera*. Aluminum sulphate was also grounded into fine powder using pestle and mortar to be used in the study.

Preparation of water sample: The water sample used in this study was sampled from the well in Kampung Gaur located in Kota Belud district, Sabah. The water is used as an actual drinking water source at the location by the rural people.

Jar tests study: The jar tests was conducted using Junke and Kunkel jar test (Lovibond ET 730) apparatus where the equipment used 4 beakers with 1000 mL capacity each with four paddles rotation. The parameters were tested before and after the treatment given. The first three beakers were filled with 1000 mL of water in each beaker, while the fourth beaker is left untreated for control. The different coagulant concentration and amount was then added to the water sample to be tested. After the addition of the coagulant, the water was mixed rapidly using 125 rpm for 5 min and then slowed down to 50 rpm for 30 min. It was then left undisturbed to settle for 1 h. After the settlement of the water treatment, the water was taken and measured.

Parameters tested: There are four important parameters that were tested in this study according to the drinking water guidelines quality such as turbidity, pH, conductivity and temperature. Turbidity was tested using turbidity meter (HACH 2100P), pH was tested using pH meter (Digimed DM-2), conductivity using conductivity meter (EC 500) and temperature using basic thermometer. All of the parameters were tested accordingly and the data obtained will be used to determine if the water treatment system using *Moringa oleifera* is in the range of the water quality. This is to ensure that system is safe to be a source of drinking water.

Statistical analysis: Data obtained from the experiments are analyzed using Microsoft Excel Office Professional Plus 2013 and pearson correlation. The p value was also determined to show if there was a significant difference with either ($p>0.05$)[8].

RESULTS AND DISCUSSION

Turbidity: The sample initial reading of the groundwater is considered as low and it is because there only certain cases could cause changes in turbidity for the groundwater due to the presence of aquifers to filter the water while surfaces water such as river water, could have dramatic increase in turbidity in cases such as after the rain because of the storm runoff that is discharged directly to the stream. Since groundwater has aquifers, the water streams is filtered by normal processes, while the surfaces water encounter immediate effect as there are no aquifers to channels the contaminants[9].

The stability of the colloidal owe its property to their static electricity and hence, with the addition of the coagulants that carries positive charges to the water, destabilization of the colloidal in the water takes place and the negative charges on the colloidal are disturbed making the coagulation of the particles possible[10], thus creating the trend shown in the Fig. 1. The most significant finding of using *Moringa oleifera* as coagulant is the reduction from initial reading of turbidity at 15 mg L^{-1} with 91.17% of removal efficiency where the lowest turbidity was achieved even with smaller doses used compared to aluminum sulphate at 55 mg L^{-1} with only 85.46% as seen in Table 1.

The patterns of reduction for both coagulants from the graph were seen to increase and decrease gradually which shows that both of them utilizes adsorption and neutralization process to balance out the charges on the colloidal and hence showing similar trend of increasing turbidity when overdosing occurred as well. The importance of dosage has on turbidity has been emphasized by Zand and Hoveidi[11]. Coagulant cause an increase in water treatment cost above its ideal dosage and this is not financially reasonable. Another reason why over-dosing should be avoided as well is because there is a probability of restabilization of the destabilized particles to occur due to the saturation of the polymer bridge[12]. The settling of the particles is disturbed making it impossible to reach the desired turbidity needed. This is the reason why both of the coagulants used showed similar trend of increasing turbidity after achieving their optimum dosage.

Table 1: Table showing treatment efficiency (%) of both coagulants used

Dosage (mg L^{-1})	Aluminum sulphate (%)	*Moringa oleifera* (%)
0	0.00	0.00
5	66.66	57.94
10	52.79	44.09
15	20.61	91.17
20	21.25	73.48
25	24.15	77.77
30	24.04	77.69
35	15.24	78.72
40	4.46	78.05
45	6.690	78.66
50	70.86	78.72
55	78.72	85.46
60	3.260	83.40

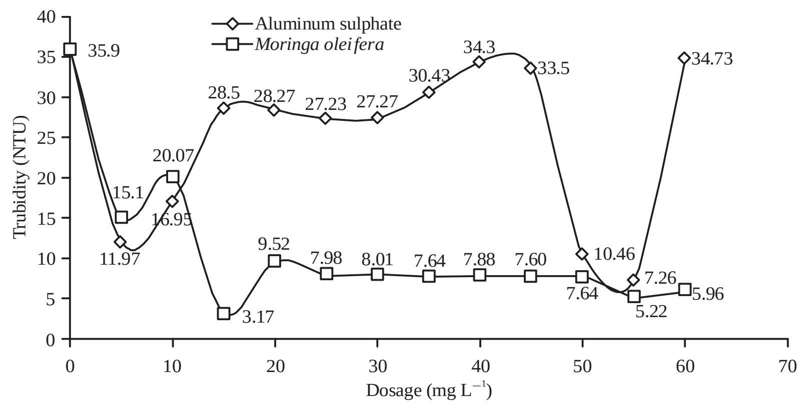

Fig. 1: Graph shows the comparison of dosage (mg L^{-1}) against turbidity (NTU) for both coagulants used

The ability of aluminum sulphate to reduce turbidity of the water sample can be explained as such, when added to water, aluminum salts are hydrolysed producing cationic species responsible for absorbing negatively charged particles of the colloidal and also for neutralizing their charge. Destabilization of the particles then can takes place[11]. As for the responsible mechanism of *Moringa oleifera* for the turbidity reduction, it is mostly due to the seed proteins[3]. Another reason that makes the purification possible is due to the functional groups in the side amino acids of *Moringa oleifera* seed proteins. The ability of *Moringa oleifera* to reduce turbidity of the water sample is due to their coagulation capacity which involves adsorption and neutralization of the positive charges colloidal that attracts in charged particles in the water. Since the *Moringa oleifera* seed proteins are charged positively at pH underneath 10 and the contaminants are considered as negatively charged particles, they bind to the contrarily charged pollutions in the water when they are added to the water sample[13].

pH: The initial groundwater pH which is not in the range of permissible limit by World Health Organization (WHO) turns more acidic in the usage of aluminum sulphate. In the case of using *Moringa oleifera* as coagulant, the pH reading remained fairly constant. The pH of World Health Organization (WHO) standard for drinking water is 6.0-8.5 and even though the initial groundwater reading is acidic, the change in the pH reading when *Moringa oleifera* solution was used results in the final pH reading being in the permitted range of standard for drinking water. The acidic initial reading of the groundwater is probably caused by soil and water natural acidification which is a biogeochemical process that happens very slowly by soil respiration, a process where soil organisms respire and produce carbon dioxide and the carbon dioxide dissolves in water giving away carbonic acid which is a type of weak acid formed in the solution[4]. This explained the acidity of the initial reading of the groundwater collected which is in accordance with the findings from Knutsson[14].

Every coagulant is said to have its own optimal range of pH which affects the efficiency of their actions thus making pH an important parameter to be considered[15]. The final pH reading for aluminum sulphate is below the permitted range of drinking water due to alkalinity consumption during hydrolysis by the coagulant. This is consistent with the results obtained from Jowa and Mguni[16], where they stated that aluminum sulphate is more acidic and hence its consumption of alkalinity is higher to prevent the water to become acidic. Sasikala and Muthuraman[17] stated for the coagulation efficiency using *Moringa oleifera,* at pH acidic which is at less than 6 and also pH that is greater than 11, their coagulation efficiency is particularly good due to the domination of positive charges on the amino acids that build the protein molecule.

The trend of the reduction of both coagulants was seen to increased and decreased gradually as seen in Fig. 2 due to the hydrolysis where the hydrogen ions are balancing out the hydroxide ions for both of the coagulants [12]. But however, the most significant finding is the usage of aluminum sulphate was seen to reduce the pH of the groundwater sample to acidic, while for *Moringa oleifera*, the most significant finding of using *Moringa oleifera* is that they do not turns water into acidic as compared to when aluminum sulphate is used even though there are some readings that fall below the limit. The research conducted by Ndabigengesere *et al.*[13] also reported the same findings as the current research where increased in dosage used for aluminum sulphate caused the pH to decrease drastically to pH reading of 4.2, while *Moringa oleifera* does not affect the pH value significantly.

Acidic water consumption is harmful known to be harmful to the consumers. Among the consequences of supplying the

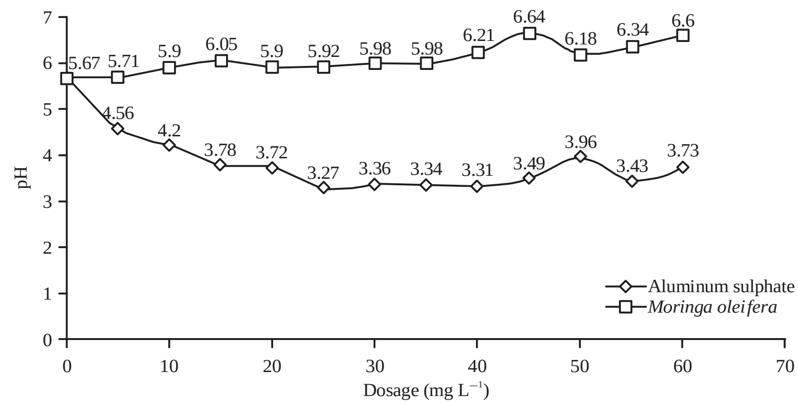

Fig. 2: Graph shows the comparison of dosage (mg L^{-1}) against pH for both coagulants used

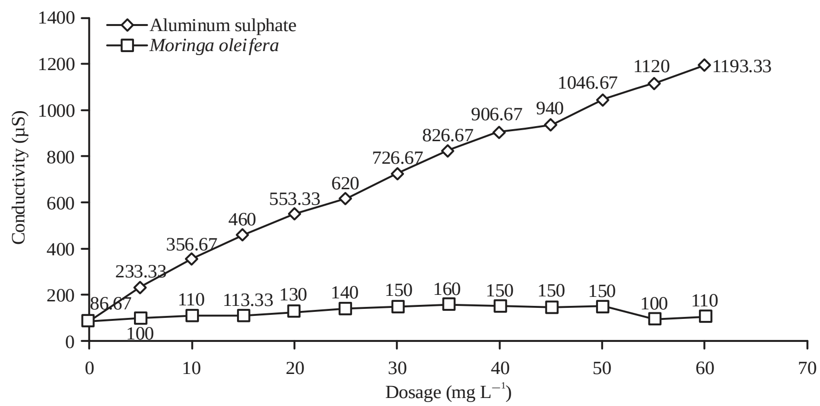

Fig. 3: Graph shows the comparison of dosage (mg L^{-1}) against conductivity (µS) for both coagulants used

water without treating their pH is corrosion of the plumbing that is used to channel the water from the water treatment plant to houses. The corrosive nature of acidic water causes metal ions such as iron, manganese, copper, lead and zinc to leach into the water, causing elevated levels of toxic metals in the water. It may also cause aesthetic problems, such as a metallic or sour taste. Thus, using plant extracts such as *Moringa oleifera* for water treatment may have an enormous advantage by eliminating the need for application of lime or bicarbonate that is needed to raise the pH, reduces life threatening effects and hence, it provides extra cost savings.

Conductivity: The trend of the initial conductivity as shown in Fig. 3 of the groundwater increased significantly when aluminum sulphate was used. However when *Moringa oleifera* was used as coagulant, the conductivity of the groundwater only increased slightly. The permissible limit of conductivity reading of World Health Organization (WHO) for drinking water is 0-3000 µS and hence the both of the coagulants are in the permissible limit allowed.

From the conductivity graph, it can be seen that with an increased in dosage, the conductivity reading also increased generally. Both of the coagulants, aluminum sulphate and *Moringa oleifera* show similar trend of increasing conductivity. But the increase in the conductivity reading was expected as a result of the ions formation in the water during the coagulation process. Formation of the ions also contributed to the overall conductivity[16]. Thus, higher coagulant dosage in the solution will eventually lead to an increase in conductivity as observed. When aluminum sulphate was used, the conductivity reading of the water increased due to the water reaction with acidic or alkaline metals. The reaction of the salt with the water is also one of the possible causes for the rise in the reading. Another reason that contributes to the rise is the dissociation of the inorganic compounds which results in the water's ability to conduct very large electric current. The conductivity value is also dependent on ions concentration in the water[18]. When *Moringa oleifera* was used, the results revealed that the use of excess *Moringa oleifera* above the ideal dosage results in the rise in the

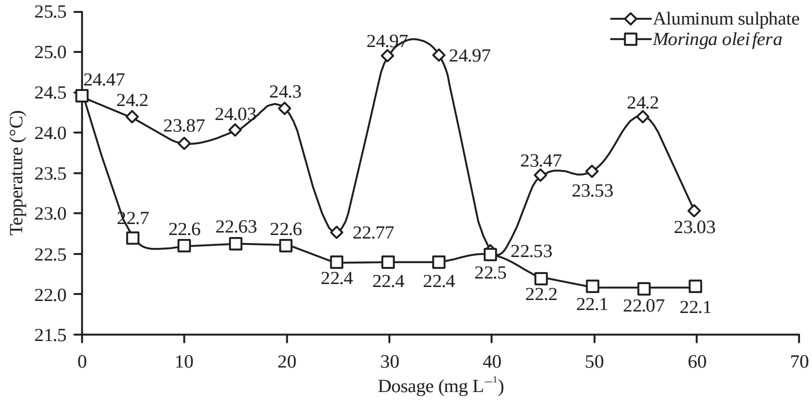

Fig. 4: Graph shows the comparison of dosage (mg L^{-1}) against Temperature (°C) for both coagulants used

conductivity reading again believed to be caused by the unbound ions that present in the water [18]. Overall in the current research, the coagulation process using *Moringa oleifera* has only slight effects on the degree of conductivity as they reacted as positively charged natural polymer coagulant.

Temperature: It was shown that at 5% concentration of the seed suspension of stock solution, both of the coagulants used are in the limit of room temperature range as seen in Fig. 4. The initial temperature of the groundwater was 24.47°C and the highest temperature after the addition of aluminium sulphate is 24.97°C meanwhile for *Moringa oleifera* is 22.7°C. Both of the coagulants readings are however still in room temperature range. This is in accordance with the study from Hendrawati *et al.*[18], where the finding from their study was found to be in line with the finding from this study. The study has stated that after the addition of the powdered *Moringa oleifera* seeds when used as coagulant in the water purification and treatment processes, the initial reading of the groundwater sample of 28.40°C only reached 29.00°C at their highest. Thus, it was concluded in the study that the use of the coagulant in the process does not affect the water temperature drastically as their temperature is still in the normal range for water.

Leon-Luque *et al.*[15], in their research has stated that temperature affects the coagulation efficiency rate since lower temperature usually takes longer for the particles for flocculation to takes place. From the study by Krupinska[19], the reason why this occurred is explained by the decreasing speed of the hydrolysis reaction and precipitation rate of the cation hydroxides and increased in water viscosity as well. Increase in viscosity of the water usually lowers the sedimentation speed of the after coagulation particles that was formed and might increase the stability of the colloidal that was supposed to be removed as well. When the study tested aluminum sulphate coagulation efficiency in the water temperature of 15 and 25°C, the coagulation efficiency of alum at 25°C achieved better removal of the particles which is 83% as compared to 15°C which is only 52%.

A study by Othman *et al.*[20], shows that the efficiency of the *Moringa oleifera* coagulation was reduced when temperature of the wastewater was increased from 30-70°C. This is most probably caused by the temperature effects where charge destabilization of the suspended solids in the wastewater occurred. This might be due to particles collision rates and also through the viscosity (concentration) effects in the water. Since increasing the temperature decreases the floc strength, the floc can be easily broken and hence decreases the efficiency rates. The coagulation rate of *Moringa oleifera* also works best at 30°C with 99.2% of suspended solids removal. The same study performed by Fitria *et al.*[21] investigated the effects of temperature at 20 and 26°C using *Moringa oleifera* as coagulant and has found out that *Moringa oleifera* works better at 26°C than at 20°C. At 26°C, the performance is higher probably because *Moringa oleifera* proteins are more active at higher temperatures.

Different findings reported different results variations as there are no fixed or constant temperature that the coagulants are said to be most effective. But however, in this case study, by comparing the coagulation efficiency of aluminum sulphate and *Moringa oleifera*, the initial water temperature of 24.47°C clearly is more favourable for *Moringa oleifera* coagulant as their efficiency rate is higher at their optimum dosage. Thus as results, the findings from this study where conducting the research at optimum room temperature gives the highest turbidity removal of 78.72% at 55 mg L^{-1} for aluminum sulphate, at final temperature of 24.2°C and 91.17% at 15 mg L^{-1} for *Moringa oleifera*, at final temperature of 22.63°C. From the different findings that were reported in this study, at normal room temperature, *Moringa oleifera* exhibits higher coagulation rate compared to aluminum sulphate.

CONCLUSION

The results indicated that seed extracts of *Moringa oleifera* were very effective in reduction of turbidity. At optimum dose, large reductions of turbidity was achieved, but above the optimum dose, there was a reduced turbidity removal efficiency of *Moringa oleifera*. The results revealed optimum dosage to treat the well water sample was 15 mg L^{-1} for *Moringa oleifera* and 55 mg L^{-1} for aluminium sulphate. In a nutshell, *Moringa oleifera* was more effective than aluminium sulphate. In general, extracts of both coagulants showed comparable turbidity removal performance with *Moringa* being 91.17 and alum 78.72%, respectively. Other significant finding revealed that extracts from the plant did not affect pH of water samples unlike alum. The plant species can meet the requirements of drinking water quality in terms of maximum permissible limit of turbidity ($\leq$5 NTU) if they are used for rural area household water treatment with further optimization.

SIGNIFICANCE STATEMENTS

This study discover the treatment efficiency of a naturally available coagulant, *Moringa oleifera* compared to a synthetic coagulant, aluminum sulphate for drinking water purposes that can be beneficial for rural area where water treatment is scarce and lacking. This study help the researchers to uncover the critical areas of drinking water quality that resulted from the usage of aluminum sulphate and *Moringa oleifera* when used as coagulants that many researchers were not able to explore. Thus a new theory on a naturally occurring coagulant-based such as *Moringa oleifera* usage and health effects to be used in water purification process can be established.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support of the University of Malaysia Sabah (UMS) Grant (GUGU0026-STWN-M-1/2016).

REFERENCES

1. Ali, E.N., S.A. Muyibi, H.M. Salleh, M.R.M. Salleh and M. Alam, 2009. *Moringa oleifera* seeds as natural coagulant for water treatment. Proceedings of the 13th International Conference on Egyptian Water Technology 2009, March 12-15, 2009, International Islamic University Malaysia, Hurghudah, Egypt, pp: 163-168.
2. Nand, V., M. Maata, K. Koshy and S. Sotheeswaran, 2012. Water purification using *Moringa oleifera* and other locally available seeds in Fiji for heavy metal removal. Int. J. Applied Sci. Technol., 2: 125-129.
3. WHO., 2006. Guideline for Drinking-Water Quality (Electronic Resources): Incorporating First Addendum. Vol. 1, 3rd Edn., World Health Organization, Geneva.
4. Yusuf, J., M.B. Yuakubu and A.M. Balarabe, 2015. The use of *Moringa oleifera* seed as a coagulant for domestic water purification. IOSR J. Pharm. Biol. Sci., 10: 6-9.
5. Ali, E.N., S.A. Muyibi, H.M. Salleh, M.Z. Alam and M.R.M. Salleh, 2010. Production technique of natural coagulant from *Moringa oleifera* seeds. Proceedings of the 14th International Water Technology Conference, IWTC'10), Cairo, Egypt, pp: 95-103.
6. Egbuikwem, P.N. and A.Y. Sangodoyin, 2013. Coagulation efficacy of *Moringa oleifera* seed extract compared to alum for removal of turbidity and *E. coli* in three different water sources. Eur. Int. J. Sci. Technol., 2: 13-20.
7. Anwar, F., S. Latif, M. Ashraf and A.H. Gilani, 2007. *Moringa oleifera*: A food plant with multiple medicinal uses. Phytother. Res., 21: 17-25.
8. Vieira, A.M.S., M.F. Vieira, G.F. Silva, A.A. Araujo, M.R. Fagundes-Klen, M.T. Veit and R. Bergamasco, 2010. Use of *Moringa oleifera* seed as a natural adsorbent for wastewater treatment. Water Air Soil Pollut., 206: 273-281.
9. Egboka, B.C., G.I. Nwankwor, I.P. Orajaka and A.O. Ejiofor, 1989. Principles and problems of environmental pollution of groundwater resources with case examples from developing countries. Environ. Health Perspect., 83: 39-68.
10. Postolachi, L., V. Rusu, T. Lupascu and A. Maftuleac, 2015. Improvement of coagulation process for the Prut River water treatment using aluminum sulphate. Chem. J. Moldova, 10: 25-32.
11. Zand, A.D. and H. Hoveidi, 2015. Comparing aluminium sulfate and Poly-Aluminium Chloride (PAC) performance in turbidity removal from synthetic water. J. Applied Biotechnol. Rep., 2: 287-292.
12. Megersa, M., A. Beyene, A. Ambelu, D. Asnake and T. Bekele *et al*., 2016. A preliminary evaluation of locally used plant coagulants for household water treatment. Water Conserv. Sci. Eng., 1: 95-102.
13. Ndabigengesere, A., K.S. Narasiah and B.E. Talbot, 1995. Active agents and mechanism of coagulation of turbid waters using *Moringa oleifera*. Water Res., 29: 703-710.
14. Knutsson, G., 1994. Acidification Effects on Groundwater: Prognosis of the Risks for the Future. In: Future Groundwater Resources at Risk, Gunay, G., A.I. Johnson and W. Back (Eds.). International Association of Hydrological Sciences, USA.

15. Leon-Luque, A.J., C.L. Barajas and C.A. Pena-Guzman, 2016. Determination of the optimal dosage of aluminum sulfate in the coagulation-flocculation process using an artificial neural network. Int. J. Environ. Sci. Dev., 7: 346-350.
16. Jowa, T. and L.L. Mguni, 2015. Treatment of low turbidity water using Poly-Aluminium Chloride (PAC) and Recycled Sludge: Case study Chinhoyi. Zimbabwe J. Sci. Technol., 10: 101-108.
17. Sasikala, G. and G. Muthuraman, 2016. A laboratory study for the treatment of turbidity and total hardness bearing synthetic wastewater/ground water using *Moringa oleifera*. Ind. Chem., Vol. 2. 10.4172/2469-9764.1000112.
18. Hendrawati, I.R. Yuliastri, E. Rohaeti, H. Effendi and L.K. Darusman, 2016. The use of *Moringa oleifera* seed powder as coagulant to improve the quality of wastewater and ground water. IOP Conf. Ser., Vol. 31.
19. Krupinska, I., 2014. Effect of the type of aluminium coagulant on effectiveness at removing pollutants from groundwater in the process of coagulation. Proceedings of the International Conference on Environmental Engineering, Volume 9, May 22-23, 2014, Vilnius, pp: 1-8.
20. Othman, Z., S. Bhatia and A.L. Ahmad, 2008. Influence of the settleability parameters for Palm Oil Mill Effluent (POME) pre-treatment by using *Moringa oleifera* seeds as an environmental friendly coagulant. Proceedings of the International Conference on Environment, December 15-17 2008, Penang, Malaysia.
21. Fitria, D., M. Scholz, G.M. Swift and S.M. Hutchinson, 2014. Impact of sludge floc size and water composition on dewaterability. Chem. Eng. Technol., 37: 471-477.