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Comparative Evaluation of the Efficiency of three Tropical Plants Extracts for the Treatment of Grey Water

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ABSTRACT

A study of the ability of three plants extracts to treat grey water from domestic source was carried out. The plant materials used were extracts of Agave sisalana leaves, Moringa oleifera seeds and Parkia biglobosa seeds. The investigation involved the applications of the extracts the respective plants singly and synergistically at dosages of 100 mg/l, 120 mg/l and 150 mg/l to treat domestic grey water. Turbidity (NTU), pH, total dissolved solids (mg/l) electrical conductivity (µs/cm), dissolved oxygen (mg/l) BOD (mg/l) and total coliforms (CFU/100 ml) were measured using standard methods. The relative performance indices obtained showed that M. oleifera + P. biglobosa had the best performance (0.84) which was closely followed by M. oleifera alone (0.83). The least performance was recorded by A. sisalana extracts alone (0.39), The study concluded the A. sisalana, M. oleifera and P. biglobosa can serve as readily available, cost-effective, and environmentally friendly alternative coagulants and antimicrobial agents in grey water treatment.

1. INTRODUCTION

The quest for cleaner and sustainable environment and the dwindling freshwater resources occasioned by climate change is rapidly increasing global interest in wastewater treatment and reuse (Igboro et al., 2019). While the obvious reason and motivation for this increasing interest is arguably the increasingly pressure on freshwater resources as a result of the rapidly increasing global population, unrelenting urbanization, droughts, and climate change (Piao et al., 2010; Owamah et al., 2021), the race to achieve the sustainable development goals (SDGs) by 2030 is the major trust behind the recent drive towards the reuse of wastewater as an alternative water supply source (Sachs et al., 2021). According to Griggs et al. (2013), the sustainability of development is dependent on its ability to meet the needs of the present, while safeguarding Earth's life-support system, on which the welfare of current and future generations depends. Consequently, a cardinal focus of the sixth Sustainable Development Goal is to improve water quality by reducing pollution, eliminating dumping, and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe re-use globally (UN, 2015; Lee et al., 2016; Sachs et al., 2021). The attainment of this goal cannot be achieved without paying attention to the twelfth goal which focuses on responsible consumption and production. It makes it necessary that the planning of water supply must be accompanied by an appropriate system of treatment, reuse, and possible resource recovery (Kazour et al., 2019). This therefore necessitates the need for wastewater reclamation since new sources of freshwater supply have become increasingly scarce, expensive, or politically controversial (Garrick et al., 2020). As a result, efforts are currently being made to identify new ways of meeting water needs (Alfa et al., 2014; Igboro et al., 2016). The reclamation of greywater for potable and non-potable use depending on the level of treatment is one of such techniques for the safe reuse of wastewater (Menge, 2010; Teh et al., 2015).

Notwithstanding the increasing attraction for the application of treated wastewater for irrigation of various crops and gardens, especially due to the limited freshwater availability and increasing food demand, there are significant safety concerns. The primary concern is the potential of damaging effects of poor-quality water on soil, plants, and humans (Alfa et al., 2014; Igboro et al., 2016; Igboro et al; 2019). For instance, the microbial population of untreated water is very diverse, and dangerous organisms can be present. Many microorganisms that can cause illness or disease, collectively known as pathogens, are usually associated with human or animal faecal matter present in wastewater and surface water sources (Sarowska et al., 2019). While irrigation water may not necessarily be of potable quality, the quality should be as less objectionable as possible especially for crops that may be consumed without further processing (Igboro et al., 2019).

Irrigation water contaminated with pathogens have often been blamed for outbreaks of foodborne illnesses (Shaheen et al., 2019). It is therefore important to carefully manage this risk when promoting the reuse of non-potable water sources to fulfil the water demand of agricultural irrigation activities.

Synthetic chemical reagents have been used traditionally as both coagulants and disinfectants in the treatment of wastewater. However, the synthetic chemicals are a cause of concern due to their non-native nature, non-degradability, and health conditions associated with their left-over residues. (Gautam and Saini, 2020). The quest for sustainability therefore has led to the exploration of natural agro-based materials that can be used as cost-effective, environment-friendly, and sustainable alternative to the application of synthetic chemicals (Gautam and Saini, 2020).

Some of the natural materials that have been explored for the treatment of greywater are extracts of *Moringa oleifera* seed (Alfa et al., 2014), *Parkia biglobosa* leaf, seed and bark (Igboro et al., 2016) and *Agave sislana* leaf (Igboro et al., 2019). The focus of the aforementioned studies was the efficiency of the various extracts in the reduction of specific physicochemical and microbial characteristics of the grey water. Thus, the results presented some percentages indicating their respective efficiencies. The limitation however is that they failed to assess these efficiencies in relation to the standards set by the World Health Organization (WHO).

While the studies established the ability of the respective plant materials to reduce the grey water physicochemical and microbial characteristics by varying percentages, a further investigation of the conformity of this treated grey water to recommended standards is reported herein. This is to establish whether the respectively treated grey water is fit for intended reuse based on recommended standard or not.

2. MATERIALS AND METHODS

2.1. Collection of Plant Leaves and Seeds

Agave sisalana leaves, *Moringa oleifera* seeds and *Parkia biglobosa* seeds were obtained from the Botanical Garden of the Department of Biological Sciences, Ahmadu Bello University Zaria, Nigeria (Figure 1a-c).


Figure 1a: *Agave sisalana* leaves

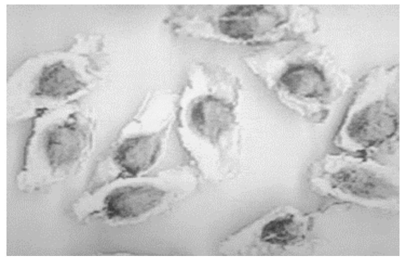
Figure 1b: *Moringa oleifera* seeds


Figure 1c*: Pakia biglobosa* seeds

2.2. Preparation of Leaf and Seed Extracts

The methods of preparation of the extracts of the respective tropical plants have been described previously (Alfa et al., 2014; Igboro et al., 2016; Igboro et al., 2019). The methods involved washing, drying, grinding, sieving and the preparation of the suspensions according to the required concentrations were adopted without modification. Dosages of 100 mg/l, 120 mg/l and 150 mg/l were obtained and utilized for this experiment.

2.3. Collection of Grey Water Sample

Greywater sample used for this study was obtained from the residential area of the Ahmadu Bello University Main Campus, Samaru, Zaria, Nigeria. The sample was collected and immediately transported in a 10-litre high density poly-ethylene container under dark conditions to the Environmental Health Engineering Laboratory of the Department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria for analysis. This was to prevent further deterioration of the greywater quality on account of continuous microbial activities (Noman et al., 2019). Characterization of the grey water sample was carried out before treatment in order to establish a baseline for the assessment of the performance of the treatment process.

2.4. Experimental Design

Twenty-one experimental setups were used out to assess the efficacy of treatment with the different extracts. The first nine of the experimental setup involved treatment of greywater with 100 mg/L, 120 mg/L and 150 mg/L dosages of *A. sisalana, M. oleifera and P. biglobosa.* The next nine setups involved the treatment of greywater with 100 mg/L, 120 mg/L and 150 mg/L dosages of *A. sisalana + M. oleifera, A. sisalana + P. biglobosa* and *M. oleifera + P. biglobosa* combined in ratio 1:1 to assess their respective combined efficiencies. The last three designs involved the application of 100 mg/L, 120 mg/L and 150 mg/L dosages of a combination of the three extracts combined in ratio 1:1:1 to assess their combined effect.

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2.5. Method of Analysis

2.5.1. Physicochemical analysis

Respective extracts dosages of 100 mg/l, 120 mg/l and150 mg/l were used to treat 500 ml of greywater samples. The experimental setups were stirred for 1 minute at rapid mixing (10 rpm) followed by slow mixing for 20 minutes (5 rpm) after which the setups were turned off to allow settling of the flocs for an hour. After settling, 20 ml of the sample was taken from the supernatant of each beaker using a pipette and placed in a small bottle for turbidity measurement. The measurement of turbidity was carried out using a turbidimeter (HACH model 2100P). Measurement of other parameters were carried out on the supernatant to determine the effect of the extracts on filtered grey water. The physicochemical analysis of the raw and treated greywater samples was carried out according to standard methods for analysis of water and wastewater (APHA, 2012). This method has been previously applied and reported (Alfa et al., 2014; Igboro et al., 2016; Igboro et al., 2019). The parameters analyzed are turbidity (T), electrical conductivity (EC), pH, dissolved oxygen (DO), total suspended solids (TSS) and biochemical oxygen demand (BOD).

2.5.2. Microbial analysis

Total coliform evaluation was carried out on the raw greywater samples as well as those treated with varying doses of the respective extracts' combinations using the plate count method described previously (Gomis et al., 2001; Nataro et al., 2011; Washington, 2012). The media used included Eosin Methylene Blue (EMB) and MacConkey Agar. The plates were incubated at 37 ^oC for 24 hours. After incubation, number of bacterial colonies was determined using colony counter and expressed as colony forming units (CFU) per 100 ml.

2.5.3. Estimation of relative performance index

The performances of the respective extract combinations were compared using the relative performance index described previously in Igboro et al. (2019) with slight modifications. The modification was in the inclusion of the conformity of the parameters to the World Health Organization (WHO)/Food and Agriculture Organization (FAO) guidelines for reuse of wastewater for irrigation (Blumenthal et al., 2000; Carr, 2005; Kotut et al., 2011; WHO, 2015). The performance of each extract combination in the reduction of the respective parameters was ranked on a scale of 1 – 7 with 1 being the least and 7 being the highest. In the case of the conformity to the guidelines, a value of 1 was assigned for conformity and value of 0 for non-conformity. They were both expressed as percentages after which the average was taken. The average performance score for each was used to determine the relative performance index.

3. RESULTS AND DISCUSSION

3.1. Characteristics of Raw Grey Water

The physicochemical and microbial characteristics of the raw grey water are presented in Table 1. The turbidity of the raw grey water was 76 NTU, the electrical conductivity was 935 µs/cm, the pH was 8.07, the dissolved oxygen was 6 mg/l, the total suspended solids was 37 mg/l, the biochemical oxygen demand was 149 mg/l while the total coliforms was 173×10^5 cfu/100 ml. These values served as the baseline for the assessment of the efficiency of treatments using the respective extracts combinations.

Table 1: Characteristics of the raw grey water

Parameter	Value
Turbidity (NTU)	76.00
Electrical conductivity (µs/cm)	935.00
pH	8.07
Dissolved oxygen (mg/l)	6.00
Total suspended solids (mg/l)	37.00
Biochemical oxygen demand (mg/l)	149.00
Total coliform (×10^5 cfu/100 ml)	173.00

3.2. Physicochemical and Microbial Characteristics of Treated Grey Water

The physicochemical and microbial characteristics of the grey water treated with 100 mg/l, 120 mg/l and 300 mg/l of the respective extracts combinations are presented in Tables 2, 3 and 4 respectively. The negative percentage reduction obtained for dissolved oxygen indicates that there was rather increase in the dissolved oxygen which was expected. This is because the dissolved oxygen is expected to increase as the waste is being stabilized (Harja et al., 2016). The results presented in Tables 2, 3 and 4 revealed that the best performances for all parameters tested were obtained at a dosage of 150 mg/l. The turbidity value obtained from treatment of greywater with 100 mg/L, 120 mg/L and 150 mg/L of *A. sisilana* did not meet up with the 5 NTU guideline set by the World Health Organization (WHO), despite the significant reduction up to 90.79 % recorded. A similar pattern was recorded for all combinations with *A. sisilana* at 100 mg/l and 120 mg/l but at 150 mg/l, *A. sisilana + M. oleifera* and the combination of the three extracts reduced the turbidity to values below 5 NTU recommended by WHO/FAO guidelines. In the case of *A. sisilana + P. biglobosa,* the final turbidity at a dosage of 150 mg/l was 5.44 NTU which was slightly above the recommended standard. More so, at dosage of 150 mg/l of all extracts combinations, the values of EC, pH, DO and BOD were all within the WHO/FAO guidelines. The total coliforms, however, did not conform to the limits of 10^3 and 10^5 respectively set by the WHO for restricted and unrestricted irrigation. This notwithstanding, reduction in the total coliforms up to 90.74% was recorded with 150 mg/l of *M. oleifera.* With exception of *A. sisilana,* the BOD of greywater treated with 150 mg/l of all extracts combinations were all within the WHO/FAO guideline (Carr, 2005).

Table 2a: Physicochemical and microbial characteristics of grey water treated with 100 mg/L dosage of extracts

Extracts combination	Turbidity (NTU)		Electrical conductivity (µs/cm)		pH		Dissolved oxygen (mg/L)	
	Value	% Reduction	Value	% Reduction	Value	% Reduction	Value	% Reduction
Agave	22.00	71.05	912.00	2.46	7.60	5.82	7.50	-25.02
Moringa	2.54	96.66	679.59	27.32	7.20	10.81	8.32	-38.69
Parkia	5.02	93.40	908.00	2.89	7.82	3.04	8.47	-41.13
Agave + Moringa	12.10	84.07	795.80	14.89	7.40	8.32	7.91	-31.86
Agave + Parkia	13.45	82.30	910.00	2.67	7.71	4.43	7.98	-33.07
Moringa + Parkia	3.55	95.32	793.80	15.10	7.51	6.93	8.39	-39.91
Agave + Moringa + Parkia	9.70	87.23	833.20	10.89	7.54	6.56	8.39	-39.91
WHO/FAO guidelines	<5		<2700		6.5 - 8.4		>2	

Table 2b: Physicochemical and microbial characteristics of grey water treated with 100 mg/l dosage of extracts

Extracts combination	Total suspended solids (mg/l)		Biochemical oxygen demand (mg/l)		Total coliform (×10^5 cfu/100 ml)	
	Value	% Reduction	Value	% Reduction	Value	% Reduction
Agave	32.00	13.51	70.00	53.02	85.00	50.87
Moringa	15.08	59.25	49.63	66.69	48.53	71.95
Parkia	0.66	98.21	46.00	69.13	90.00	47.98
Agave + Moringa	23.54	36.38	59.81	59.86	50.00	71.10
Agave + Parkia	16.33	55.86	58.00	61.07	60.00	65.32
Moringa + Parkia	7.87	78.73	47.81	67.91	40.00	76.88
Agave + Moringa + Parkia	15.91	56.99	47.81	67.91	74.51	56.93
WHO/FAO guidelines	<20		<30		0.01 - 1*	

Table 3a: Physicochemical and microbial characteristics of grey water treated with 120 mg/l dosage of extracts

Extract combination	Turbidity (NTU)		Electrical conductivity (µs/cm)		pH		Dissolved oxygen (mg/L)	
	Value	% Reduction	Value	% Reduction	Value	% Reduction	Value	% Reduction
Agave	13.00	82.89	876.00	6.31	7.53	6.67	8.69	-44.87
Moringa	2.35	96.91	706.68	24.42	7.03	12.89	8.96	-49.36
Parkia	4.90	93.55	862.00	7.81	7.58	6.09	9.03	-50.45
Agave + Moringa	7.67	89.90	791.34	15.36	7.28	9.78	8.83	-47.11
Agave + Parkia	9.01	88.15	869.00	7.06	7.56	6.38	8.86	-47.66
Moringa + Parkia	3.68	95.16	784.34	16.11	7.30	9.49	8.99	-49.90
Agave + Moringa + Parkia	6.79	91.07	814.89	12.85	7.38	8.55	8.99	-49.90
WHO/FAO guidelines	<5		<2700		6.5 - 8.4		>2	

Table 3b: Physicochemical and microbial characteristics of grey water treated with 120 mg/l dosage of extracts

Extract combination	Total suspended solids (mg/L)		Biochemical oxygen demand (mg/l)		Total coliform (×10^5 cfu/100 ml)	
	Value	% Reduction	Value	% Reduction	Value	% Reduction
Agave	29.00	21.62	40.43	72.87	70.00	59.54
Moringa	14.26	61.46	33.74	77.36	33.42	80.68
Parkia	1.13	96.96	32.11	78.45	80.00	53.76
Agave + Moringa	21.63	41.54	37.09	75.11	30.00	82.66
Agave + Parkia	15.06	59.29	36.27	75.66	40.00	76.88
Moringa + Parkia	7.69	79.21	32.93	77.90	35.00	79.77
Agave + Moringa + Parkia	14.80	60.01	32.93	77.90	62.67	63.77
WHO/FAO guidelines	<20		<30		0.01 – 1.00	

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Table 4a: Physicochemical and microbial characteristics of grey water treated with 150 mg/l dosage of extracts

Extract combination	Turbidity (NTU)		Electrical conductivity (µs/cm)		pH		Dissolved oxygen (mg/L)	
	Value	% Reduction	Value	% Reduction	Value	% Reduction	Value	% Reduction
Agave	7.00	90.79	777.00	16.90	7.43	7.93	9.38	-56.26
Moringa	2.21	97.10	720.17	22.98	6.97	13.63	9.52	-58.74
Parkia	3.88	94.90	771.00	17.54	7.45	7.68	9.69	-61.56
Agave + Moringa	4.77	93.73	748.59	19.94	7.20	10.78	9.45	-57.50
Agave + Parkia	5.44	92.84	774.00	17.22	7.44	7.81	9.53	-58.91
Moringa + Parkia	3.21	95.78	745.59	20.26	7.21	10.66	9.61	-60.15
Agave + Moringa + Parkia	4.47	94.12	756.06	19.14	7.28	9.75	9.61	-60.15
WHO/FAO guidelines	<5		<2700		6.5 - 8.4		>2	

Table 4b: Physicochemical and microbial characteristics of grey water treated with 150 mg/l dosage of extracts

Extract combination	Total suspended solids (mg/L)		Biochemical oxygen demand (mg/l)		Total coliform ($x10^5$ cfu/100ml)	
	Value	% Reduction	Value	% Reduction	Value	% Reduction
Agave	27.00	27.03	23.45	84.26	50.00	71.10
Moringa	8.56	76.86	19.76	86.74	16.02	90.74
Parkia	1.16	96.86	15.55	89.56	51.49	70.23
Agave + Moringa	17.78	51.94	21.61	85.50	19.31	88.84
Agave + Parkia	14.08	61.94	19.50	86.91	25.75	85.12
Moringa + Parkia	4.86	86.86	17.66	88.15	22.53	86.98
Agave + Moringa + Parkia	12.24	66.92	17.66	88.15	40.34	76.68
WHO/FAO guidelines	<20		<30		0.01 - 1*	

The respective extracts combinations exhibited antimicrobial activities which are related to physio-chemical characteristics of some secondary metabolites which include saponins, glycosides, terpenoids, alkaloids, flavonoids, and tannins (Clark et al., 1981; Teponno et al., 2016). Tannins have been reported to prevent the development of micro-organisms by precipitating microbial protein and making nutritional protein unavailable for them (Clark et al., 1981; Teponno et al., 2016).

3.3. Performance Indices

The relative performance indices and performance ranking for all the extracts combination are presented in Table 5. The results show that *M. oleifera + P. biglobosa* had the best performance with an index of 0.84 which was closely followed by *M. oleifera* only with an index of 0.83. The least performance was recorded by *A. sisilana* alone with an index of 0.39 signifying a 39 % average performance based on percentage reduction and conformity with specified guidelines for reuse. The indispensable role of media in the reclamation of water has been strongly reported (Adin and Asano, 1998; Bhuptawat et al., 2007; Ferrera et al., 2015; Gupta et al., 2016). The optimal performance of the three natural media as well as their respective combinations is a step in the right direction towards the comprehensive reclamation and reuse of domestic grey water (Prodanovic et al., 2017; Gassie and Englehardt, 2017; Nautiyal et al., 2017; Uliana et al., 2017). However, the recommendations of the WHO with respect to reuse of grey water with these characteristics for irrigation should be strictly adhered to especially in crop restrictions and the method of application

(WHO, 2015). The guideline recommended the use of close – to – the – ground method of application of treated grey water for irrigation. Although significant reduction in pollutant load was recorded in this study, the subsurface irrigation recommended for heavily contaminated grey water is also recommended in this study where it is feasible (WHO, 2015).

Table 5: Relative performance indices of the seven extracts combinations

Extract combination	Performance index	Rank
Agave	0.39	7
Moringa	0.83	2
Parkia	0.74	3
Agave + Moringa	0.69	5
Agave + Parkia	0.57	6
Moringa + Parkia	0.84	1
Agave + Moringa +	0.72	4

4. CONCLUSION

The study concludes that although extracts of *A. sisalana* leave*, M. oleifera* and *P. biglobosa* seed were able to achieve an appreciable level of stabilization of grey water, the best performance will be obtained from the combination of *M. oleifera* and *P. biglobosa* with a performance index of 0.84. *M. oleifera* alone with a performance index of 0.83 will be a very close option that can achieve maximal results as well. The study further demonstrated that the combinations of the respective extracts combine the advantages of the constituent plants for optimum treatment efficiency which can go a long way to reduce the effect of competing interest for the plants.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Adin, A. and Asano, T. (1998). The role of physical-chemical treatment in wastewater reclamation and reuse. *Water Science and Technology*, *37*(10), pp. 79-90.

Alfa, M.I., Igboro, S.B., Ajayi, S.A., Dahunsi, S.O. and Ochigbo, B.O. (2014). Assessment of the antimicrobial efficiency of Moringa oleifera seed extracts in the treatment of grey water. *British Journal of Applied Science & Technology*, *4*(3), pp. 558-567.

American Public Health Association (APHA) (2012). Standard Methods for Examination of Water and Wastewater. 22nd ed. American Public Health Association, Washington DC.

Bhuptawat, H., Folkard, G.K. and Chaudhari, S. (2007). Innovative physico-chemical treatment of wastewater incorporating Moringa oleifera seed coagulant. *Journal of hazardous materials*, *142*(1-2), pp. 477-482.

Blumenthal, U.J., Mara, D.D., Peasey, A., Ruiz-Palacios, G. and Stott, R. (2000). Guidelines for the microbiological quality of treated wastewater used in agriculture: recommendations for revising WHO guidelines. *Bulletin of the World Health Organization*, *78*, pp. 1104-1116.

Carr, R., (2005). WHO guidelines for safe wastewater use—more than just numbers. *Irrigation and Drainage: The journal of the International Commission on Irrigation and Drainage*, *54*(S1), pp. S103-S111.

Clark, A.M., El-Feraly, A.S. and Li, W.S. (1981). Antimicrobial activity of phenolic constituents of Magnolia grandiflora L. *Journal of pharmaceutical sciences*, *70*(8), pp. 951-952.

Ferrera, I., Mas, J., Taberna, E., Sanz, J. and Sánchez, O. (2015). Biological support media influence the bacterial biofouling community in reverse osmosis water reclamation demonstration plants. *Biofouling*, *31*(2), pp. 173-180.

Garrick, D., Iseman, T., Gilson, G., Brozovic, N., O'Donnell, E., Matthews, N., Miralles-Wilhelm, F., Wight, C. and Young, W. (2020). Scalable solutions to freshwater scarcity: Advancing theories of change to incentivise sustainable water use. *Water Security*, *9*, p. 100055.

Gassie, L.W. and Englehardt, J.D. (2017). Advanced oxidation and disinfection processes for onsite net-zero greywater reuse: A review. *Water research*, *125*, pp. 384-399.

Gautam, S. and Saini, G. (2020). Use of natural coagulants for industrial wastewater treatment. *Global Journal of Environmental Science and Management*, *6*(4), pp. 553-578.

Gomis, S.M., Riddell, C., Potter, A.A. and Allan, B.J. (2001). Phenotypic and genotypic characterization of virulence factors of Escherichia coli isolated from broiler chickens with simultaneous occurrence of cellulitis and other colibacillosis lesions. *Canadian Journal of Veterinary Research*, *65*(1), pp. 1-6.

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M.C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N. and Noble, I. (2013). Sustainable development goals for people and planet. *Nature*, *495*(7441), pp. 305-307.

Gupta, P., Ann, T.W. and Lee, S.M. (2016)., Use of biochar to enhance constructed wetland performance in wastewater reclamation. *Environmental Engineering Research*, *21*(1), pp. 36-44.

Harja, G., Nascu, I., Muresan, C. and Nascu, I. (2016). Improvements in dissolved oxygen control of an activated sludge wastewater treatment process. *Circuits, Systems, and Signal Processing*, *35*(6), pp. 2259-2281.

Igboro, S.B., Alfa, M.I., Ismail, A., Dahunsi, S.O. and Komami, M. (2016). Evaluation of the Efficiency of Parkia Biglobosa (Locust Bean) Seed, Leaf and Bark Extracts for the Treatment of Grey Water. *Nigerian Journal of Scientific Research*, *15*(1), pp. 75-83.

Igboro, S. B., Osayande, I. O., Alfa, M. I. and Jolaiya V. B. (2019). Assessment of the efficiency of extracts of agave sisilana leaves, moringa oleifera seed and parkia biglobosa seed in greywater treatment: a comparative study. *Nigerian Journal of Scientific Research*, *18*(4), pp. 344-361.

Kazour, M., Terki, S., Rabhi, K., Jemaa, S., Khalaf, G. and Amara, R. (2019). Sources of microplastics pollution in the marine environment: Importance of wastewater treatment plant and coastal landfill. *Marine Pollution Bulletin*, *146*, pp. 608-618.

Kotut, K., Ngángá, V. and Kariuki, F. (2011). The potential of a low cost technology for the greywater treatment. *Open Environmental Engineering Journal*, *4*, pp. 32-39.

Lee, B.X., Kjaerulf, F., Turner, S., Cohen, L., Donnelly, P.D., Muggah, R., Davis, R., Realini, A., Kieselbach, B., MacGregor, L.S. and Waller, I. (2016). Transforming our world: implementing the 2030 agenda through sustainable development goal indicators. *Journal of public health policy*, *37*(1), pp. 13-31.

Menge, J., (2010). Treatment of wastewater for re-use in the drinking water system of Windhoek. *City of Windhoek, Namibia, http://www. wastewater. co. za.*

Nataro, J.P., Bopp, C.A., Fields, P.I., Kaper, J.B. and Strockbine, N.A. (2011). Escherichia, shigella, and salmonella. In *Manual of Clinical Microbiology, 10th Edition* (pp. 603-626). American Society of Microbiology.

Nautiyal, R., Uliana, S., Raj, I., Shah, B., Rathore, K. and Singh, A., (2017). Decentralized treatment of grey water by natural coagulants in the presence of coagulation aid. In: *Proceedings of the 2nd World Congress on Civil, Structural, and Environmental Engineering*. Barcelona, Spain, April, 2017 (pp. 2-4).

Noman, E.A., Al-Gheethi, A.A.S., Bakar, S.A., Radin Mohamed, R.M.S., Talip, B.A. and Mohd Kassim, A.H., (2019). Treatment Technologies of Household Greywater. In: *Management of Greywater in Developing Countries* (pp. 125-147). Springer, Cham.

Owamah, H.I., Alfa, M.I., Oyebisi, S.O., Emenike, P.C., Otuaro, E.A., Gopikumar, S. and Kumar, S.S. (2021). Groundwater quality monitoring of a popular Niger Delta university town in Nigeria. *Groundwater for Sustainable Development*, *12*, p. 100503.

Piao, S., Ciais, P., Huang, Y., Shen, Z., Peng, S., Li, J., Zhou, L., Liu, H., Ma, Y., Ding, Y. and Friedlingstein, P. (2010). The impacts of climate change on water resources and agriculture in China. *Nature*, *467*(7311), pp. 43-51.

Prodanovic, V., Hatt, B., McCarthy, D., Zhang, K. and Deletic, A. (2017). Green walls for greywater reuse: Understanding the role of media on pollutant removal. *Ecological Engineering*, *102*, pp. 625-635.

Sachs, J., Kroll, C., Lafortune, G., Fuller, G. and Woelm, F., (2021). *Sustainable development report 2021.* Cambridge University Press.

Sarowska, J., Futoma-Koloch, B., Jama-Kmiecik, A., Frej-Madrzak, M., Ksiazczyk, M., Bugla-Ploskonska, G. and Choroszy-Krol, I. (2019). Virulence factors, prevalence and potential transmission of extraintestinal pathogenic Escherichia coli isolated from different sources: recent reports. *Gut pathogens*, *11*(1), pp. 1-16.

Shaheen, M.N., Elmahdy, E.M. and Chawla-Sarkar, M. (2019). Quantitative PCR-based identification of enteric viruses contaminating fresh produce and surface water used for irrigation in Egypt. *Environmental Science and Pollution Research*, *26*(21), pp. 21619-21628.

Teh, X.Y., Poh, P.E., Gouwanda, D. and Chong, M.N. (2015). Decentralized light greywater treatment using aerobic digestion and hydrogen peroxide disinfection for non-potable reuse. *Journal of cleaner production*, *99*, pp. 305-311.

Teponno, R.B., Kusari, S. and Spiteller, M., (2016). Recent advances in research on lignans and neolignans. *Natural product reports*, *33*(9), pp.1044-1092.

Uliana, S., Shah, B., Raj, I., Rathore, K., Nautiyal, R. and Singh, A. (2017). Comparative Study of Different Natural Coagulants for the Treatment of Grey Water with Conventional Alum. In: *Proceedings of the 2nd World Congress on Civil, Structural, and Environmental Engineering, Barcelona, Spain, April 2 - 4, 2017* (pp. 4-5).

United Nations (UN) (2015). Transforming our world: the 2030 Agenda for Sustainable Development. New York: United Nations

Washington, J.A. (2012). *Laboratory procedures in clinical microbiology*. Springer Science & Business Media.

World Health Organization (WHO) (2015). *Sanitation safety planning: Manual for safe use and disposal of wastewater greywater and Excreta*. World Health Organization.