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Evaluation of the Efficiency of Ceramic Water Filter Improved by Dried Duckweed Plant (*Lemna minor*) in Wastewater Treatment

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Authors' contributions

This work was carried out in collaboration among all authors. Author JOO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SAO and BJD managed the analyses of the study and supervised the work. Author BJD managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The lack of clean water sources due to pollution and industrialisation is a major problem in many countries including Nigeria. To overcome this challenge, various methods have been adopted including phytoremediation treatment. This study evaluates dried duckweed an aquatic plant and its removal efficiency in comparison with other locally available treatment materials. This was achieved by formulating ceramic water filters (C.W.F) categorized into four different types- clay and kaolin(P1), clay, kaolin and sawdust(P2), clay, kaolin and charcoal(P3) and clay, kaolin and duckweed(P4). These filters were subjected to contaminated water and the following physicochemical parameters Colour, pH, Conductivity(Ec), Fluoride(F^-), Magnesium(Mg^{2+}), Nitrites(NO_2^-), Sulphates (SO_4^{2-}), Ammonia (NH_3) and Total Suspended Solids (TSS) and Total Nitrogen were determined before and after filtration. In all the ceramic water filters, the filter improved by duckweed showed the best removal efficiency of Colour – 100%, Conductivity(Ec) - 72.60%, Fluoride(F)- 99.82%, Magnesium(Mg^{2+})- 51.68% Nitrites(NO_2^-)-92.34, Sulphates (SO_4^{2-})-

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46.09%, Ammonia (NH_3)-98.75%, and Total Suspended Solids (TSS)- 85.43% and Total Nitrogen (TN) -83.79% indicating that duckweed is capable of adsorbing inorganic and organic pollutants from water.

Keywords: Ceramic water filters; clay; duckweed; phytoremediation; water sources; water treatment.

1. INTRODUCTION

Availability of fresh water controls the major part of the world economy. The adequate supplies of water are necessary for agriculture, human consumption, industry as well as recreation. With the advancement of technology and industrial growth, fresh water resources all over the world are being threatened. One sixth of the world's population suffers from fresh water unavailability situation [1].

Contaminated water causes problems to health and leads to waterborne diseases which can be prevented by taking measures even at the household level. In both developing and industrialized nations, a growing number of contaminants are entering water supplies from human activity: from traditional compounds such as heavy metals and distillates to emerging micro-pollutants such as endocrine disrupters and nitrosamines. Increasingly, public health and environmental concerns drive efforts to decontaminate waters previously considered clean. More effective, lower-cost, robust methods to disinfect and decontaminate waters from source to point-of-use are needed, without further stressing the environment or endangering human health by the treatment itself [2].

Effective water treatments through conventional methods which rely on heavy aeration are expensive to install and operate. Hence, there is a need to explore some non-conventional methods which are not only economically viable and easy to operate but are eco-friendly [3].

For this purpose, duckweed *lemnar minor* a floating macrophyte as shown in Fig. 1, serves as phyto-remediation technology which is capable of extracting nutrients or pollutants coupled with a fast growing rate proves to be an excellent candidate for water treatment. Duckweed grows faster when the nutrients are in abundant medium. They utilize waste water nutrients and are cost effective, yielding protein-rich plant biomass as by-products [4].

Also, duckweeds possess a unique ability to accumulate starch and this can be converted into ethanol as a source of bio-fuel. Moreover, they can grow on less fertile land and hence they do not compete for fertile land that can be used for growing other agricultural commodities [5].

Fig.1. Duckweed plant (*Lemna minor*)

Duckweed wastewater treatment systems remove, by bioaccumulation, as much as 99 percent of the nutrients and dissolved solids contained in wastewater [6]. These substances are then removed permanently from the effluent stream following the harvesting of a proportion of the crop. The plants also reduce suspended solids and biological oxygen demand (BOD) by reduction of sunlight in lagoons. Duckweed systems distinguish themselves from other effluent wastewater treatment mechanisms in that they also produce a valuable, protein-rich biomass as a by-product. Depending on the wastewater, the harvested crop may serve as an animal feed, a feed supplement supplying protein/energy and minerals, or a fertilizer. The question of toxic elements must be considered if certain types of waste material serve as the nutrient source for duckweed culture; for example, duckweed will absorb heavy metals and insecticides from the wastewater. It may, therefore, have to be decontaminated prior to feeding to animals if heavy metals are present in the water [3].

Most researchers, however, suggest that efficiency gains using duckweed are greater in secondary and tertiary treatments of effluents where organic sludge has already been removed or converted into simple organic and inorganic molecules that can be used directly by duckweed [7,8,9,10].

The performance of ceramic water filters has been significantly improved by the use of burnout materials which increase the flow rate by creating a network of pores. Burn out materials such as sawdust helps generate pores, increasing the flow rate and reducing the efficiency of the ceramic water. Charcoal which has been used as an additional material to adsorb odour and colour from the filter hence, further increasing the flow rate with no significant removal of inorganic and organic pollutants which are very detrimental to health [11].

This study evaluates the potentials of dried duckweed plant, formulated and incorporated into a ceramic water filter, and its effectiveness in treating water when compared with other locally available materials. To achieve this, four (4) different filters were produced containing clay and kaolin (P1) clay, kaolin and sawdust (P2) clay, kaolin and charcoal (P3) and clay, kaolin and duckweed (P4). These filters were treated with contaminated water and various physico-chemical properties of the water were measured before and after treatment.

2. MATERIALS AND METHODS

The materials used for the research are: clay, kaolin ($AL_2O_3.2SiO_2.2H_2O$), sawdust, charcoal, duckweed, and water. The clay was obtained from Girei, Adamawa State. Kaolin was obtained from Alkaleri LGA of Bauchi State. Sawdust and charcoal were obtained in Jambutu, Adamawa State. Duckweed plants were obtained from Lake Gerio, Yola, Adamawa State, Nigeria.

2.1 Formulation of the Ceramic Water Filters

The different mixtures of the filters were moulded by ceramists from Industrial Design and Ceramics Department in MAUTECH, Yola. The mixtures were moulded into a filter of clay and kaolin (P1), clay, kaolin and sawdust (P2), clay, kaolin and charcoal (P3) clay, kaolin and Duckweed (P4) as seen in Fig. 2 and 3. The different moulded samples were dried for four (4) weeks to remove all moisture content and fired to prevent cracking as seen in Fig.4. This further reduced the size of the ceramic filters [13].

Fig.2. Mould for casting formulations

Fig.3. Formulated filter “green” wares

Fig.4. Fired ceramic filters

Table 1. General properties of house water treatment system

Treatment	Availability & practicality	Technical difficulty	Cost	Microbial efficacy
Boiling at 100°C	Varies	Low–moderate	Varies	High
Chemical treatment	High to moderate	Low–moderate	Moderate	High
Solar disinfection	High	Low–moderate	Low	Moderate
UV lamp treatment	Varies	Low–moderate	Moderate–High	High
Coagulation sedimentation/filtration	Varies	Low–moderate	Varies	Varies

Source [12]

2.2 Filtration Test

The efficiency of the filtration by each filter indicates that the filters must be able to reduce as much contaminants as possible to a level within the standard drinking water range. Hence, the water before the filtration was from a well-known contaminated source.

The source of the contaminated water as seen in Fig. 11 was collected from Bwarranji community which gets its drinking and domestic water from the off stream of River Benue which covers about 1,083km in length and rises in Northern Cameroun as B'enoue at about 1,340m and it is located in Adamawa State a North-eastern part of Nigeria with a population of 3,737,223 people and land mass of 36,917km^2 and it supplies water to the treatment plant in Jimeta-Yola the Adamawa capital which is located between Longitudes 12º26' E and Latitude 9^o 16'N [14] and serves as a source of livelihood for the local community.

The contaminated water was obtained using the 20litres rubber bucket and it was visibly very dirty as seen in Fig 5. It was directly filtered the ceramic water filters within 24 hours. This was done by tightly placing each of the ceramic water filters on a 13litres transparent rubber as seen in Fig 5. The filter pots filtered the contaminated water for 24 hours so as to get appreciable quantity of water for the analysis as seen in Fig 8. The rubbers were labelled "P1" "P2" "P3" "P4" respectively for different filter pots with such label.

Fig.5. Sample of bad water

Fig.6. Filtration of contaminated water

Fig.7. Filtration Process

Fig.8. Filtration set-up

Fig.9. Filtrates from different CWF

2.3 Water Analysis

The following parameters were analysed: Odour, Colour, pH, Conductivity (Ec), Fluoride (F^-), Magnesium (Mg^{2+}), Nitrites (NO_2^-), Sulphates (SO_4^{2-}), Free Ammonia (NH_3), and Total suspended solids (TSS).

The samples of the filtered water (after) and the unfiltered water (before) were collected in a clean wash bottle. The sample was first used to rinse the wash bottles before filling [15].

The sample wash bottles were labelled "before" "P1" "P2" "P3" "P4" for the contaminated water (before) and filtered water (after) respectively. The wash bottles containing each sample of water was taken within 24 hours to the Adamawa State Water Board Chemical Laboratory for analysis.

3. RESULTS AND DISCUSSION

The texture of the ceramic filters as seen in table2 Shows that P1 had a smooth texture because there was no addition of sawdust. While P2 texture was significantly rough due to the addition of sawdust.

However, this roughness reduced from P2 to P3 to P4, and this can be attributed to the decrease in the percentage of burn-out materials in the filter formulation.

In table3 it was observed that the removal efficiency of the filters with respect to anions (F^-), cations (Mg^{2+}), nitrites (NO_2^-), sulphates (SO_4^{2-}), and free ammonia (NH_3), was due to the ion exchange on the ceramic surface and formation of precipitate as oxides and hydroxides, and only P4 filter which a gave a reduction value of 51% agreed to the study by [16], that most developed ceramic filters could remove cations with more than 50% from water. However, the removal efficiency of magnesium and sulphate ions was apparently low thus increasing the total hardness ($MgSO_4$) of the filtered water. This might be due to the high weathering activities of the rocks around the community, which indicates the presence of the mineral, gypsum [17]. According to Nigerian Industrial Standards [18] and World Health Organisation [19] report, there is no health implication for maximum presence of hardness. However, P4, showed the highest removal efficiency of these anions and cationic radicals due to its high adsorption capacity [16].

Fig.10. Map of Nigeria showing River Benue
Source: en.wikipedia.org/wiki/Benue_River

Fig.11. Water sample collection point at Bwarranji community an off-stream of River Benue
Source: www.gettyimages.com

Table 2. Texture/Appearance of Each filter

Filter	Texture/Appearance
P1	Smooth
P2	Highly rough
P3	Moderately rough
P4	Slightly Rough

Table.3. Filtration Efficiency Data

S/N	Parameters	Before Treatment	After Treatment			
			P1% P2%		P3%	P4%
1	Colour(TCU)	2.89	100	99.27	99.41	100
2	pH	9.64	7.86	8.00	8.15	7.49
3	Conductivity(mg/l)	520.0	70.29	52.69	62.60	72.60
4	Fluoride(mg/l)	2.23	99.69	99.51	99.60	99.82
5	Magnesium(mg/l)	8.24	38.72	42.21	37.38	51.68
6	Nitrites(mg/l)	0.257	100	100	100	100
7	Sulphates(mg/l)	29.77	40.64	39.37	39.67	46.09
8	Ammonia(mg/l)	16.42	94.21	93.89	93.61	98.75
9	TSS(mg/l)	240.00	73.78	65.40	73.73	85.43
10	TN(mg/l)	37.32	78.27	72.96	75.54	83.79

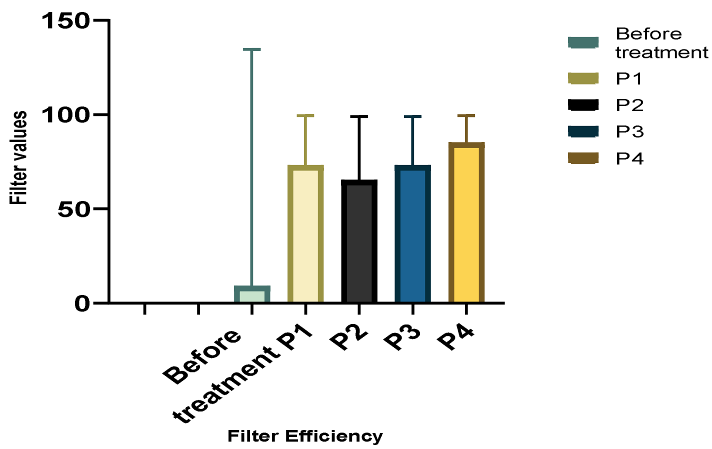

Fig.12. Bar graph showing the median values and interquartile range of the different CWF

The ceramic filters were evaluated for conductivity (Ec) and pH of the source water. Electrical conductivity is related to the amount of ions present in a given solution. The conductivity was significantly reduced by P4 (72.60%) filter because of its high adsorption capacity of these ions, however, this shows that the turbidity of the water is high.

The pH value of the source water (9.64) was relatively high in alkalinity and was above the maximum permissible limit (6.5-8.5) prescribed by Nigerian Industrial Standard [18] but was reduced after filtration by all the filters within a range of (7.86-8.15) as seen in Table 3. The decrease in pH of the filtrate indicates a significant reduction of the Total Suspended Solids by adsorption [20].

The average reduction of ammonia by P4 was 98% and this was slightly above the value reported by Selavarani et al. [21] which was 96% but agree to the value reported by Kutty et al. [22] which was 98% indicating that duckweed gives a significant reduction of ammonia. Removal efficiency of 99% of nitrite was also reported by Selavarani et al. [21] and this agrees with our result for all the filters (>99%) for nitrite removal. A significant reduction of fluoride by all the filters was within 99% range and agrees with the report of Kiaglo et al. [23] which was 99.33%, indicating that addition of burn out material increases the removal efficiency of fluoride in wastewater.

The average reduction of TN for all the filters was >70% except for P4 which was 84%, this value was higher than the value reported by Mohammed and Rasha [24] which was 63%. This shows that the filters significantly reduced the decomposed inorganic and organic aerobic nitrogenous matter from the wastewater.

Total Suspended Solid (TSS) is the measure of particulate matter suspended in water and it is used to describe the extent of pollution in wastewater [25]. According to our study, P4 gave the highest removal efficiency of 85.43% and this agrees with the study made by Gupta [3]. The lowest removal efficiency was recorded by P2, this was due to the addition of sawdust in its formulation, hence increasing its pore size and allowing suspended solids to pass through. The low pore size recorded for P1, P3 and P4 enables the filters to remove particles and pathogens by size exclusion principle [26].

Fig. 8. shows the median and interquartile range of values for filters both in the treatment of the different water parameters and between the filters. From the 2 way ANOVA analysis there was a significant difference ($P=0.0021$) between P1, P2, P3 and P4. A significant difference ($P< 0.0001$) was recorded between the water parameters (treatment) and the filters (exposure).

4. CONCLUSION

The result presented here are the most recent systematic comparison of dried duckweed composite filters and their relative removal efficiency of pollutants and contaminants from wastewater. Our key finding from the analyses is that dried duckweed is as effective as its fresh state in water and can improve CWFs in wastewater treatment. This confirms the studies made by most researchers that duckweed plant is a good phytoremediation tool for wastewater treatment. This suggest that the quality of drinking water especially in developing countries like Nigeria, can be enormously improved by the use of duckweed, either incorporated as ceramic water filter, duck weed pond or duckweed tank. Duckweed which have been under-utilized have proven to be an efficient nutrient sink and an effective tool in contaminated water treatment. The use of this rich aquatic plant will go a long way to reduce the burden of water- borne diseases and also ensure safe, clean and sustainable water supply.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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