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(RESEARCH ARTICLE)

Design and performance evaluation of a water filtration system using charcoal, activated carbon, moringa seeds and sand

Olumide Aderemi Aderibigbe *, Samuel Okemute Egwenu, Daniel Ekanem John, Abiola Michael Ajegunmo, Ibrahim Tope Usman and Kolade Joseph Adetoyinbo

Rocket Propellant Development Systems, Bola Ahmed Tinubu Centre for Space Transport and Propulsion, LASU Epe Campus, Lagos, Nigeria.

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Abstract

Access to potable water remains a significant challenge, particularly in rural communities where inadequate water treatment contributes to the prevalence of waterborne diseases such as diarrhea, skin abscesses, cellulitis, and other infections. This study aimed to design and evaluate low-cost and effective water filtration systems using sand, charcoal, activated carbon, and Moringa seeds as filter media. The performance of the developed filters was assessed based on flow rate and selected water quality parameters, including pH, electrical conductivity (EC), turbidity, dissolved oxygen (DO), and total dissolved solids (TDS). Four filtration systems were designed using locally available materials, with each filter incorporating one of the selected media. Experimental evaluation showed that the sand filter achieved the highest flow rate (4.08 mL/s), followed by the charcoal filter (2.45 mL/s), activated carbon filter (2.05 mL/s), and Moringa seed filter (0.75 mL/s). The Moringa seed filter demonstrated superior water quality performance, producing the lowest turbidity (5.39 NTU) and the lowest electrical conductivity, while the sand filter recorded the highest turbidity (22.48 NTU) and EC values (196–261 µS/cm). The findings indicate that although the sand filter provides the greatest filtration rate, the Moringa seed filter offers better contaminant removal and improved water quality. Overall, the developed filtration systems present cost-effective alternatives for household water treatment, with the Moringa seed filter showing the greatest potential for improving drinking water quality in resource-limited communities.

Keywords: Evaluation; Activated carbon; Moringa seed; Water; Purification; Filtration systems

1. Introduction

Water is one of the Earth's most valuable natural resources and is indispensable for sustaining life, maintaining ecosystem functions, and supporting agricultural, industrial, and economic development. Despite its abundance, only a small fraction of the world's water resources is readily available and suitable for human consumption. Furthermore, increasing population growth, urbanization, industrialization, and climate change have intensified water scarcity and deteriorated water quality in many regions. Water contamination remains a major environmental and public health concern. Surface water sources, including rivers, lakes, and streams, are particularly vulnerable to contamination from domestic wastewater, agricultural runoff, industrial effluents, atmospheric deposition, and naturally occurring geological materials. Groundwater, although generally less exposed, may also become contaminated through seepage from waste disposal sites, agricultural activities, and industrial operations. Microbial contamination, resulting from bacteria, viruses, parasites, and other pathogenic microorganisms originating from human and animal waste, represents one of the most significant threats to drinking water safety.

* Corresponding author: Samuel Okemute Egwenu

Water purification is the process of removing undesirable chemical substances, biological contaminants, suspended solids, and dissolved gases from water to make it suitable for its intended use. Although the primary objective of water purification is to produce safe drinking water for human consumption, treated water is also essential for medical, pharmaceutical, chemical, and industrial applications. Water purification technologies have evolved over time and encompass a range of physical, biological, chemical, and advanced treatment processes. Physical methods include filtration, sedimentation, and distillation; biological methods include slow sand filtration and biologically active carbon; chemical methods involve coagulation, flocculation, and chlorination; while advanced treatment methods employ technologies such as ultraviolet (UV) irradiation and other forms of electromagnetic radiation for disinfection.

The selection of an appropriate water treatment method depends on the nature and concentration of contaminants in the source water, the intended use of the treated water, and the applicable water quality standards. In practice, multiple treatment processes are often integrated to achieve the desired water quality. Household point-of-use treatment systems also play an important role in improving the quality of domestic water supplies. Collectively, these treatment methods aim to reduce or eliminate contaminants such as suspended particles, bacteria, viruses, parasites, fungi, algae, and dissolved impurities that may pose risks to human health.

Drinking contaminated water is closely associated with the transmission of waterborne diseases, including diarrhea, cholera, typhoid fever, dysentery, skin infections, cellulitis, and skin abscesses. These diseases disproportionately affect populations in developing countries where access to adequate water treatment and sanitation infrastructure remains limited. In Nigeria, particularly in rural communities, residents rely heavily on untreated surface water from rivers, streams, ponds, and lakes for their domestic needs, while in urban areas, borehole water systems serve as the primary source of water supply; however, lack of monitoring and treatment often compromise water quality.

Recognizing the importance of safe water and sanitation, the United Nations included **Clean Water and Sanitation (Sustainable Development Goal 6)** among the Sustainable Development Goals (SDGs), with the objective of ensuring universal access to safe and affordable drinking water by 2030. Achieving this goal in Nigeria requires sustained investment in water infrastructure, effective water quality monitoring, and the promotion of affordable point-of-use water treatment technologies. Such technologies are particularly valuable because they can operate without electricity or complex distribution systems, making them well suited for rural and resource-constrained communities.

Among the various point-of-use treatment technologies, low-cost water filters fabricated from locally available materials have attracted considerable attention due to their affordability, accessibility, and environmental sustainability. Materials such as sand, charcoal, activated carbon, and *Moringa oleifera* seeds have demonstrated significant potential for improving water quality by removing suspended solids, reducing turbidity, and eliminating microorganisms and other contaminants. The development and of such filtration systems offer a sustainable approach to enhancing access to safe drinking water while reducing dependence on expensive imported filtration technologies.

This study therefore focuses on the design and evaluation of water filtration systems made from locally available materials, including sand, charcoal, activated carbon, and *Moringa oleifera* seeds. The performance of these filtration systems is assessed using selected water quality parameters and flow rate measurements. The findings are expected to contribute to the development of affordable, efficient, and sustainable water treatment solutions suitable for households and rural communities in developing countries.

2. Materials and Methods

2.1. Equipment and Materials

The following equipment and materials were used. EC meter, pH meter, TDS meter, turbid meter, blender, petri film, retort stand and clamp, sand (0.50mm, 1.00mm, 2.43mm particle size), gravel, charcoal, activated carbon, sample bottles, pulverized moringa seeds, cotton, PET Transparent Plastic bottles (150cm), jaw crusher, sieve and Beakers.

2.2. Design of the Water Filters: Criteria for design

The following criteria guided the design of the water filters. A filter with an acceptable flow rate, ability to remove the impurities and contaminants in water and small scale and affordable filter. Four different rapid sand filters were designed and constructed using 150 cm PET Transparent water bottles (Fig 1A) using charcoal (Fig 1F), activated carbon (Fig 1E), pulverised Moringa seed (Fig 1G), sand bed of different particle sizes (Figure 1B, 1D, 1I, 1J) and gravel (Fig 1C). The sand (the filter bed) has a strong influence on the effectiveness ofthe filtration and it should be at least

45 cm in depth. Bacteria and viruses are trapped in the Schmutzdecke. Bacteria and biological activity maximizes in the Schmutzdecke but will continue up to 20 cm deep in the sand of the filter bed. A certain minimum level of dissolved oxygen should be present to support the aerobic actions that occur in the bed, after the initial installation of the Sand Filter. The soil sample for the filter bed was collected from the river bed, washed, sun-dried and sieved to 0.5mm, 1.00mm and 2.35mm. The gravel was sourced from the local market and crushed to 3.00mm using a jaw crusher at the point of purchased. The wood charcoal (Figure 1F) was made by burning the locally available wood obtained from dried trees in an open environment for about 15 minutes and allowed to cool in an open space then the resulted charcoal shown in Figure 1F was collected and resized to 2.00 mm using grinding machine. Moringa Seed was sourced from the local market in Osogbo in Osun state, Nigeria, sun-dried for three days, crushed using crusher, sieved and pulverized as shown in Figure IG.

Figure 1A PET (150cm)

Figure 1B Sand (2.35mm particle size)

Figure 1C Gravel

Figure 1D Sand (0.5mm particle size)

Figure1E Activated carbon

Figure1F Sand (0.5mm particle size)

Figure1G Pulverized moringa seed

Figure 1H Cotton

Figure 1I sand (1.00mm particle size

Figure 1J Sand (>2.35mm particle size)

The first filter was built using gravel, sand bed with a particle size of 0.5mm, 1.00mm, and 2.35mm, cotton and charcoal with a layer thickness of 100 mm each. The second filter was made of the same material of same layers except that the charcoal was replaced with activated carbon but the layer is less than 100 mm due to the limited availability of activated carbon. The third filter was constructed in the same manner but Moringa seeds were used to replace charcoal. Moringa seed was used with a layer thickness of 100 mm. The fourth filter is sand bed of 0.25 mm, 0.5 mm, 1.00 mm, 2.35 mm, greater than 2.35 mm as shown in figure 1B and gravel in figure 1C.

The raw water sample was collected at different periods from the stream located in Mojoda, Epe, Lagos state, Nigeria. Figures 2A, and 2B show the raw water source and the collected raw water sample.

Figure 2A Raw water source (River)

Figure 2B Raw water sample

Four different filters setups were designed as shown in Figure 3 and 4, using sand, charcoal, pulverized Moringa seeds and activated carbon respectively, arranged from left to right.

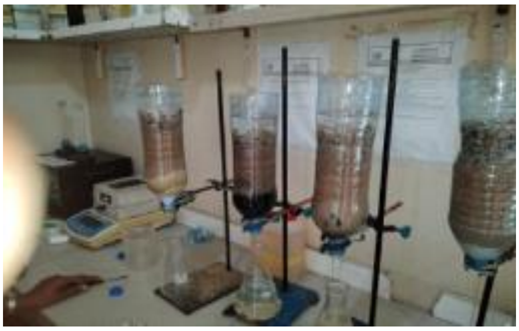

Figure 3 Four Filters Setups

Figure 4 Washing the filters

The filter set ups were washed by running clean water through the filters to make sure the filtering media are properly washed. This was done until the system reached ripping time when which is a time taken to start getting the clean water as filtrate. At this point, the filtration was started at the same time for the four filters as shown in Figure 4 and the time was recorded. The flow rate was calculated and tabulated.

2.3. Water Quality Measurements

Tests on the quality of the water were done both before and after each filter was used. pH, electrical conductivity (EC), turbidity, chemical oxygen demand (COD), biological oxygen demand (BOD), and microbiological (Bacteria) detection were the parameters that were measured. The rate of filtration was also assessed. In order to determine which filter is better to use for domestic and commercial purposes, the raw water was also filtered using an industrial filter that was purchased from the market. The results were then compared with those of the designed filters. As demonstrated in Figures 5A and 5B, a pH kit was used to measure the pH, electrical conductivity (EC), and dissolved oxygen (DO); a turbidity meter, figure 5C was used to measure the turbidity; a TDS meter, figure 5D was used to measure the total dissolve solid (TDS). Every reading's ambient temperature was recorded as well.

Figure 5A p^H Kit

Figure 5B p^H, EC and DO Readings

Figure5C Turbidity Measurement

Figure 5D TDS Measurement

3. Results and Discussion

3.1. The Water Filters

The filtered purified water samples from each of the filters are shown in Figure 6.

Figure 6 Filtered water samples (clear)

The engineering drawings with the dimensions showing the depth of each of the filter mediums are shown in Figure 7.

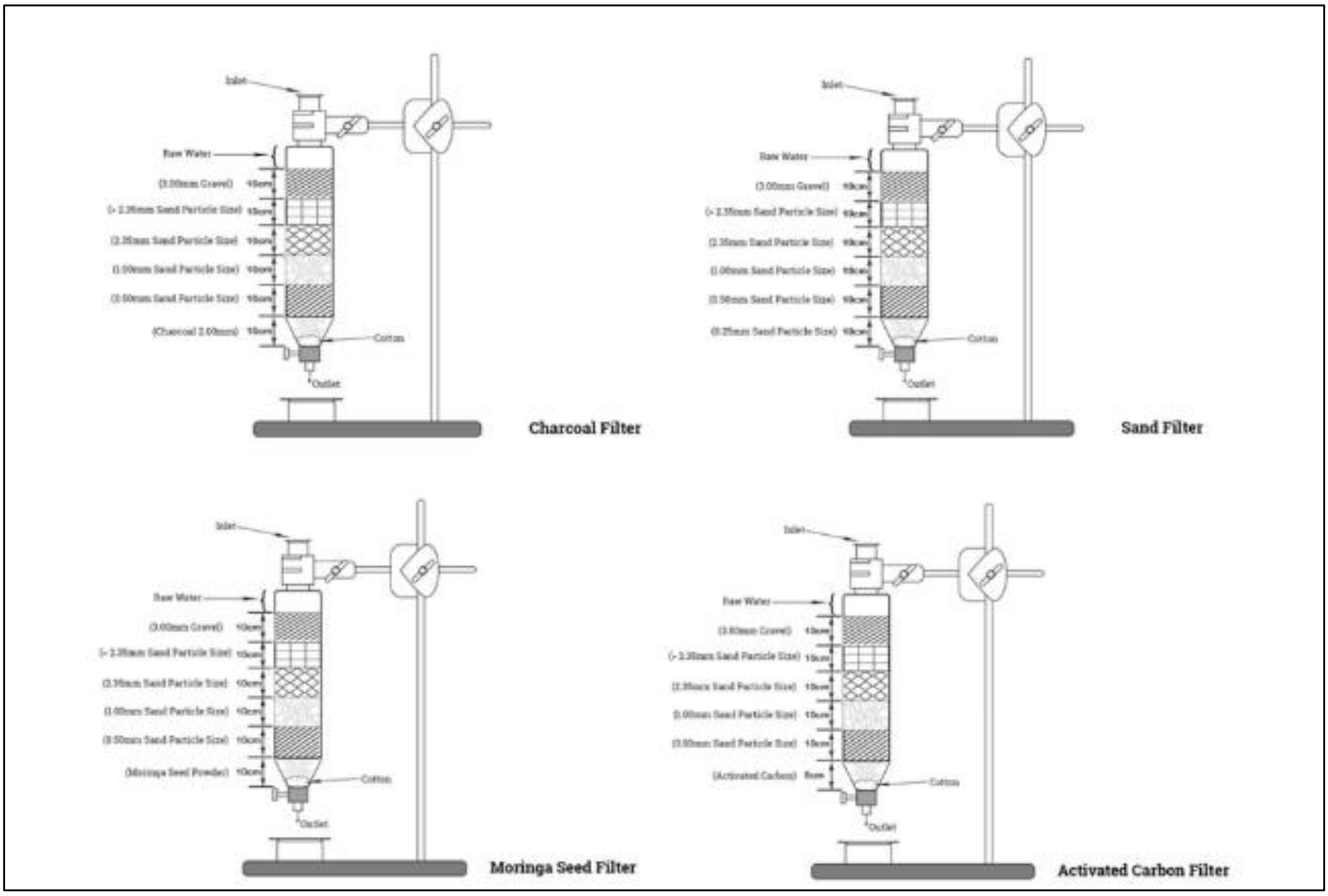

Figure 7 Drawings of the the four filters setup

3.2. Water Quality

The corrosiveness of water is largely influenced by its pH, with lower pH values indicating higher corrosive potential. The pH values obtained from the filtered water ranged from 6.47 to 7.01, which fall within the World Health Organization (WHO) recommended guideline of 6.5–8.5 for drinking water. These results indicate that all four filtration systems produced water with acceptable pH levels suitable for domestic consumption. Among the filters evaluated, the *Moringa oleifera* seed filter demonstrated the best overall performance. It achieved the lowest turbidity values, decreasing from an initial value of 78.0 NTU to 4.86 NTU on the first day and further to 4.18 NTU on the third day. Since turbidity is an indicator of water clarity and the acceptable range for drinking water is 1–5 NTU, the Moringa filter effectively reduced turbidity to within the recommended standard. Overall, the Moringa filter exhibited superior performance in terms of electrical conductivity (EC), dissolved oxygen (DO), total dissolved solids (TDS), and turbidity, followed by the charcoal, activated carbon, and sand filters. Electrical conductivity (EC), which reflects the concentration and mobility of dissolved ions in water and is influenced by temperature, was also evaluated for each filtration medium. The average EC values obtained were 248 µS/cm for the charcoal filter, 249 µS/cm for the activated carbon filter, 196 µS/cm for the Moringa filter, and 261 µS/cm for the sand filter.

3.3. Filtration Rate

Three filtration trials were conducted over three consecutive days, and the corresponding results are presented in Tables 1, 2, and 3. The sand filter consistently exhibited the highest filtration rate, recording flow rates of 3.76 mL/s, 4.57 mL/s, and 3.92 mL/s on Days 1, 2, and 3, respectively. In contrast, the *Moringa oleifera* seed filter showed the lowest flow rates, with values of 0.83 mL/s, 0.79 mL/s, and 0.63 mL/s over the same period. The overall filtration performance, obtained by averaging the flow rates from the three trials (Table 4), showed that the sand filter achieved the highest mean filtration rate of 4.08 mL/s, followed by the charcoal filter (2.45 mL/s), activated carbon filter (2.05 mL/s), and *Moringa oleifera* seed filter (0.75 mL/s). The observed differences in filtration rates can be attributed primarily to the particle size and pore structure of the filter media. Sand, having relatively larger particle sizes and greater pore spaces, allows water to pass through more rapidly. Conversely, the finely ground *Moringa oleifera* seeds create a denser filtration bed with smaller pore spaces, resulting in a slower filtration rate. Charcoal and activated carbon exhibited intermediate flow rates because of their moderate particle sizes and porous structures.

Table 1 Day One Results for the analysis and evaluation of the filtration systems

Parameter	Sand Bed	Moringa (Seed)	Charcoal	Activated Carbon	Raw Water
P^H	6.70	6.5	6.47	6.61	7.0
Temperature (^oC)	25.7	25.7	25.7	25.7	25.7
EC(µS/cm)	290	207	265	305	450
DO (mg/L)	6.80	5.85	6.28	6.50	7.40
Turbidity (NTU)	22.35	4.86	10.64	9.25	95
TDS (ppm)	49.0	43.0	52.0	50.0	48.0
Flowrate (mL/sec)	3.76	0.83	2.75	2.21	_

Table 2 Day Two Results for the analysis and evaluation of the filtration systems

Parameter	Sand Bed	Moringa (Seed)	Charcoal	Activated Carbon	Raw Water
P^H	6.90	6.52	6.72	6.56	7.01
Temperature (^oC)	26.8	26.8	26.8	26.8	26.8
EC (µS/cm)	300	205	270	250	320
DO (mg/L)	6.78	5.45	6.17	6.45	7.32
Turbidity (NTU)	25.38	7.15	15.25	11.65	95.0
TDS (ppm)	49.0	43.0	52.0	50.0	48.0
Flow rate (ml/sec)	4.57	0.79	2.58	2.12	_

Table 3 Day Three Results for the analysis and evaluation of the filtration systems

Parameter	Sand Bed	Moringa (Seed)	Charcoal	Activated Carbon	Raw Water
P^H	6.76	6.54	6.87	6.69	6.95
Temperature (°C)	25	25	25	25	25
EC (µS/cm)	194	175	209	192	250
DO (mg/L)	6.89	6.06	6.37	6.56	7.46
Turbidity (NTU)	19.73	4.18	11.45	8.86	78.0
TDS (ppm)	49.0	43.0	52.0	50.0	48.0
Flow rate (ml/sec)	3.92	0.63	2.03	1.83	-

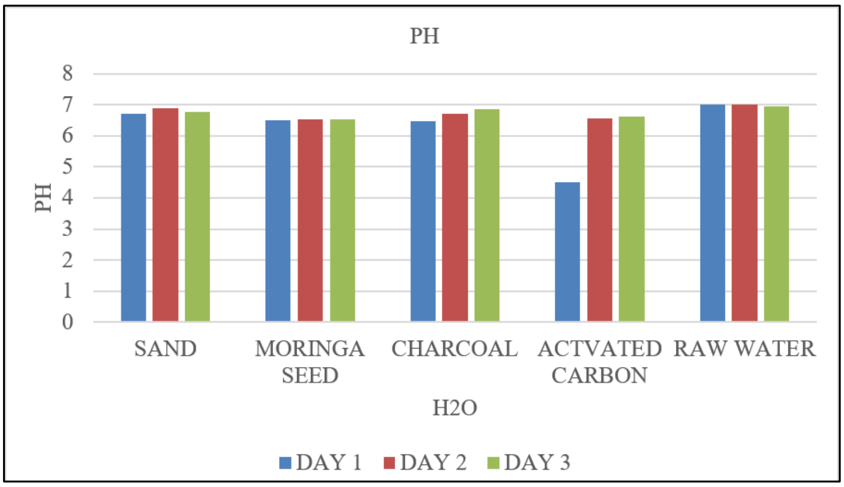

Figure 8A P^H Values

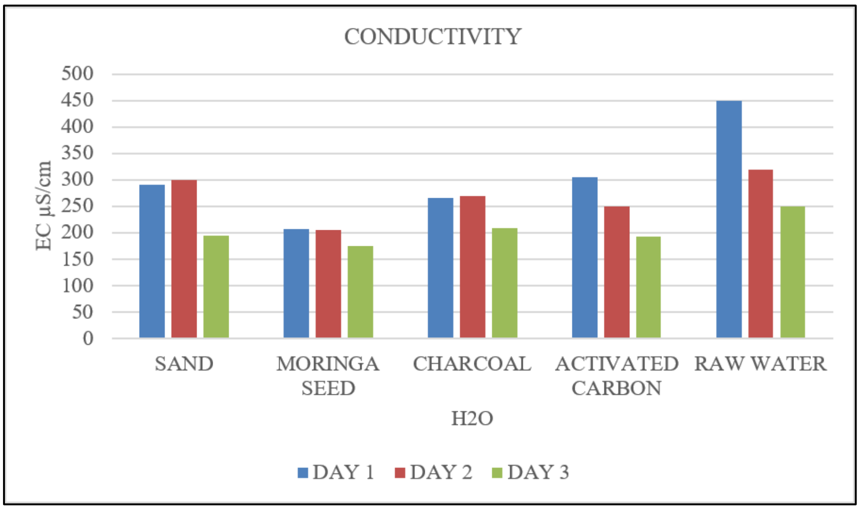

Figure 8B Conductivities values

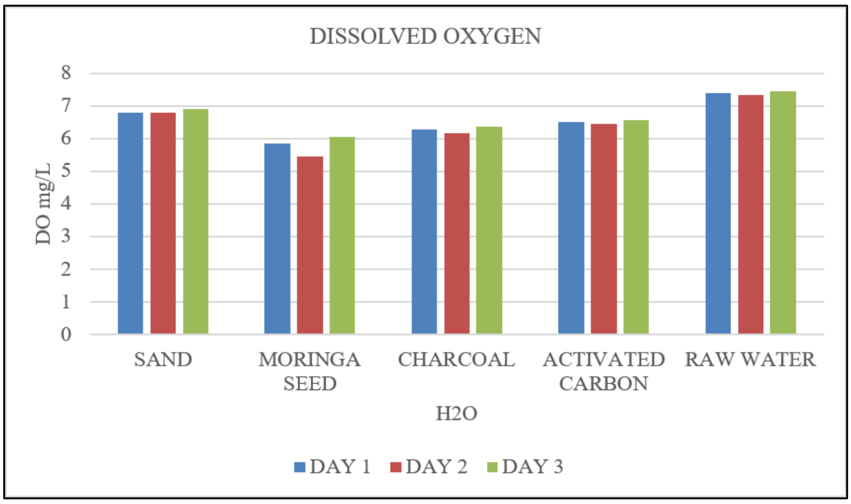

Figure 8C DO Values

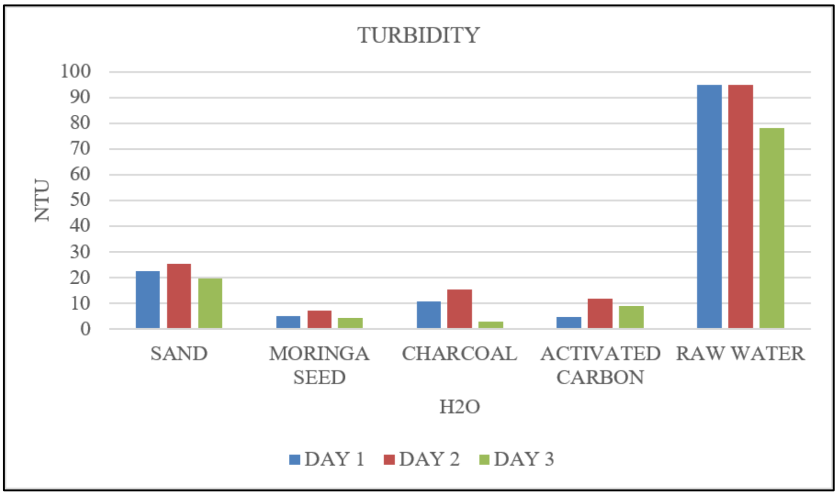

Figure 8D Turbidity Values

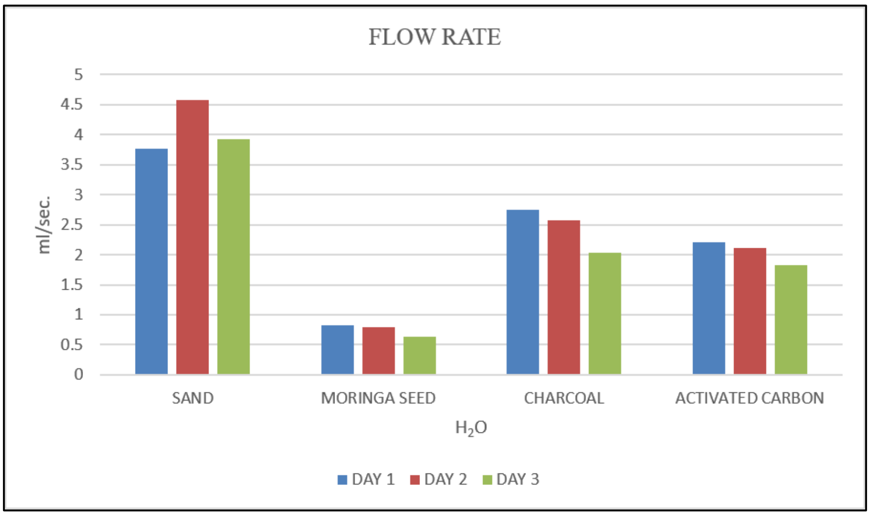

Figure 8E Flow Rate Values

Table 4 Overall performance of the filters

Parameter	Sand Bed	Moringa (Seed)	Charcoal	Activated Carbon	Raw Water
P^H	6.76	6.52	6.526	6.62	7.02
EC (µS/cm)	261	196	248	249	340
DO (mg/L)	6.82	5.78	6.27	6.50	7.39
Turbidity (NTU)	22.48	5.39	12.44	9.92	85
TDS (ppm)	49	43	52	50	48
Flow rate (ml/sec)	4.08	0.75	2.45	2.05	-

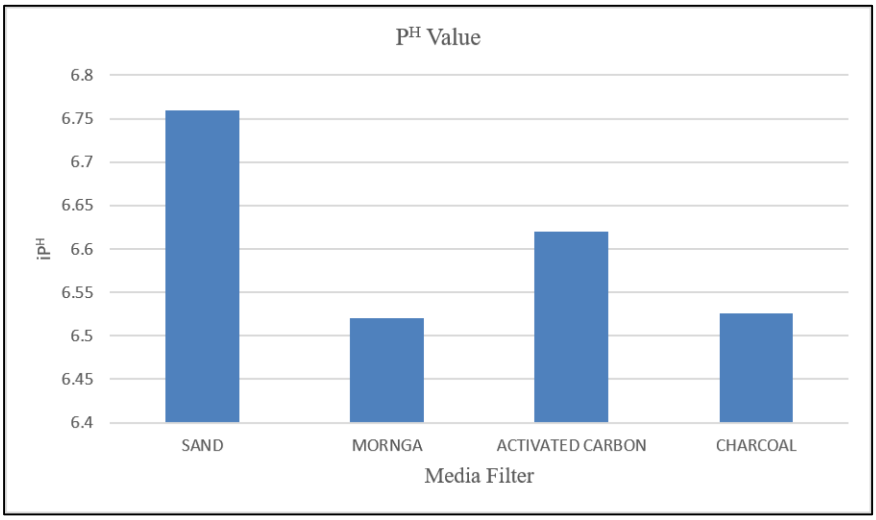

Figure 9A Average P^H performance

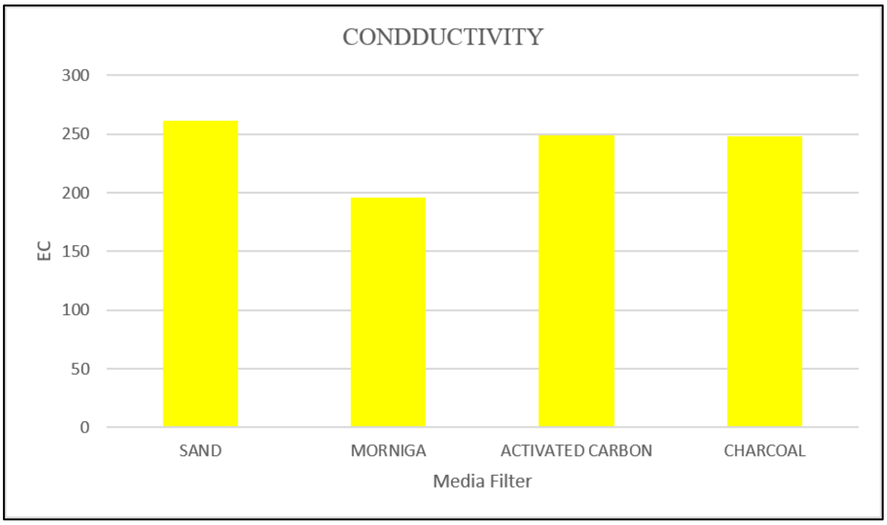

Figure 9B Average Electric Conductivity Performance

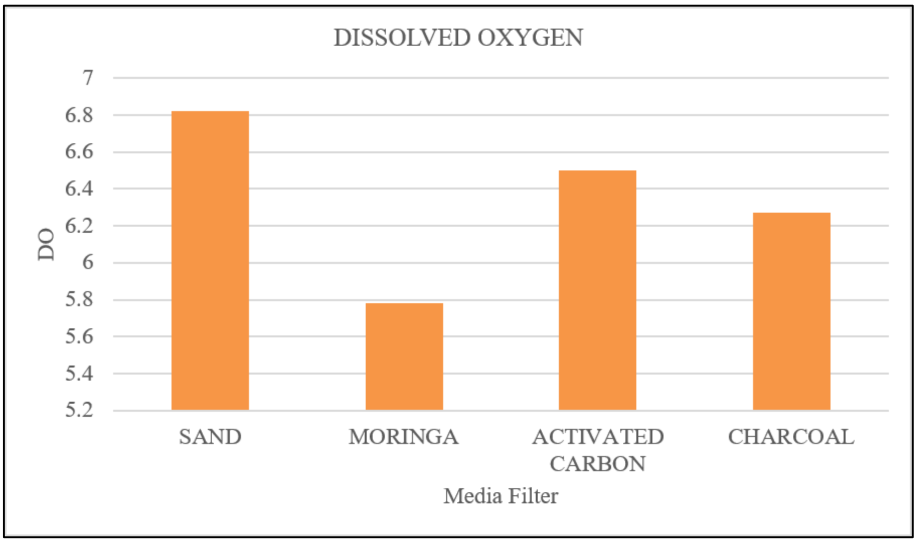

Figure 9C Average DO Performance

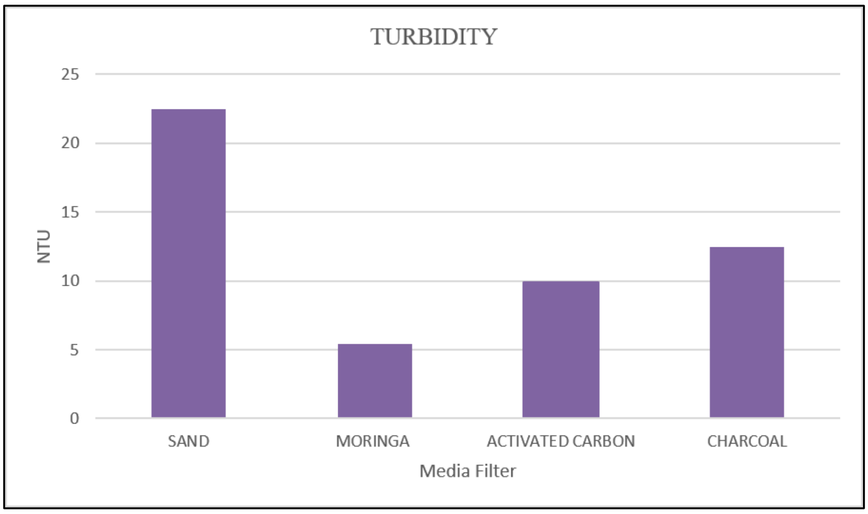

Figure 9D Average Turbidity Performance

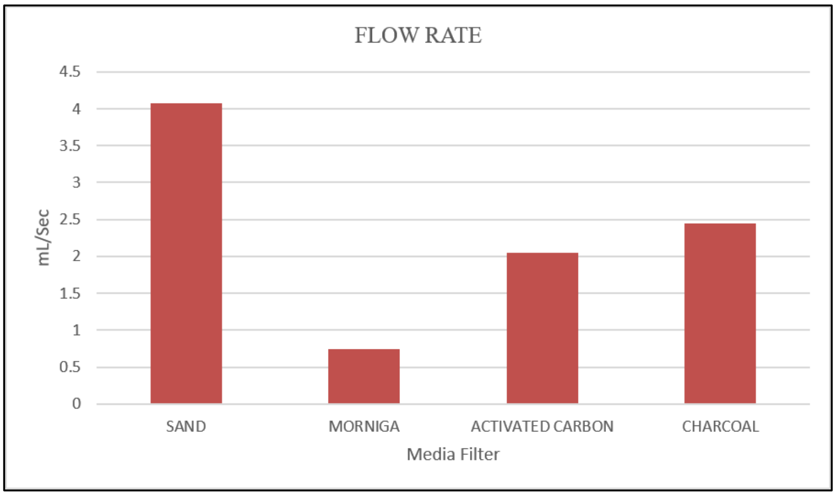

Figure 9E Average Flow Rate

3.4. Overall Performance

The overall performance of the four filtration systems is presented in Table 4 and Figures 9A–9E. The values were obtained by averaging the results from the three filtration trials (Days 1, 2, and 3) for each water quality parameter, as presented in Tables 1, 2, and 3. The results indicate that the pH values of water filtered through all four media were within the World Health Organization (WHO) recommended range for drinking water (6.5–8.5), confirming that each filtration system produced water with acceptable pH levels. Among the filters, the sand filter recorded the highest average filtration rate of 4.08 mL/s, which falls within the typical operating range of commercial household water filters (2.5–5.0 mL/s). Although the average turbidity of the Moringa filter across all trials was 5.39 NTU, it remained considerably lower than those of the other filtration media, indicating superior clearness. The lowest average filtration rate (0.75 mL/s), indicate the slower flow likely increased the contact time between the water and the filter medium, thereby enhancing contaminant removal efficiency. The Moringa filter also recorded the lowest electrical conductivity (EC) value of 196 μS/cm, which is well below the recommended limit of 300 μS/cm, reflecting its greater effectiveness in reducing dissolved ionic constituents. A notable limitation of the Moringa filter was the gradual development of an unpleasant odour during prolonged use, which may be attributed to microbial growth or the decomposition of residual organic matter within the filter medium.

4. Conclusion

Among the filtration materials evaluated (sand, moringa, charcoal, and activated carbon), moringa demonstrated the best overall performance due to its exceptional water purification ability, as well as its accessibility and low cost resulting from its widespread local availability. Although the moringa filter exhibited a slower flow rate and required a longer filtration time, it was highly effective in removing most contaminants and impurities from raw and polluted water. Despite these advantages, the moringa filter has certain limitations. The filter medium is susceptible to bacterial growth, which can eventually produce an unpleasant odour in the treated water. In addition, the moringa medium tends to coagulate during filtration, reducing its permeability and making the filtration process more difficult.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

There are no conflicts of interest.

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