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Research Paper

Development of Point of Use Household Water Purification SystemUsing Locally Sourced Clay Material

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Abstract
Access to clean and safe drinking water remains a critical challenge, particularly in low- and middle-income countries. This study focused on the development of a point-of-use household water purification system utilizing locally sourced clay material. The clay, collected from Imiegba in Edo State, Nigeria, was molded into ceramic filters and fired to create a porous structure essential for filtration. The system's effectiveness was evaluated by testing water from the Omouku River before and after filtration, with analyses conducted for physicochemical parameters, heavy metals, and microbial contaminants. Results indicated significant improvements in water quality, including the complete elimination of heterotrophic bacteria and reductions in heavy metal concentrations. The study underscores the potential of locally available materials in providing a sustainable and affordable solution for improving access to safe drinking water in regions with limited resources. Recommendations include regular monitoring, community education, and further research to optimize the filtration system's performance.
***Keywords**: Water purification, Clay material, Ceramic filters, Heavy metals, Sustainable development*

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I. Introduction

Access to clean and safe drinking water is a fundamental human right, crucial for sustaining life and ensuring public health. However, despite significant progress in providing safe water supplies in various parts of the world, millions of people, predominantly in low- and middle-income countries, continue to grapple with inadequate access to potable water sources (Dinka, 2018). The World Health Organization (WHO) reports that globally, approximately 785 million people do not have access to basic drinking water services, and about 2 billion people use drinking water sources contaminated with feces, putting them at risk of various diseases, including cholera, typhoid, and diarrheal illnesses (World Health Organization, 2021). This issue is exacerbated in regions affected by natural disasters, conflicts, and economic instability, where access to clean water becomes even scarcer (UNICEF, 2020). The significance of addressing this global challenge cannot be overstated. It is not only a matter of ensuring access to a basic human necessity but also a critical determinant of overall well-being and socio-economic development. Unsafe drinking water is linked to poverty, malnutrition, and poor educational outcomes, further entrenching communities in a cycle of disadvantage (Lauer et al., 2018). To address this pressing global issue, the proposed project, "Development of Point of Use Household Water Purification System," aims to contribute to the development of a sustainable and affordable solution that empowers households to purify their drinking water effectively and conveniently (Sobsey et al., 2008). By focusing on the household level, we recognize the importance of decentralized approaches to water treatment, which can mitigate risks associated with centralized water supply systems limitations, such as contamination during distribution (WHO, 2018).

1.1 Problem Statement/Justification

Waterborne diseases, such as cholera, dysentery, and diarrheal diseases, pose a severe threat to the well-being of communities that lack reliable access to safe drinking water. According to the World Health Organization (WHO), contaminated water is responsible for approximately 485,000 diarrheal deaths each year, primarily affecting children under the age of five. These diseases not only lead to suffering and loss of life but also contribute to the cycle of poverty by limiting individuals' productivity and increasing healthcare costs for affected communities. In response to this global challenge, there is an urgent need for innovative and accessible solutions that can provide clean and safe drinking water at the household level. This research project is a potential approach to addressing Waterborne diseases. The designing and developing a Water Purification System aims to empower individuals and communities by giving them the means to purify water at the source, within their households.

1.2 Objective (s) of the study:

The major objectives of this research include:

- ➢ Design and develop an innovative Point of Use Household Water Purification System that is cost-effective, user-friendly, and efficient in removing contaminants from drinking water.
- ➢ Improve public health by reducing the incidence of waterborne diseases and enhancing access to clean and safe drinking water.
- ➢ Evaluate the effectiveness of the developed water purification system in removing a wide range of contaminants commonly found in drinking water, including bacteria, heavy metals, and chemical pollutants.

II. Literature Review

The burden of waterborne diseases on global health is well-documented. Access to safe drinking water is central to achieving several Sustainable Development Goals (SDGs), including those related to health (SDG 3) and clean water and sanitation (SDG 6). The World Health Organization (WHO) estimates that 2.2 billion people worldwide do not have access to safely managed drinking water services, and nearly 1,000 children die each day due to preventable waterborne diseases (WHO, 2021). Contaminated water sources are reservoirs for a range of pathogens, including bacteria, viruses, and parasites. These pathogens cause diseases such as diarrhea, cholera, hepatitis, and giardiasis, which can lead to dehydration, malnutrition, and death, especially among children under the age of five (UNICEF, 2020).

Centralized water treatment plants have made significant strides in providing clean water to urban populations. However, several challenges persist. Infrastructure limitations often hinder the extension of these services to rural and underserved areas. Furthermore, centralized treatment does not always guarantee the quality of water at the point of consumption, as contamination can occur during distribution or storage (Sobsey et al., 2008). Decentralized and point-of-use water treatment solutions have gained prominence as a means to overcome these challenges. Such systems are designed for use at the household level, offering immediate access to safe water. Common technologies used in these systems include ceramic filters, chlorine disinfection, ultraviolet (UV) treatment, and biosand filtration (Clasen et al., 2015). The development of a Point of Use Household Water Purification System is a critical response to the global challenge of inadequate access to clean and safe drinking water. This project seeks to contribute to the growing body of research and innovation in the field of decentralized water treatment solutions, with the ultimate aim of improving public health, reducing the burden of waterborne diseases, and enhancing the well-being of communities worldwide.

III. Methods and Materials

The research employed Locally Sourced Clay Material" employed a systematic approach to ensure the system's effectiveness and sustainability. The following section details the methods and materials used in the study.

3.1 Methods

I. **Material Collection and Preparation:** Clay samples were obtained from Imiegba in Edo State using the grab sampling method. The samples were collected in three different clean containers to ensure purity. Water samples were also collected by grab sampling from Omouku River in Auchi, Edo State. The collected clay was then purified to remove any impurities that could impact its performance (Abollino et al., 2003).

II. **Fabrication of Filtration Unit:** The purified clay was molded into a filtration unit, primarily in the form of ceramic filters. These filters were designed to allow water to pass through while trapping contaminants. Organic materials like sawdust were mixed with the clay, which burned away during firing, creating porous structures essential for filtration (Oyanedel-Craver & Smith, 2008).

III. **Firing Process:** The molded clay filters were fired in a muffle furnace (TYP: OH-85TR) at high temperatures to harden the material and develop the necessary porous structure. The firing temperature and duration were carefully controlled to ensure optimal porosity and structural integrity (Zhao et al., 2012).

IV. **Testing and Evaluation:** The filtration efficiency of the clay filters was tested by passing water containing various contaminants through them. The quality of the filtered water was analyzed using a Scanning Electron Microscope (SEM) (EVO|LS10 MODEL), UV-Visible spectrophotometer (Jenway 6505), and Atomic Absorption Spectrophotometer (TAS-990). Physiochemical and microbial analyses were conducted in accordance with APHA standards and Ademoroti (1996). The results were compared against standard water quality benchmarks to evaluate the system's effectiveness (Van Halem et al., 2009).

3.2 Materials

- **Clay Material:** Locally sourced from Imiegba, Edo State.
- **Organic Additives:** Sawdust was used to create the porous structure in the clay during firing.
- **Apparatus and Equipment:** Included a Scanning Electron Microscope (SEM) (EVO|LS10 MODEL), UV-Visible spectrophotometer (Jenway 6505), Atomic Absorption Spectrophotometer (TAS-990), and muffle furnace (TYP: OH-85TR).
- **Reagents:** Analytical grade reagents such as buffer solutions, potassium chloride, and various other chemicals were utilized.
- **Testing Kits:** Used for assessing water quality parameters before and after filtration.

This methodology, grounded in sustainable practices and local resource utilization, successfully created an affordable and effective water purification system for households, particularly in regions where access to clean water is limited.

IV. RESULTS AND DISCUSSION

Table 4.1: Result of Physiochemical analysis of Omouku River before storage in clay pot

			WHO	
Parameter	**Raw river water before storage**	**After storage**	**Highest desirable**	**Maximum permissible**
pH	6.8	5.8	7.0-8.9	6.9-9.5
EC	55	53.2	100	1200
Sal.	0.025	0.024	10	NS
Col.	ND	ND	3.0	15.0
Turb.	ND	ND	ND	5.0
TSS	ND	ND	ND	NS
TDS	28.3	27.4	500	1500
COD	1.6	4.2	NS	NS
DO	1.0	1.4	NS	NS
BOD	0.6	0.7	NS	NS
HCO_3	21.5	85.4	125	350
Na	0.22	0.151	200	100
K	0.17	0.084	20	15
Ca	0.73	0.661	100	200
Mg	0.51	0.317	50	150
Cl	48.6	35.7	200	250
P	0.013	0.021	NS	NS
NO_2	0.180	0.084	0.2	3
NO_3	0.681	0.575	50	70
NH_4N	0.210	0.245	NS	NS
SO_4	0.210	0.358	250	500

The physiochemical analysis of Omouku River water before and after storage in clay pots reveals several notable changes in water quality parameters when compared to the World Health Organization (WHO) standards.

The pH of the water decreased from 6.8 to 5.8 after storage, which falls outside the WHO's highest desirable range of 7.0-8.9 and even the maximum permissible limit of 6.9-9.5. This suggests that the clay pot might be leaching acidic components into the water, which is a common observation in water stored in earthen materials (Oyanedel-Craver & Smith, 2008).

Electrical conductivity (EC) and salinity exhibited slight decreases after storage, indicating that the clay pot might be partially retaining some ions. However, both parameters remained well within the WHO permissible limits, suggesting that the clay pots do not significantly affect the ionic composition of the water.

Interestingly, the concentration of bicarbonates (HCO_3^-) increased significantly from 21.5 mg/L to 85.4 mg/L, though still within the WHO acceptable limits. This could be due to the dissolution of carbonate minerals from the clay, which is consistent with findings from other studies on water stored in clay-based filters (Van Halem et al., 2009).

The water's Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) increased slightly, suggesting some level of organic matter degradation occurring during storage. Although these parameters are not regulated by WHO, the increase warrants attention as it may indicate the development of anaerobic conditions within the clay pot (Zhao et al., 2012).

Overall, while the water's essential ions remained within safe limits, the pH reduction and increases in bicarbonates and organic demand indicators highlight the need for further refinement of the clay material used in the filtration process to ensure it does not adversely affect water quality during

Table 4.2: Result of Heavy Metal Analysis of Omuoku River Water before Storing in Clay Pot

	Result	Sample result	WHO	
Parameter	**Raw river water**		**Highest desirable**	**Maximum permissible**
Fe	0.861	0.193	1	3
Mn	0.108	0.070	0.1	0.1
Zn	0.375	0.094	0.01	3.0
Cu	0.073	0.055	5.0	15.0
Cr	0.044	0.018	0.5	0.05
Cd	0.021	0.006	0.003	0.003
Ni	0.020	0.003	10	100
Pb	0.038	0.010	0.01	0.01
V	0.011	0.001	ND	ND
THC	ND	ND	500	500

From the above data, the heavy metal analysis of Omouku River water before and after storage in clay pots reveals notable reductions in the concentrations of various metals, which are compared against WHO standards.

Iron (Fe) levels decreased significantly from 0.861 mg/L to 0.193 mg/L, remaining well within the WHO's permissible limit of 3 mg/L. This reduction suggests the clay pot effectively adsorbed iron, a common outcome observed in studies involving clay filtration (Abollino et al., 2002). Manganese (Mn) also showed a reduction from 0.108 mg/L to 0.070 mg/L, just at the WHO's maximum permissible level of 0.1 mg/L, further indicating the clay's ability to remove certain heavy metals effectively.

Zinc (Zn) and Copper (Cu) concentrations were reduced to 0.094 mg/L and 0.055 mg/L, respectively, both well below the maximum permissible limits, indicating the clay's efficacy in reducing these metals. Chromium (Cr) and Cadmium (Cd) levels decreased to 0.018 mg/L and 0.006 mg/L, respectively, with cadmium still slightly above the WHO desirable limit but within the permissible range.

Lead (Pb) levels, although reduced from 0.038 mg/L to 0.010 mg/L, are at the WHO's maximum permissible limit, suggesting the need for careful monitoring of lead contamination in clay filtration systems (Oyanedel-Craver & Smith, 2008).

Overall, the results indicate that storing water in clay pots can significantly reduce the concentration of heavy metals, making it safer for consumption. However, careful selection and preparation of clay are essential to optimize its filtration properties.

Table 4.3: Result of Microbial Analysis of Omouku River before Storage in Clay Pot.

S/N	SAMPLE	TOTAL HETEROTROPHIC BACTERIAL COUNTS (CFU/ML)
1	**Omuoku River Water**	3×10^3

The total heterotrophic bacterial count for Omouku River water before storage in a clay pot is reported as 3×10^3 CFU/ML. This level of bacterial contamination indicates a significant presence of microorganisms, which can pose health risks if consumed untreated.

Relevant literature highlights that river water often contains high levels of heterotrophic bacteria due to the presence of organic matter and potential contamination sources. According to the World Health Organization (WHO), water with bacterial counts above 100 CFU/100 mL is considered unsafe for drinking without treatment, emphasizing the importance of purification systems.

Clay pot filters have been shown to effectively reduce bacterial contamination. Studies, such as those by Lantagne (2001), demonstrate that ceramic filters can decrease bacterial counts by up to 90%, making them a viable option for improving water safety. The use of locally sourced clay for such filters not only provides an affordable solution but also supports sustainable practices. Therefore, integrating clay pot filtration could significantly improve the microbial quality of Omouku River water, aligning with established research on ceramic water filters' efficacy.

Table 4.4: Result of Physiochemical Analysis of Omuoku River after Storing in Clay Pot

	Sample Result	WHO	
Parameters		**Highest desirable**	**Maximum permissible**
pH	5.8	7.0-8.9	6.9-9.5
EC	53.2	100	1200
Sal.	0.024	10	NS
Col.	ND	3.0	15.0
Turb.	ND	ND	5.0
TSS	ND	ND	NS
TDS	27.4	500	1500
COD	4.2	NS	NS
DO	1.4	NS	NS
BOD	0.7	NS	NS
HCO_3	85.4	125	350
Na	0.151	200	100
K	0.084	20	15
Ca	0.661	100	200
Mg	0.317	50	150
Cl	35.7	200	250
P	0.021	NS	NS
NO_2	0.084	0.2	3
NO_3	0.575	50	70
NH_4N	0.245	NS	NS
SO_4	0.358	250	500

The physicochemical analysis of Omuoku River water after storage in a clay pot reveals several key insights relative to WHO standards.

1.pH (5.8): The pH is slightly below the WHO's desirable range (7.0-8.9), indicating the water is somewhat acidic. This is within the permissible range but could affect taste and potential corrosivity.

2. Electrical Conductivity (EC) and Total Dissolved Solids (TDS): Both are within acceptable limits (EC: 53.2 µS/cm, TDS: 27.4 mg/L), suggesting that the clay pot effectively reduces ionic contamination.

3. Salinity (Sal.): The low salinity (0.024) is well below the WHO guideline, indicating minimal issues with saline contamination.

4. Coliforms: The absence of coliforms (ND) is promising as it suggests effective microbial reduction by the clay pot.

5. Turbidity: The non-detectable turbidity (ND) aligns with WHO standards, indicating good clarity.

6. Nutrient and Metal Concentrations: Parameters like NO2, NO3, and NH4N are well within limits, but potassium (K) is slightly above the desirable level, which could be an area of concern.

The data suggests that the clay pot effectively improves water quality, aligning with literature that supports ceramic filters' capability to reduce turbidity and bacterial contamination (Lantagne, 2001). However, continuous monitoring is advised to address potential issues such as pH and potassium levels.

Table 4.5: Result of Heavy Metal Analysis of Omuoku River After Storage in Clay Pot

	Sample Result	WHO	
Parameter		**Highest desirable**	**Maximum permissible**
Fe	0.193	1	3
Mn	0.070	0.1	0.1
Zn	0.094	0.01	3.0
Cu	0.055	5.0	15.0
Cr	0.018	0.5	0.05
Cd	0.006	0.003	0.003

Ni	0.003	10	100
Pb	0.010	0.01	0.01
V	0.001	ND	ND
THC	ND	500	500

The heavy metal analysis of Omuoku River water after storage in a clay pot shows varying results relative to WHO standards:

1. **Iron (Fe)**: At 0.193 mg/L, the iron concentration is below the WHO maximum permissible limit of 3 mg/L, indicating safe levels for consumption.
2. **Manganese (Mn)**: The value of 0.070 mg/L is under the WHO limit of 0.1 mg/L but above the desirable level of 0.1 mg/L. This is acceptable but suggests the need for further monitoring.
3. **Zinc (Zn)**: At 0.094 mg/L, zinc levels are well below both the highest desirable and maximum permissible limits (3.0 mg/L), indicating minimal health risks.
4. **Copper (Cu)**: The concentration of 0.055 mg/L is much lower than the WHO permissible level of 15 mg/L, which is favorable.
5. **Chromium (Cr)**: The concentration of 0.018 mg/L exceeds the desirable limit of 0.05 mg/L but is under the maximum permissible level, suggesting monitoring is necessary.
6. **Cadmium (Cd)**: At 0.006 mg/L, cadmium levels are below both desirable and permissible limits, which is positive.
7. **Lead (Pb)**: The level of 0.010 mg/L is right at the WHO permissible limit, which suggests that while it is acceptable, lead levels should be carefully monitored.
8. **Nickel (Ni)** and **Vanadium (V)**: Both are within the acceptable range, though vanadium (V) is not detected (ND), indicating no concern.

The results generally indicate that the clay pot is effective in reducing heavy metal concentrations, aligning with literature that supports ceramic filters' capability to remove such contaminants (Smith et al., 2006). However, chromium and lead levels should be monitored closely to ensure ongoing safety.

Table 4.6: Result of Microbial Analysis of River Water during Storage in Clay Pot.

TIME	SAMPLE	TOTAL HETEROTROPHIC BACTERIAL COUNTS (CFU/ML)
Day 2	**Omuoku River Water**	$0{\times}10^3$

The microbial analysis of Omuoku River water stored in a clay pot shows that the total heterotrophic bacterial count on Day 2 is $0{\times}10^3$ CFU/ML. This indicates a complete reduction in bacterial counts within just two days of storage in the clay pot.

This result is consistent with research on the effectiveness of clay pot filters. According to Lantagne (2001), ceramic water filters can significantly reduce bacterial contamination, often achieving near-total removal of bacteria. The reduction to zero bacterial counts suggests that the clay pot's porous structure and antimicrobial properties effectively eliminate microbial contaminants.

The rapid decline in bacterial counts underscores the potential of clay pots for improving water safety, especially in regions where access to clean water is limited. Such filters are valued for their ability to provide safe drinking water by reducing microbial load efficiently. Continuous monitoring and maintenance of the clay pots are crucial to ensure sustained effectiveness and safety (Wegelin et al., 2000).

V. Summary, Conclusion and Recommendation

5.1 Summary

The study on the development of a point-of-use household water purification system using locally sourced clay materials demonstrated significant improvements in water quality. Analysis of Omouku River water revealed notable reductions in microbial contamination after storage in clay pots, with total heterotrophic bacterial counts decreasing from $3{\times}10^3$ CFU/ML to $0{\times}10^3$ CFU/ML within two days, indicating the effectiveness of clay pots in microbial removal (Lantagne, 2001; Smith, Johnson, & Davis, 2006).

5.2 Conclusion

Physicochemical analyses showed that while parameters like pH, electrical conductivity (EC), and total dissolved solids (TDS) were generally within acceptable limits, pH was slightly below the WHO desirable range, and potassium (K) was marginally high. Heavy metal analysis confirmed that most metals, including iron (Fe), manganese (Mn), and zinc (Zn), were within safe limits. However, chromium (Cr) and lead (Pb) levels were close to permissible thresholds, indicating the need for ongoing monitoring (Wegelin, Elmore-Meegan, & Stauber, 2000).

5.3 Recommendations

1. **Regular Monitoring:** Continuous monitoring of microbial and physicochemical parameters is essential to ensure consistent water safety, particularly for chromium and lead levels.
2. **pH Adjustment:** Explore methods to adjust the water's pH, potentially through additional treatment steps or materials, to ensure it falls within the desirable range.
3. **Community Education:** Educate local communities on the benefits and maintenance of clay pot filters to ensure effective use and longevity.
4. **Research and Development:** Further research should focus on enhancing the clay pot's ability to manage high potassium levels and optimizing performance for various water quality parameters.

These recommendations aim to improve the reliability and effectiveness of clay pot filtration systems, enhancing access to safe drinking water in affected regions.

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