EVALUATION OF COMPOSITES FROM NANO-CLAY AND RECYCLED POLYTHENE TEREPHATHALATES FOR POINT-OF-USE WATER FILTRATION SYSTEMS

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Abstract: **In the present study, point-of-use (POU) water filtration systems were fabricated using montmorillonite clay and polyethylene terephthalate (PET), and evaluated for use in rural communities of Nigeria, including internally displaced person's (IDP) camps. Both montmorillonite clay and polyethylene terephthalate were sourced locally from sites around Makurdi in Benue State – Nigeria. The PET was processed to micro size and sieved on a No. 2 microns sieve to obtain 0.07 μm particles while clay was processed into Nano particles and mixed with the micron sized PET particles in an industrial mixer to obtain a homogenous content. Five (5) cup-shaped filter samples were produced using five different weight percent (wt.%) ratios (Nano-clay/PET) of 50:50, 60:40, 70:30, 80:20 and 90:10 - designated as A, B, C, D and E respectively. The filter samples were aged and cured in an oven at 130ºC (above glass transition temperature) for about 30 mins to cause distortion on the PET particles to create predetermined pore sizes. The filter samples were evaluated on the basis of mechanical (shatter index), physical (water absorption, porosity and flow rate), chemical (water pH, total dissolved solids and turbidity) and biological (microbial removal efficiency) properties. Results of shatter index test indicated that all samples exhibited shatter resistance of well over 90% indicating high durability and ability to withstand handling stresses especially during packaging and transportation. Analyses of the untreated and treated water samples showed removal efficiencies for turbidity, TDS, and TSS as 79%, 64% and 62% respectively. All results obtained were within the WHO limit. In general, all the samples showed excellent performance in the removal of harmful microbes for all bacteria studied, while samples D and E demonstrated an improved capacity to eliminate E. coli and total coliform. Based on ANOVA, it was concluded that filter sample C which high significance, comprising 70 wt% fine-clay and 30 wt% PET met the most standard requirements for point-of-use drinking water filter quality. This sample also exhibited the fastest discharge of 1.92 litres/hr compared to the other samples. Filter sample C was therefore recommended for use by rural communities as it consistently produced high-quality water that complied with most turbidity and microbiological limits for drinking water.**

Keywords: **Nano-clay/PET; Point-of-use; Water filtration; flow rate; Turbidity; microbial removal efficiency.**

I.   INTRODUCTION

Clean water and effective sanitation are essential to good health and wellbeing of all humans (Joy *et al*, 2021; Surekha *et al,* 2023). Most poor and vulnerable people especially those living in rural communities and Internally Displaced Persons (IDPs) living in camps however, faces challenges of lack of quality water and are prone to water borne diseases due to consumption of water from polluted sources (UNICEF/WHO, 2019). Currently in Nigeria, there are over 59.1 million displaced citizens' camps across different states of the Federation (IDMC, 2022). Benue state alone has close to two million IDPs in twenty-seven (27) IDP camps (Vanguard, April 1st, 2022 report).

These rural communities including IDPs require clean drinking water to enjoy quality lifestyles. Several water purification devices have been implemented by health organizations with varying degrees of success (UNICEF, 2020). However, many of the purification devices are for large-scale community water purification which are complex, and often require maintenance by skilled personnel that are not always available in rural communities. If problems occur with the infrastructure of the purification method in communities, it is difficult to obtain replacement parts.

Point-of-use treatments are short-term water purification methods that allow people to purify water just before drinking. The most common method of which is boiling, which has been implemented for centuries. Although boiling does destroy Escherichia coli and other bacteria and protozoan cysts that can cause diarrhea, boiling frequently requires large amounts of fuel, which is either lacking or takes a toll on the environment (Imtiyaz *et al*, 2021). Wood collection is another concern for many women living in areas subjected to civil unrest, kidnapping and armed banditry coupled with the decline of sources of wood for boiling.

Another type of Point-of-use water purification is the use of chlorine solution to decontaminate water. Chlorine water purification improves water quality by killing bacteria (Bruce and Sharon, 2017; CDCP, 2020). Chlorination also has the added benefit of leaving a residue that can prevent recontamination. However, chlorination has its setbacks in that, it is not effective in inactivating protozoan cysts and the chlorine taste may be unpleasant to many users (Susan and Nozaic, 2017). Cost for acquisition of chlorine may also be a hindrance to the users thereby, making this process of purification less sustainable than other methods.

Filtration is one of the most effective yet simplest water treatment processes. Several point-of-use filtration systems have been designed, produced and characterized for their performance levels as well as for the economic feasibility and social acceptability (Honieh and Mokshapathy, 2019). Their performance levels were determined by the removal efficiencies in terms of turbidity and microbiological parameters.

Slow sand filters (SSF) are a type of water filters that are cost effective and relatively simple to use (Pescod et al, 2019; Kaldibek *et al,* 2023). One type of SSF is the bio-sand filter, which requires a schmutzdecke, a biological layer of algae that filters the organic molecules from the contaminated water. Below the layer, the other sand layers remove the bacterial impurities. Although the algae layer removes organic waste from the water, it will retain the contaminants unless it is regularly cleaned through agitation (Changgyeong *et al,* 2019). Another drawback for the bio-sand filter method is that, if the biological layer is not completely formed, the filter is not shown as effective. It implies that the villagers must either have multiple sand filters available or use other means to keep their water clean.

Ceramic filters are the most commonly used filters at the household level, and have the advantage of being produced globally at a low cost, with wide acceptance in many low-income countries (Ismaiel *et al,* 2013; Weart *et al,* 2017, Chaukura *et al*, 2023). Ceramic filters can have pores as small as 25 microns, thus removing bacteria and protozoa, but only partly removing viruses, usually with 2log to 3log efficiency, while allowing flow that will range from 2L to 15L, depending on the type and number of filtering elements (Akosile *et al,* 2020). They sometimes include activated carbon in their core to remove taste and odour, and/or can be coated or impregnated with silver to avoid bacterial growth on the ceramic surface. Some ceramic filters come with additives such as bromine that are released in the filtered water to reportedly remove viruses as well (WHO, 2018). However, these additives often have a limited lifetime in terms of efficiency and their efficiency is not yet documented enough.

Nano-clay based adsorbent filters have emerged in recent times, as alternative technology for point-of-use water filtration systems (Ismaiel *et al*., 2013; Ali and Gupta; 2018). Filters with different proportions and porosities of clay to sawdust by volume have been researched on. The porosimetry data provided some useful insights into how the different ranges of pore sizes could contribute to the trapping of bacteria. It was concluded that the range of nano and micron-scale pores can trap single-celled and multicellular organisms that cause water-borne diseases. However, the nanoscale pores were not sufficient enough to trap viruses with sizes of about 10–30 nm. They suggested the need for adsorbing surfaces that attract viruses during flow through the CWFs.

In another study, Weart *et al*, (2017) also used a combination of clay and sawdust in varying ratios to produce and characterize point-of-use filters. The filters were found to be effective in removing bacteria as well as larger cells such as helminth ova, typically between 10 μm and a few hundred microns in size, suggesting that point-of-use CWFs with different porosities could be used to filter out most of the bacterial pathogens in water.

Fidelis *et al*, (2019) and Akosile *et al*, (2020) produced and characterized a cost-effective ceramic filter using clay and sawdust to improve the physical and biological quality of drinking water and to check its general filtration efficiency. Both results showed removal efficiencies of 80% and 100% for coliform and E. coli bacteria respectively.

Ihekweme, (2021) characterized filters from clay and rice husk of particle size 435µm to increase porosity, flow rate and other filtration properties. The result showed that pH and total dissolved solids were within standards prescribed by the World Health Organization for drinking water. Shobha and Mansoor (2022) also observed significant enhancement of adsorption capacity for different classes of pollutants including heavy metals, dyes, nutrients, organic micro pollutants and microbial pathogens from water when they used clay/biomass as filters in their study.

It is clear from above that much research focusing on development and characterization of Nano-clay-based composite for water filtration have been undertaken by researchers with significant achievements. Whereas Clay/biomass systems have good prospects for water filtration, the tendency of these biomass to decompose within the filters after prolonged period of use is one factor that needs to be considered whilst selecting biomass as filler material for water filters. Degradation of the biomass may result in further contamination of the water and also produce foul and irritable odours.

In the present study, Nano-clay/recycled PET composites were produced and evaluated as alternative material for water filtration in rural Communities. The goal was to construct a filter that will be easy to use and composed of items that are readily available and non-degradable during usage. Nano-clay and recycled PET as reinforcement is an option that requires attention based on the fact that PET is non-degradable and has capacity to remain so even with prolonged period of use. This is an advantage that cannot be overlooked (Awad, 2021). The fact that the clay can be used at nano level is also an added advantage to the process. Another benefit of this study is that, it would help clean up our environment of PET that currently poses disposal issues to governments and the society.

The study is significant because many local communities in Nigeria, including the Internally Displaced Persons (IDP) Camps, lack the resources to undertake large-scale water treatment infrastructure projects. With this system, it could be possible for the people to treat their drinking water simply and effectively. The small-scale water filtration system could be brought into remote areas and provide the means of purifying previously contaminated water. This could save countless lives every year. Filtering local sources of water would also eliminate the need to import large quantities from elsewhere to the IDP Camps, saving relief funds for alternative uses.

II. EXPERIMENTATION

Material Sourcing and Preparation

Polyethylene terephthalate (PET) bottles were sourced from collection centers around Makurdi metropolis. Preparation of PET particles was carried out as per Ihekweme, (2021). The bottles were thoroughly washed with water to remove remnants of foreign materials and other sand particles. They were alkaline treated to remove other foreign impurities and then sun-dried for 24 hours. The dried PET bottles were crushed into pellets using a Jaw Crusher and thereafter oven-dried for 24 hours. The oven-dried PETs were later grinded to micro size and sieved on a No. 2 microns sieve to obtain 0.07 µm particles. Montmorillonite clay was collected locally in both dry and wet form from Adaka Clay Depot in Gwer-East Local Govt. of Benue State, where large deposits exist. The clay was oven-dried, crushed into powder and sieved on a 5-micron sieve. Preparation of montmorillonite clay into Nano particles was carried out at federal institute of industrial research Oshodi (FIIRO), Lagos-Nigeria in accordance with the ASCE procedures described in Ismaiel *et al*, (2013).

Preparation of test sample

The already prepared Nano clay particles were mixed with the micron sized PET particles in an industrial mixer (Model A-200) to obtain a homogenous content. Five (5) samples were produced using five different ratios (Nano-clay/PET) of 50:50, 60:40, 70:30, 80:20, 90:10 and 100:0 percent by weight (wt %). Distilled water was added to the mixture in small amount until the mixture attained a lump of mouldable paste (Akosile *et al,* 2020). The paste was then transferred to specially prepared wooden moulds, cast, aged and heat-treated at 130ºC for 30 minutes, in line with Wang *et al,* (2012), to cause a distortion on the PET particles resulting in increased pore sizes. The composite samples were then allowed to cool under natural conditions to prevent the material from cracking.

Fabrication of ceramic filter cups

Water filter cups (Fig. 1) were produced from the mix ratios (Nano-clay to PET) using solid cast method in line with Wang *et al,* (2012). Each mixture was separately poured into a basin filled with 1000 ml of distilled water to dissolve. The mixture

was vigorously mixed in a big compounding container and then sealed in polyethene bags and aged for approximately two days to improve plasticity. Thereafter, the paste was removed from the bags and kneaded on a flat table to form mouldable balls. The balls were then transferred to specially designed cup-shaped wooden moulds. Cup-shaped filter samples were produced by pressing the balls into the moulds using a hydraulic machine. The cast filter samples were aged under standard atmospheric conditions and then oven-treated at 130ºC (slightly above glass transition temperature) for 30 minutes. The filter samples were then allowed to cool inside the firing kiln for two days under natural conditions to prevent the material from cracking.

Shatter Resistance of filter cups

Shatter resistance test was carried out to determine durability of the filter samples and their ability to withstand handling stresses especially during packaging and transportation. The test was conducted under standard conditions using (ASTM, 2018) code D 440–86; with some modifications described in Tembe *et al,* (2014) and Akosile *et al,* 2020). This involved dropping the filter samples three times from a specific height of 1.5 m onto a surface. The fraction of the filter sample retained was used as an index of the filter breakability. The percentage weight loss of the filter was expressed as a percentage of the initial mass of the material remaining on the solid base, while the shatter resistance was obtained by subtracting the percentage weight loss from 100 (Equation 1).

$$\text{Shatter Resistance } = 100 - \left[\frac{\text{Initial weight before shatter} - \text{Weight after shattering}}{\text{Initial weight before shattering}}\right] \qquad (1)$$

Scanning Electron Microscopy of water filters

SEM analysis was carried out to determine pore size and pore size distribution in the filter samples. The porosity of any filter media determines the rate of flow of fluid, while the pore size and pore size distribution of a filter are important in determining the filter's efficiency in removing particulates from water. Using ASTM, (2020) standards in line with a modified procedure described in Ihekweme (2021), Scanning electron microscope (SEM) images of the filter samples were captured with a Carl Zeiss SEM (Model: Evo10LS-EDAX) at a very high count per second. The obtained micrographs were later used to analyze porosity by the number and size of pores of the samples with highest flow rate.

Physical Properties

Determined Physical properties of the filters included water absorption, porosity and flow rate (Fidelis *et al;* 2019).

Water absorption test

Water absorption capacity of the Nano-clay/PET composite filters was investigated in accordance with ASTM, (2020) code D570, using the adapted methodology by Ihekweme (2021). The water absorption was calculated on triplicate measurements. Samples were cut into film samples of 30 x 30 x 5 mm and weighed as dried mass. Thereafter, they were inserted in 250 ml of distilled water for 30 mins in a measuring cylinder. They were again removed, drained and re-weighed. The amount of water retained per dried weight of the film samples was then calculated as water absorption capacity. The flow rate was calculated by dividing the volume of water measured in the lower cylinder by the time taken to filter.

Flow rate analysis

Flow rate of the samples was obtained in accordance with ASTM, (2019) code D4404 using Shobha and Mansoor, (2022). The filter cups were first soaked in water for 24 hours to get saturated after which about 5000 mL of clean water was used to fill each of the filter cups. Graduated cylinders were used to determine the volume of water filtered through each cup every hour.

$$\text{Flow Rate} = \frac{\text{Volume of filtered water (mL)}}{\text{Period taken to filter the water (Hour)}} \qquad (2)$$

Water Quality Analysis

Water samples from two different sources (shallow-well water and untreated stream water), around Ucha Community near the JS Tarka University Benue State – Nigeria were subjected to filtration with a view to ascertaining the individual efficiencies of the cup filters. To evaluate the water treatment performance of the filter samples, water qualities before and after filtration were measured and tested. Water quality parameters including turbidity, pH, total dissolved solids, and total E coli count were investigated (Monika *et al,* 2024). The quality of raw water used in the study is shown in Table I.

Turbidity analysis

Turbidity of the water before and after filtration was determined using spectrophotometer with the 'EPA 180' measurement mode in accordance with MRBDC, (2018) with some modifications as described in Ababu *et al*, (2018). Turbidity removal efficiency was calculated using the following relationship.

$$\text{Turbidity removal efficiency}(\%) = \frac{\text{Raw water sample value} - \text{Filtered water sample value}}{\text{Filtered water sample value}} \times 100 \qquad (3)$$

Water pH

The pH was measured by Electrometric Method Using Laboratory pH Meter Hanna Model HI991300 using the Kansas Department of Health and Environment (KDHE) guideline and EPA (Environmental Protection Agency) standards (EPA, 2023). The values obtained were compared to the standard pH rating on drinking water by ALPHA, (2016).

Total dissolved solids (TDS)

The APHA 2510 A TDS 139 tester (APHA, 2016) was used to determine the Total Dissolved Solid (TDS) following ISO, (2019) code 3025, Part 10, 16 and 17 and in line with Shuaib-Babata (2017). TDS removal efficiency was calculated from the following relationship:

$$\%\text{TDS removal efficiency} = \frac{\text{Raw water sample value} - \text{Filtered water sample value}}{\text{Filtered water sample value}} \times 100$$
$$(4)$$

Microbial removal efficiency

This test was carried out in accordance with WHO, (2020) and American Water Works Association (AWWA) Standard codes B100 and C653 for water filtration following a modified procedure described in Greg *et al*, (2013). Water samples were tested twice and recorded for each filter sample. MRE was calculated using the following relationship:

$$\%\ \text{MRE} = \frac{\text{Raw water sample value} - \text{Filtered water sample value}}{\text{Filtered water sample value}} \times 100 \qquad (5)$$

Statistical Analysis

Data used to assess water quality before and after treatment through each filter device were subjected to one-way analysis of variance (ANOVA) (Fig. 2), to compare more than two groups. Comparisons were made between the treatment means of each filter device per water source to determine if there were significant differences between treatments. Where differences were observed, pair-wise comparisons were performed to compare the two groups. The interpretation was performed at the 95% confidence limit.

III.   RESULTS AND DISCUSSION

Shatter resistance of filter cups

Figure 3 reveals that shatter index of the filter cups diminished steadily as proportion of Nano-clay increased with corresponding decrease in that of PET. Sample A and B, with highest percentage of Nano-clay, have reasonably highest shatter index compared to samples C, D and E with lower percentages. Tembe *et al*, (2014) and Fidelis *et al*, (2019) while conducting studies on properties of Nigeria clay and sawdust for household ceramic water filters, also confirmed that strength of materials depends on the level of reinforcement. In the present study, the high shatter index of sample A **i**ndicates high durability of the filter samples and the ability to withstand handling stresses especially during packaging and transportation. Sample D and E in the present study, have the least strength due to lesser content of PET hence cannot withstand handling stresses. Therefore, of the two-material combinations, PET is a more effective material than Nano-clay for shatter resistance requirements.

Water Absorption Capacity

From Figure 4, it can be observed from the figure that, samples A, B and C have significantly lower percentage water absorption compared to samples D and E which have noticeably higher percentage water absorption. Sample E recorded

the highest percentage water absorption with value above 50%, in comparison with sample A with percentage water absorption below 10%. As can be inferred from Figure 4, increasing nanoclay composition from 50% wt. to 90% wt. and reducing PET composition from 50% wt. to 10% wt., percentage water absorption of the samples increased. That is, the higher the composition of nanoclay in a sample, the higher the capacity of the samples to absorb water (Shuaib-Babata, 2017). Samples A, B and C therefore had low percentage water absorption due to high PET content compared to D and E based on that fact. It implies that, in sample D and E where there was high amount of nanoclay compared to sample A, B and C, it will take more time for water to be absorbed in the material before final discharge. The implication of the result is that, of the two constituent materials used in this research, nanoclay is a more potent constituent material than PET, in determining the percentage water absorption of the sample filters.

Porosity and flow rate of filter samples

Flow rate and porosity are inter-related. The porosity of any filter media determines the rate of flow of fluid, while the pore size and pore size distribution of a filter are important in determining the filter's efficiency in removing particulates from water. It is a fact that low porosity militates against flow rate (Shuaib-Babata *et al*, 2017). From the result (Fig. 5), it can be observed that the sample that exhibited the fastest discharge is sample C comprising of 70 wt.% clay and 30 wt.% PET. This sample exhibited the fastest discharge of 1.92 litres/hr. Sample B also exhibited high flow rate (1.5 litres/hr) although this is lower than C. Samples A and D exhibited lower flow rate while sample E was identified to be the slowest. The decreasing flow rate in the sample D and E may be due to higher amount of clay as compared to PET. The high plasticity of clay gives rise to a closely packed structure leading to lower porosity (Fidelis *et al*, 2019 and Anuradha *et al*, 2019). The SEM micrographs of samples B and C (Fig. 6 & 7) reveal that, there are interconnected sponge-like cavities and inter-crystalline pores of sizes approximately 2µm for sample B and 3µm for sample C. It is clear therefore that pore size and pore size distribution of a filter are important in determining the filters' efficacy at removing particulates from water as well as influencing the flow rate. The above results also show that apart from pore size and pore size distribution there is also an additional factor that will influence flow rate; this being optimum combination of constituent materials (Nanoclay and PET). A major concern about locally fabricated Point-of-use filters is their ability to produce adequate clean drinking water to serve the population. It is clear from these results that, samples with 70 wt.% clay and 30 wt.% PET would produce filters with excellent flow rates necessary for the purpose. Data collated by Nnaji, *et al*., (2016) indicates that average daily water intake ranges between 1.8 and 5.0 litres per capita per day (LPCD). It is obvious from our results that the filter with 30% PET can conveniently satisfy this requirement.

Turbidity and Turbidity Removal Efficiency

Figures 8 & 9 represent changes in turbidity and turbidity removal efficiency respectively as composition of the samples was varied. The results, obtained using total dissolved (TDS) test, show that turbidity increased with increasing proportion of PET (Fig. 8). Generally, the filters were found to be very effective in removing suspended solids from water. Highest turbidity value of 63 NTU was observed in sample A (comprising 50 wt% Nanoclay-50 wt% PET) while sample E (comprising 90 wt% Nanoclay-10 wt% PET) had the lowest turbidity value of about 4 NTU compared to turbidity value of 97 CTU for the untreated water. Samples A, B, and C have significantly lower turbidity removal efficiencies of about 32%, 38% and 50% respectively, compared to samples D and E with 73% and 95% respectively, for both water sources S1 and S2. It can be concluded that over 90% of the turbidity was eliminated when nano-clay composition was steadily increased. That is, the higher the composition of nano-clay in the samples, the higher the capacity of the sample to eliminate turbidity in the water. The implication of the results is that, of the two constituents used in this formulation, nano-clay is a more potent constituent than the PET in turbidity elimination. Ababu *et al*, (2018), and Asrafuzzamn *et al*, (2018) reported the standard turbidity value for drinking water, based on WHO recommendation, to be one that is less than 10 NTU. The results in the present study showed that the produced water filters are capable of removing turbidity up to the standard level.

The pH of treated water

Variation of pH with sample composition is represented in Figure 10. The pH decreased steadily from 8.1and 7.1 to 7.7 and 7.2 for water sources S1 and S2 respectively, as proportion of PET was varied from 50wt% to the lowest value of 10wt%. The pH of raw water samples was about 9.8 (slightly basic) compared to that of treated water. The decrease in pH of filtrate is possibly due to removal of dissolved solids by the filter samples. Samples C, D and E have significantly lower pH values compared to sample A and B. Sample E recorded the lowest pH value for both water sources S1 and S2 with values below 8.0, compared to sample A with a pH value of over 8.0. Fidelis *et al*, (2019) and Manak, (2020) report pH value of between

6.5 and 8.5 as standard recommended by WHO for drinking water. Result of the present study compares favourably with specified standards implying that the two-material combinations are adequate for production of quality drinking water.

Total Dissolved Solids (TDS) Removal

Total dissolved solid expresses the total amount of dissolved metals and all the other inorganic materials in the water. The change in TDS with sample composition is shown in Figure 11. TDS for the filtered water ranged from 82.9 mg/L to 38.62 mg/L for water sample S1 and between 83.85 mg/L and 39.81 mg/L for water sample S2. Performance of the filters with respect to suspended solids removal is considered to be very high based on Illinois Department of Health specifications which classified TDS level of less than 500mg/L as satisfactory, between 500 – 1000mg/L as less than desirable and between 1000 – 1500mg/lL as undesirable and over 1500mg/L as unsatisfactory (IDH, 2000; Shuaib-Babata *et al,* 2017). The present study also shows values below the recommended WHO standard maximum of 600mg/L. Under this classification, water whose TDS is above 600 mg/L is considered to be unpalatable for drinking. This trend is also represented in Figure 12 where samples A, B, and C have significantly lower dissolved solids removal efficiencies of between 60 and 70% compared to samples D and E with values well above 70%. Generally, the filters with highest proportion of clay (80 wt.% and 90 wt.% respectively) were found to be more effective in removing suspended solids from water having removal efficiency range between 77% and 81%. The implication of the results is that of the two constituents used in this study, nano-clay is a more potent constituent than the PET in TDS removal.

Total Coli Content (TCC) and Microbial Removal Efficiency (MRE)

TCC in drinking water refers to the number of coliform bacteria found in the water. It provides a basic indication of the sanitary condition of the water source. A high count indicates potential contamination including the possibility of disease-causing pathogens. Results in Figure 13 and Table II shows a steady decrease in total coliform count. This is an indication of the ability of the filter samples to remove pathogens from the raw water sources. Scientifically, *Staphylococcus, Proteus spp, Vibrio spp. and Entrobacter* have harmful effects on human health and can cause various diseases and sicknesses (Mesbah *et al*, 2014; Ontario, 2022; Ramirez and Giron, 2023). The table indicates that sample D and E significantly reduced the total bacteria content of the raw waters to just one compared to samples A and B where only a few bacteria isolates were removed. In Sample C, the bacterial content was reduced to about two (*Klebsiella spp., and Bacillus spp*.). *Klebsiella spp*. detected in drinking-water are generally biofilm organisms and are unlikely to present health risks (Nishtha *et al*, 2022). According to a report by Turnbull, (2019), a large majority of *Bacillus* species are harmless *saprophytes*. While the pathogenic properties of *Bacillus Cereus* are well established, very limited information is available about risks associated with administration of other *Bacillus* species. The risk of water-borne diseases due to *Bacillus spp*. is also considered low (Sorokulova *et al*, 2018; Rodrigo *et al*, 2021). The results in the present study indicate that, the combination of nanoclay and PET is able to remove microbes up to the minimum required level. Results of Figure 14 also revealed a steady increase in MRE as the proportion of Nano-clay increased. The figure also revealed that all the filter samples had good total coliform removal efficiency of above 80%. The filters achieved better removal efficiency as the proportion of Nano-clay was gradually increased; reaching a peak value of approximately 93% at 90wt.% Nano-clay and 10wt.% PET composition. Comparatively, samples with the highest proportions of nano-clay [Sample D (80wt.% Nano-clay/20wt.% PET) and E (90wt.% Nano-clay/10 wt.% PET)] performed better than the other filters in removing microbial contaminants. The removal efficiency of between 77-93% was observed for these samples which agrees with standards prescribed for drinking water. Sobsey *et al*, (2018) also confirmed the high capacity of clay to substantially remove coliform from drinking water. Shuaib-Babata *et al,* (2017) while studying sustainability of clays for water filters, recorded 80% microbial removal efficiency while Ababu *et al*, (2018) in a study on adsorption process for microbial removal from water, achieved 96% coliform removal. Similarly; Fidelis *et al*, (2019) in a study on Bacteria removal efficiency and properties of Nigeria clay for household ceramic water filter recorded about 90% MRE. Akosile *et al,* (2020) also achieved 95% MRE from filtered water in their filtration study using clay.

IV. CONCLUSION

Nanoclay-PET hybrid composite was developed and characterized for Point-of-Use water filtration. At the end of the study, it was concluded that the filter sample C containing 70% wt. clay to 30% wt. PET met the most standard requirements for point-of-use drinking water filter quality. This sample also exhibited the fastest discharge of 1.92 litres/hr compared to the other samples. Filter sample C was therefore recommended for use by rural communities as it consistently produced high-quality water that complied with most turbidity and microbiological limits for drinking water.

V. APPENDICES

Tables and Figures

TABLE I: Quality parameters of raw water used in the study

Water Source	Turbidity (NTU)	TDS (g/L)	Total Coli Count (CFU)	pH
Well Water	0.97	0.202	$7.8 \times 10^1 \pm$	9.80
Stream Water	0.92	0.211	$8.5 \times 10^1 \pm$	9.71

Table II: Microbiological quality of water before and after filtration

Quality before filtration

Water Source	Bacteria Isolates	Av. Microbial Content (%)
Well Water	*Entrobacter, Bacillus spp., Klebsiella, Staphylochoccus spp., Proteus spp.*	100
Stream Water	*Vibrio spp., Entrobacter, Bacillus spp., Klebsiella, Staphylochoccus spp., Proteus spp., Citrobacter.*	100

Quality after filtration

A (50:50)	*Bacillus spp., Klebsiella, Staphylochoccus spp.,*	11.48
B (60:40)	*Klebsiella, Bacillus spp., Proteus*	10.28
C (70:30)	*Klebsiella, Bacillus spp.*	9.93
D (80:20)	*Bacillus spp.*	4.88
E (90:10)	*Bacillus spp.*	3.70

Fig. 1: Ceramic filter cup samples produced from respective mixtures of Nano-clay and PET

Fig. 2: Summary of Filter/Water Properties using a One-Way ANOVA
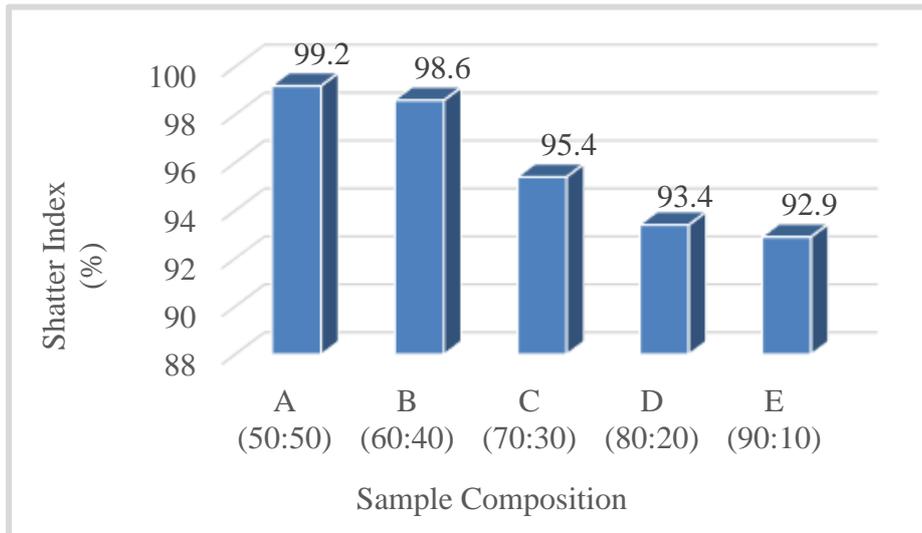
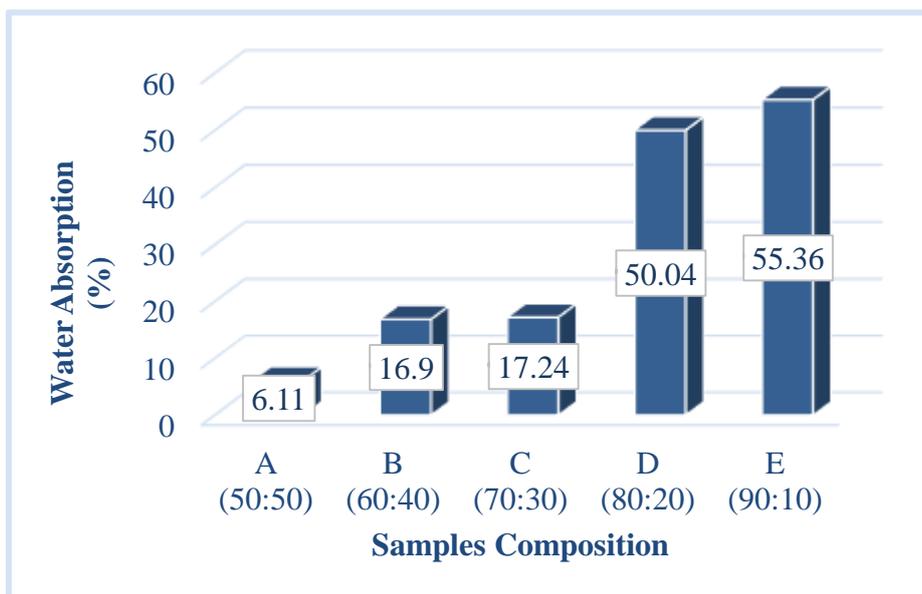**Fig. 3: Variation of Shatter Index with Sample Composition**

Fig. 4: Variation of Percentage Water Absorption with Sample Composition
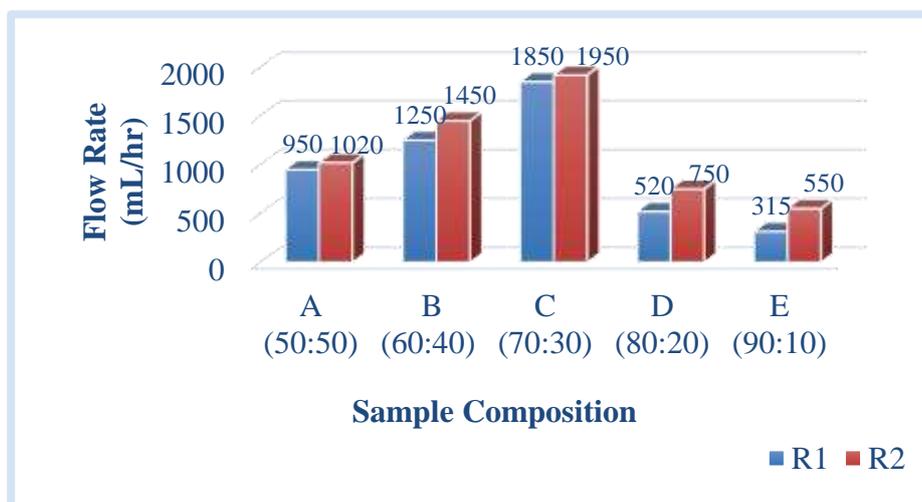

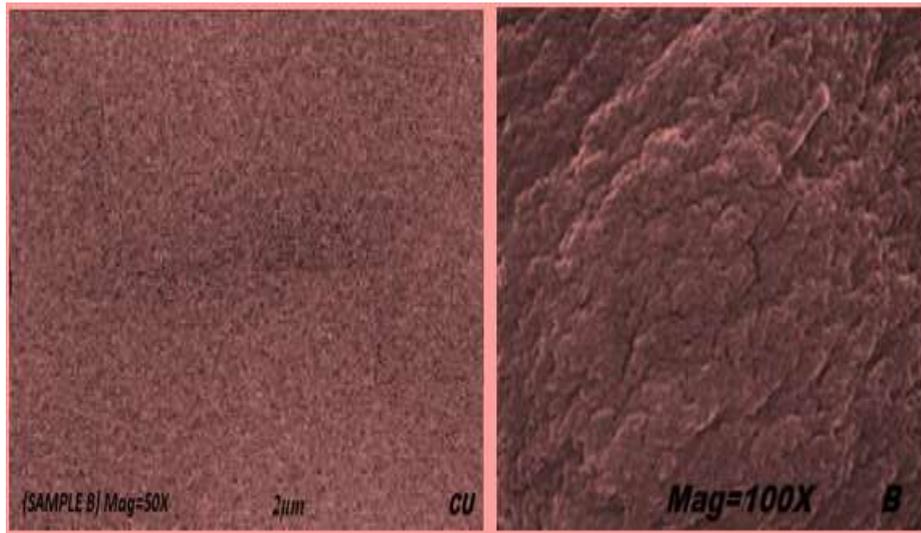**Fig. 5: Variation of Flow Rate with Sample Composition**

Fig. 6: Surface Image of Sample B (60:40) under a Scanning Electron Microscope (SEM), showing Pores
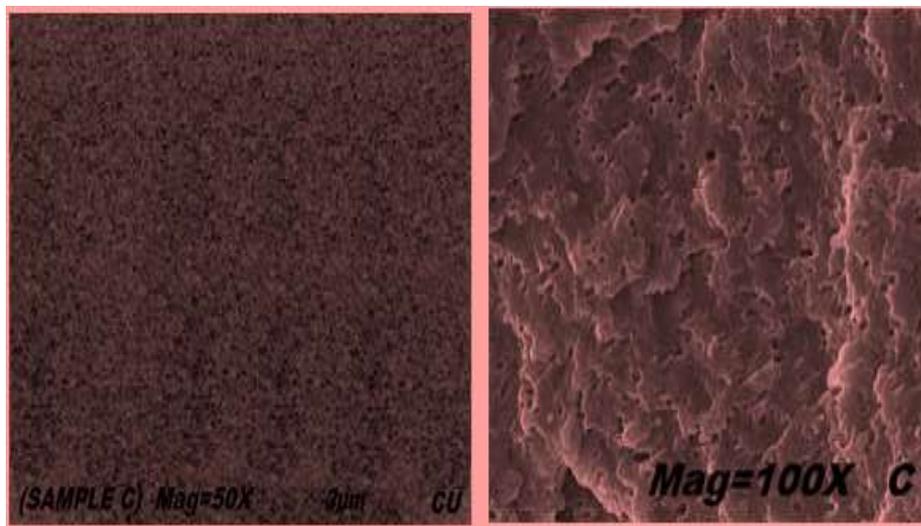

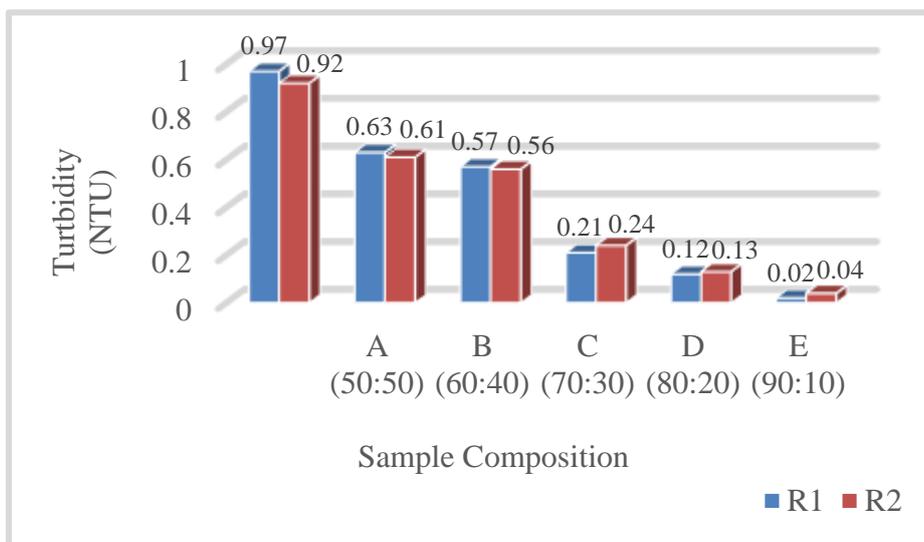**Fig. 7: Surface Image of Sample C (70:30) under a Scanning Electron Microscope (SEM) showing Pores.**

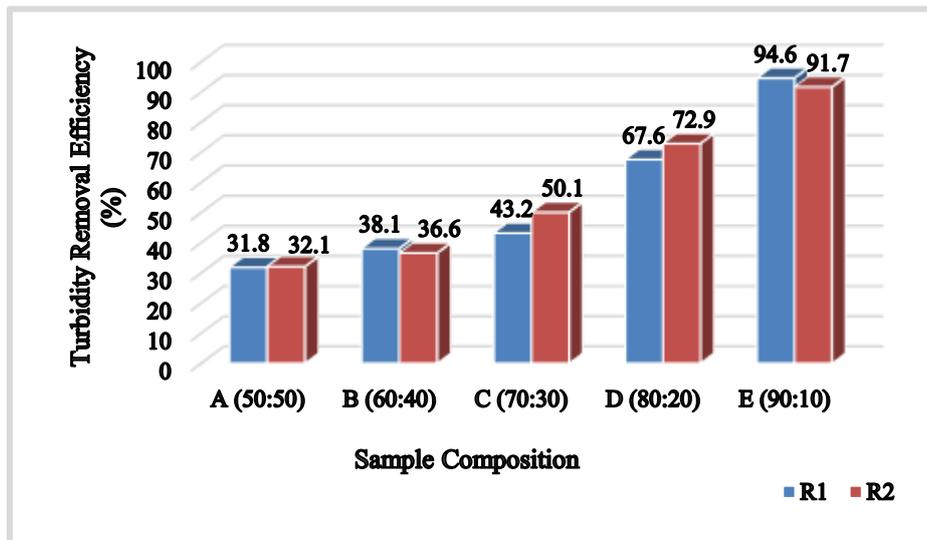**Fig. 8: Variation of Turbidity with Sample Composition**

Fig. 9: Variation of Turbidity Removal Efficiency with Sample Composition
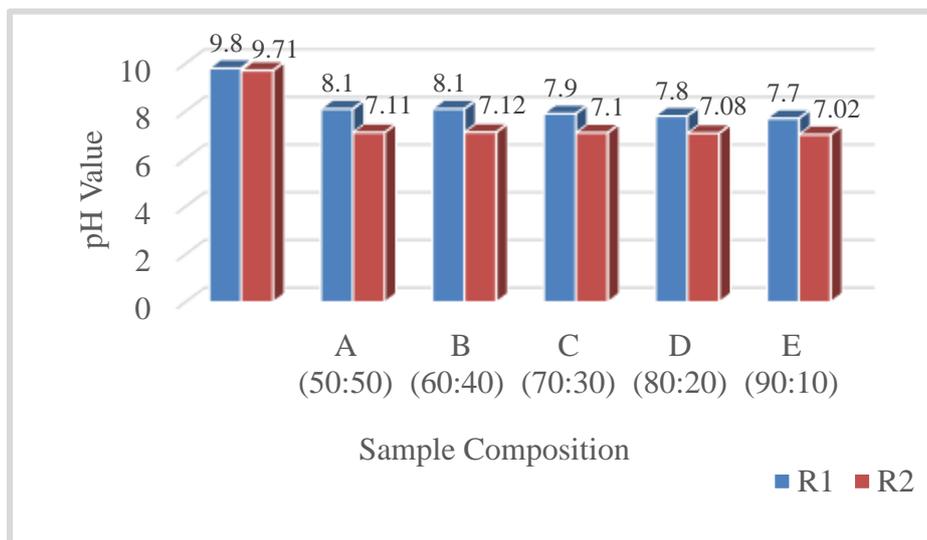

Fig. 10: Variation of pH with Sample Composition
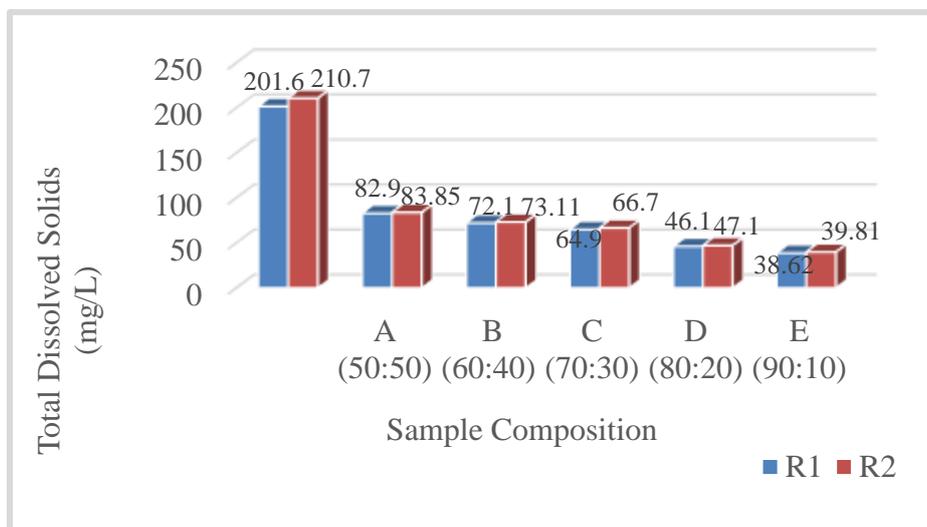

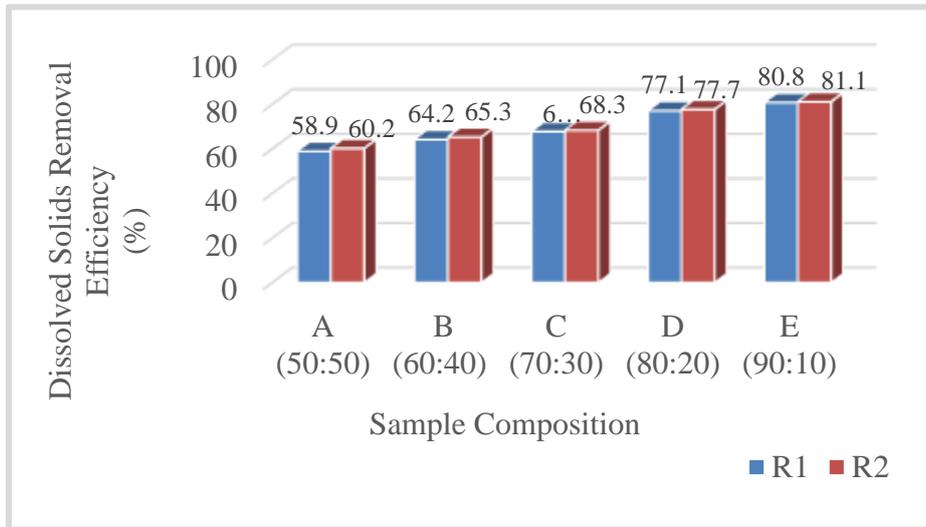**Fig. 11: Variation of TDS with Sample Composition**

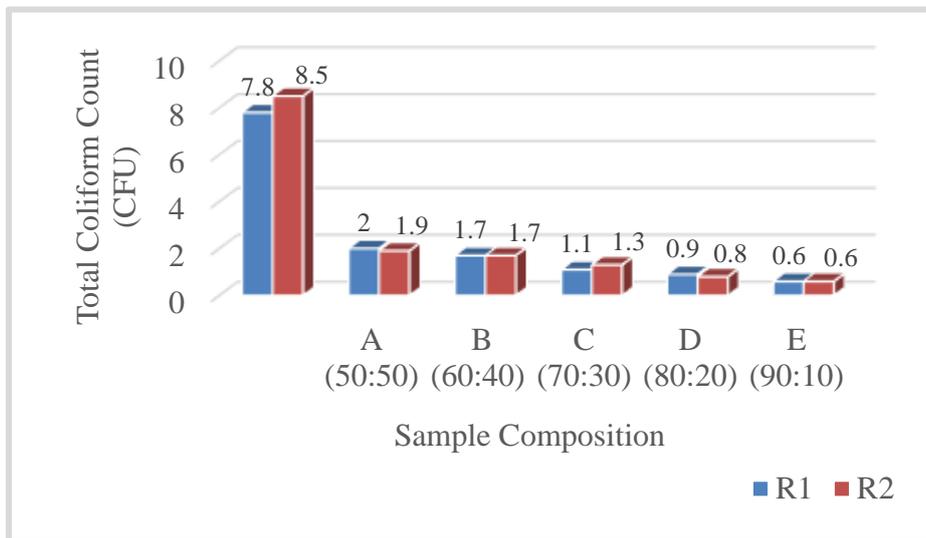**Fig. 12: Variation of TDS Removal Efficiency with Sample Composition**

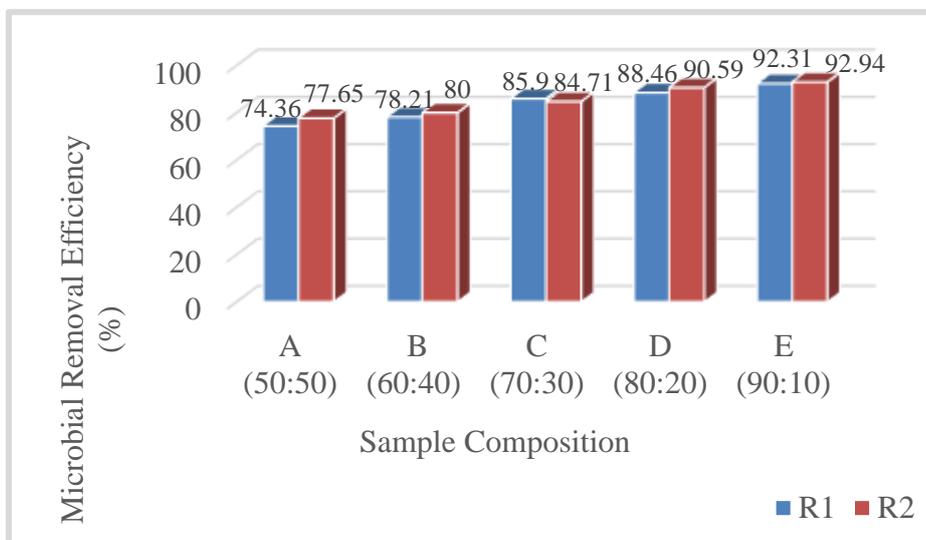**Fig. 13: Variation of Total Coliform Count with Sample Composition**

Fig. 14: Variation of Microbial Removal Efficiency with Sample Composition

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