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Performance of Home-Made Activated Carbon Ceramic Filter on Quality of Surface and Underground Water from Msambweni, Kwale County, Kenya

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Abstract

About 17 million Kenyans lack access to clean water, causing fears of water-borne diseases. This is a consequence of contaminants introduced through human acts, including agricultural activities, industrialization, poor waste disposal, and poor drainage. In Msambweni, Kwale County, the scenario is not any different. The removal of contaminants in water to reach the World Health Organization and Kenya Bureau of Standards permissible qualities of clean water for human consumption is generally expensive. This is a challenge for residents of Msambweni, who 74.9 % live below the poverty line. This research aimed at fabricating an activated carbon-ceramic (ACC) filter using locally available finely crushed clay and sawdust and test its efficiency, i.e. removal of Escherichia coli and total coliform, the effect on temperature, turbidity, total dissolved solids, dissolved oxygen, salinity, pH, electrical conductivity, dissolved ions of Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^- and SO_4^{2-}. The test was carried on three selected water sources of deep underground, hand pump, and surface water before and after filtration using the ACC filter. The physicochemical parameters were measured using an aqua read meter while the aqua genx test kit was employed for the bacteriological analysis. Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^- and SO_4^{2-} were analyzed using atomic absorption spectroscopy (AAS) and calorimetry. Statistical analysis was performed by SPSS software version 21. The turbidity and DO were beyond the WHO recommended limits at (30.00±1.00 NTU) and DO (4.21±0.96 mg/L) from the specimen drawn from hand pumps before filtration. The Mean±SE ranged from 22.72±1.15-23.24±1.22°C (Temperature); 4.99±0.01-30.00±1.00 NTU (Turbidity), 51.12±31.85-68.62±66.93 mg/L (TDS), 4.21±0.96-7.48±0.33 mg/L (DO), 3.85±0.78-5.17±0.56 mg/L (salinity), 7.37±0.15-7.46±0.02 (pH) and 0.18±0.01-0.87±0.03 mg/L (EC). These levels decreased significantly after filtration of the water samples using the fabricated ACC Filter, subsequently falling within admissible limitation in line with the WHO excellence levels. Amounts of Faecal *E. Coli* (CFU/100 ml) and Faecal Coliforms (MPN/100 ml) before filtration ranged between 1.00±0.00 - 5.00±0.00 and 12.00±00 - 25.00±0.00 respectively, being higher than the WHO standards. However, the levels decreased significantly after filtration falling within permissible levels. The levels of dissolved ions (mg/L) were within WHO standards before filtration (BF). Notably, Mg^{2+} ranged from 1.04±0.01 in underground water and HCO_3^- ranged 225.67+0.58 in the surface water samples. These levels decreased to 0.35±0.01 for Mg^{2+} and 30.50+0.10 for HCO_3^- in underground and surface water samples, respectively, after filtration. The fabricated ACC Filter was found to remove Faecal E. Coli effectively and Faecal Coliforms in all water samples, improving turbidity but with minimal effect on dissolved ions in water hence recommended for use.

Keywords: Activated carbon, Ceramic filter, Surface water, Underground water, Water sampling
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1. Introduction

It is projected that by 2025, about 40 % of the world's population will face scarcity of safe drinking water (Hoekstra *et al.*, 2012). This translates to a 10 % increase in people who lack access to safe and readily available water (Hagemann *et al.*, 2013). The dangers associated with unsafe drinking water are waterborne diseases that kill almost 5 million children and cause sickness to nearly 17 % of the world's population each year (Roche *et al.*, 2017).

In 2017, the World Health Organization (WHO) and United Nations Children's Fund (UNICEF) approximated that about 50 % of illnesses in Kenya are water, sanitation, and hygiene-related. According to WHO, 94 % of these ailments can be evaded by accessing safe drinking water (Hoekstra *et al.*, 2012). These dangers are a result of bacteriological (Total coliform and *Escherichia coli[E.Coli]*), physicochemical parameters (temperature, turbidity, total dissolved solids, dissolved oxygen, salinity, pH, and electrical conductivity) and dissolved ions(Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^- and SO_4^{2-}) levels of water being beyond those recommended by the WHO (Uhuo et la., 2014).

In Kenya, 43 % of the population lack pure drinking water (Mwihaki, 2018). Due to the high population in some counties, there is a lack of reliable and purified water (Guo *et al.*, 2017). Msambweni sub-County, in Kwale county Kenya for example, has approximately 74.9 % of its population faced with water scarcity (Mutuku *et al., 2013)*. A good proportion (71 %) of the residents rely on natural water sources such as ponds, shallow wells, and rivers whose quality deteriorates during wet seasons. According to Mutuku *et al.* (2013), the remaining smaller proportion of residents obtain quality, reliable, adequate water and sanitation services from the Kwale Water and Sewerage Company (KWAWASCO), one of the Water Service Providers (WSPs). According to Ferrer Ramos (2019), it is feared that due to the rapid expansion and population growth in Kwale, the need for quality, reliable and adequate water will increase.

According to the Environmental Protection Agency (EPA), only 10 % of surface water has no contaminants, though studies on the determination of water quality have shown varying results (Olago, 2018). In Kwale County, for example, both the quality and quantity of water in shallow wells in the area were generally acceptable for domestic use. (Chalala *et al*., 2017b). On the contrary, a study on groundwater pollution by Chepkemoi (2017) found that 13 % of boreholes were contaminated with *E. coli*, compared to 30 % of natural springs and 69 % of open wells. Chalala *et al.* (2017) reported that the pH of surface water sources ranged from 6.5 to 8.5 with limits exceeding those of standards for conductivity, chlorides, turbidity, and Total Dissolved Solids (TDS). Magnesium, iron, sodium, and potassium nutrients were below the permissible levels for irrigation water.

Most surface water sources are contaminated with total coliforms, including *E. coli* hence not suitable for domestic use (Coleman *et al*., 2013). Water quality in boreholes (32%) and wells in the county have been shown to either permanently or temporarily fail to reliably discharge good quality drinking water to the locals (Kilwake, 2016). The contaminants are introduced through high usage of fertilizer in sugar cane farming and poor waste disposal methods (Anastopoulos *et al*., 2017)

Water can be purified through physical, chemical, and biological processes (Bolisetty, Peydayesh & Mezzenga, 2019), such as membrane filtration, adsorption, and boiling. Physical methods include sedimentation, screening, filtration, degasification, and equalization. Chemical processes include chlorination, ozonation, neutralization, coagulation, adsorption, and ion exchange. Biological methods include activated sludge treatment, trickling filtration, oxidation ponds, lagoons, aerobic digestion, and anaerobic digestion (Lariyah *et al.*, 2016).

Purifying water using filtration, solar disinfection, and chlorination in removing biological contamination is expensive, hence finding limited application, especially in the rural setups (Zaman *et al*., 2017). Membrane filtration is costly and needs electricity to run, and its initial capital is huge hence generally unaffordable for the poor(REF). Boiling as an alternative method is more expensive due to the amount of fuel used which commonly is charcoal (Ponce-Robles *et al*., 2017).

Activated carbon filters have been used to address the challenges in water purification (Dong *et al*., 2019). The filters are small pieces of carbon, typically in granular or powdered block form, treated to be highly porous. The use of activated carbon ceramic filters effectively improves the physicochemical properties of water, removes and inactivates bacteria and bacterial indicators of disease-causing organisms (Lantagne & Yates, 2018). These filters can be designed in the shape of a flowerpot or bucket for easy use at home.

This study aimed at providing an effective and cheaper way of purifying natural waters. It will design an alternative way of purification, which will reduce the burden of water-borne diseases caused by *E. coli* and other coliforms. The method will be affordable for all classes of peoples

2. Methods

2.1 Research design

An activated carbon ceramic filter was fabricated using clay and sawdust. These materials are readily available in Msambweni. The clay is found as a large residue from the Base Titanium mine. According to the company's annual reports, on average, out of the 49,000 tonnes of ore they mine per day, mineral product tonnage is only 2,000 tons per day.

On a large scale, this project would reduce volumes of left-over clay. Sawdust or coconut husks are easily found in carpenters` workshops and coconut factories in the area. Tests of physicochemical parameters, bacterial contamination, and levels of dissolved ions were carried out in the water sample collected from three water sources during the wet and dry season. The levels of physicochemical parameters were tested *in situ* using aquaread multi-parameter equipment; microbial concentrations were done using aqua genx test kits while levels of major cations and anions were determined using Atomic Absorption Spectroscopy (AAS). These tests were done before and after water filtration using activated carbon ceramic filters to assess their effectiveness in water purification. Statistical analysis was performed by SPSS software version 21.

2.2 The Study Area

The Study area was the Msambweni sub-county, Kwale County, Kenya. Kwale has a total area of 8,270.3 km^2 and has a total population of 866,820 people (2019 census). It is approximately 4°10′S and 39°27′E (www.latlong.net accessed on 23/08/2020). It experiences high humidity and temperature averaging 31°C making it one of the warmest regions in Kenya (Weather History of Kwale County, world data, March 2020). The long rainy season is from the end of March to the end of May, the cool and dry season from June to October, and the short rainy season from October to November. The main economic activities are fishing, subsistence farming, mining, and sugar cane farming. The primary water sources in the sub-county are surface water from rivers and dams, both deep and shallow underground water (Sila, 2019).

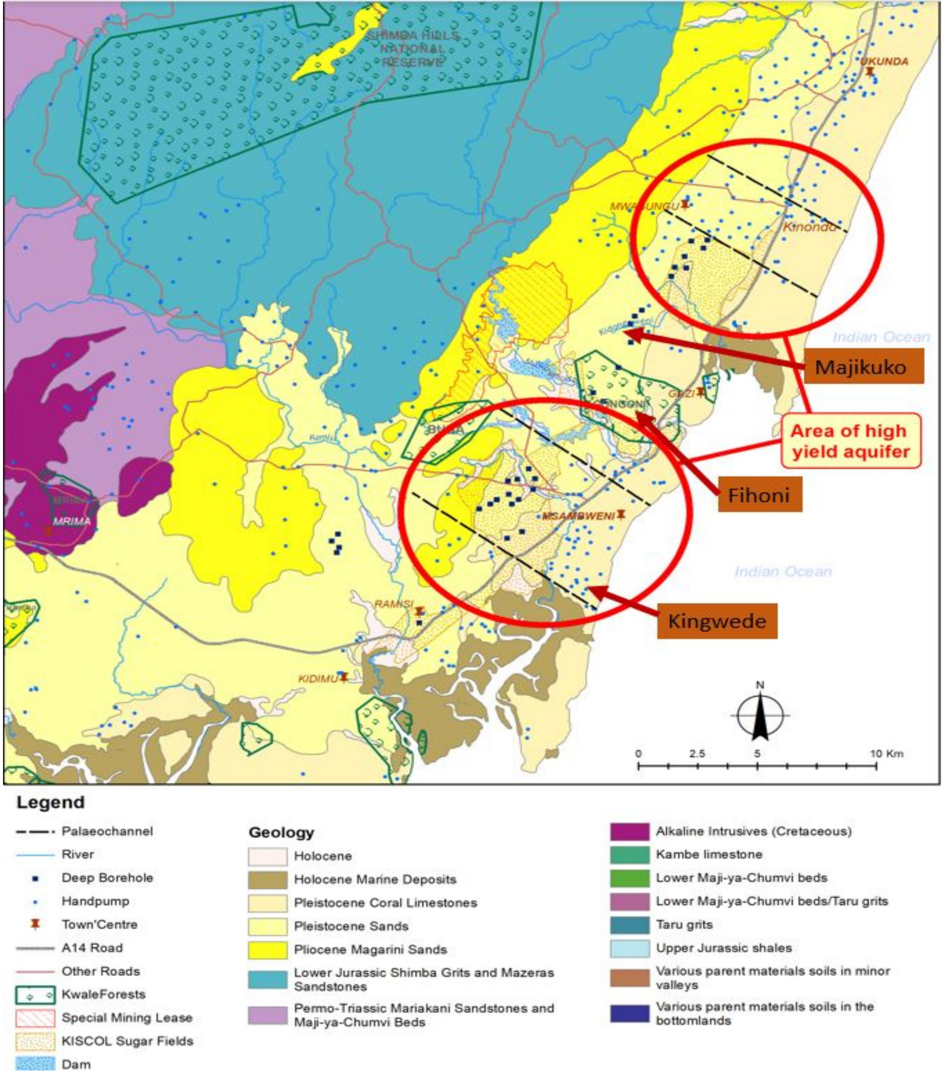

Figure 2.1: Sampling sites and water sources distribution around Msambweni.
Source: University of Nairobi

2.3 Fabrication of an Activated Carbon Ceramic Filters

Fabrication of the filter required raw material of clay and sawdust, which were collected around Base Titanium's mine site of Kwale mineral sands company and carpentry workshop, respectively. The fabrication required a grinder, mechanical presser machine, and a methane Kiln, as detailed in appendix VI.

According to potters for peace, for better results, the clay is supposed to be ground and sieved using a 0.002 mm diameter sieve to make sure that it's fine and free of large debris. The fine clay should then be mixed with fine ground sawdust to form a homogenous mixture in the ratio of 6:4. This is to make sure more carbon is embedded in the ceramic filter (Nichols, 2016).

This results in a large amount of carbon which will increase the contact time of water with carbon because of the slow flow rate hence increasing the adsorption of contaminants. The smaller the pore size, the more effective the filter. The mixture of clay and sawdust was kneaded using warm water dissolved with 2 mL of 3.2 % colloidal silver in 250 mL of filtered water (Nnaji, Afangideh & Ezeh, 2016). This was done by adding small quantities of water until it formed a soft dough.

The kneaded dough was transferred to the presser, where it was moulded to the ceramic filter with the shape of a bucket (See appendix VI). The ceramic filter was allowed to dry with natural heat (about 29°C) for three weeks. It was then taken to the methane kiln, where it was heated to temperatures of 960 °C. The kiln used butane gas as a source of fuel, and a silver cone was used to detect the highest temperatures reached when it melted and started coiling since the cone usually has a melting point of 960°C (Zereffa & Bekalo, 2017).

2.4 Water Sampling

Sample collection of the three sites was done according to Onyuka *et al.,* 2011. using sample containers: 2 x 500ml polypropylene container for *in-situ* analysis, 2 x 1000 ml amber glass bottle for dissolved ions, and 2 x 500 ml sterile plastic bottle for bacteriological analysis. These bottles had been disinfected using soap and water, cleaned using 10 % nitric acid, rinsed three times with the sampled water before collection (). The procedure started with washing hands with soap, letting the water run out of the tap, collecting the sample by filling the bottle while avoiding skin contact, replacing the cap, labelling, and packaging in the transportation container.

Although the three sampling sites were different in terms of sources, the sample collection method used was grab sampling. A single sample of 500 ml was obtained from a sample site at a specific time during the wet and dry season. Two water sets were collected at each sample site, whereby one set was filtered through the activated carbon ceramic filter. Then each of the two sets was divided into three groups *insitu* (physicochemical parameters), microbial contamination, and dissolved ions analysis. This resulted in six water samples per site, totaling 18 samples collected per session.

Table 2.1 GPS Coordinates of the Sample Sites

Site	GPS coordinates		Well depth (m)	Description
	Easting	Northing		
Kingwede (G1)	550930	9503532	105	Underground (Borehole) water
Majikuko (G2)	553710	9514590		surface water
Fihoni (G3)	553726	9513314	4.84	Open well (Handpump)

Samples for *Insitu* parameters were analyzed on-site, the bacteriological analysis was analyzed 6 hours from the time of sampling in the Base titanium's laboratory. The samples for analyses of major cations and anions were airlifted to the crop nutritional laboratory in Nairobi, Kenya, to reach not later than six hours after collection.

During transportation, they were stored in suitable cooler boxes with ice with minimal light intrusion to maintain the temperature between 1°C and 5°C. Each sample bottle was labelled in the field using an appropriate waterproof label, with the sample site reference number, date, time, and sample designation. All the samples were maintained in the freezer and kept refrigerated until needed for microbiological and chemical analyses.

All the parameters were examined as outlined in stipulated procedures according to the American Water Works Association. The duplicate analysis was carried out for selected sites to check for errors involved in sampling and analysis. A procedural blank was analyzed to check for the presence of contamination or other interference with the instrument.

2.4.1 Underground water (Borehole) sampling

Groundwater in the well casing is not considered representative of the general groundwater at a given location. To ensure that the groundwater samples from the monitoring boreholes, which represented the water held in the subsurface strata and not water held stagnant in the borehole casing, it was necessary to evacuate the monitoring bores before sampling. A standard procedure is to pump a well until 3 bore volumes have been removed (Awual wt al., 2013). The purged volumes were calculated on-site from the measured static 'water levels (measured using an electronic well dipper T) (See appendix **X**).

Standard Well Volume Calculation (Kuo, 2014).

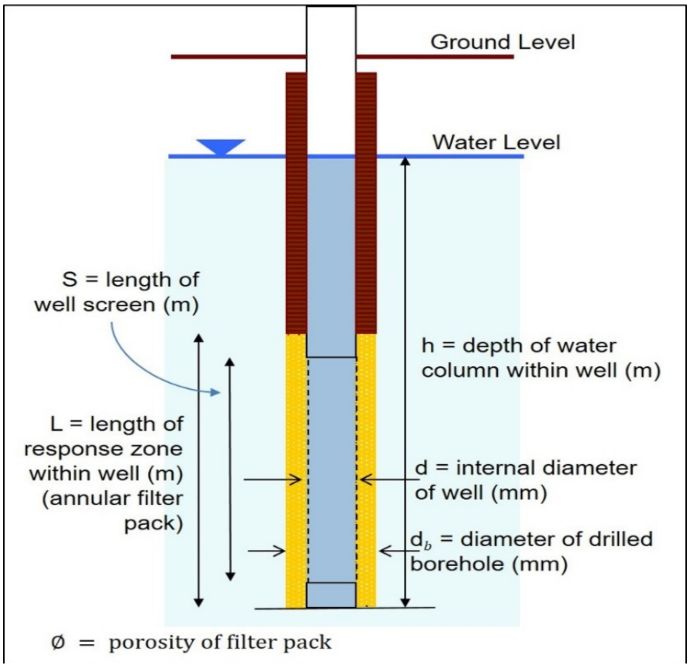

Figure 3.2: Underground water dimensions

2.4.2 Surface water sampling

Grab samples of surface water were collected directly into sample bottles. The sample bottle was immersed below the water surface. The water was allowed to slowly run into the bottle minimizing turbulence (Perlman, 2014). Care was taken not to disturb the sediment since analytes (such as metals) could be impacted by turbidity (Perlman, 2014).

2.4.3 Open well sampling

The water was pumped and left to run for 3 minutes, and samples were collected via the tap (See appendix **IX**).

2.3 Instrumentation

Various equipment was used in the study.

2.4 Calibration of Equipment

The calibrations for insitu water quality meters were done daily during sample testing for physicochemical analysis. The following equipment were calibrated for to measurement respectively.

2.4.1Hach Turbidity Meter

It was used to measure turbidity. The zero-point calibration was performed with the instrument light source turned off (Blank or dark calibration) to remove interference from residual light in the optics or environment. The sample cell was filled with about 15 mL of distilled water handling the sample cell by the top. It was then capped. The cell was wiped with a soft, lint-free cloth to remove water spots and fingerprints. A thin film of silicone oil was applied and wiped with a soft cloth to obtain an even film over the entire surface. The instrument was then turned on.

The sample cell was inserted in the instrument cell compartment so that the orientation mark aligned with the raised orientation mark in front of the cell compartment. Automatic range selection was made by pressing the RANGE key. The instrument displayed AUTO RNG when it was in automatic range selection. Selected signal averaging mode by pressing the SIGNAL AVERAGE key. The display showed SIG AVG. Pressed read, and the instrument displayed 0 NTU. Recorded the turbidity after the lamp symbol turned off. The above procedure was repeated with 20 NTU and 70 NTU (Penerbit, 2014).

2.4.2Aqua Read Meter

It measured electrical conductivity, turbidity, temperature, dissolved oxygen, total dissolved solids, salinity, and pH. Calibration was done by removing the cap from a new container of Rapid Cal solution and washing the lid from the pH copper cathode using distilled water. The probe was then dropped inside the Rapid Cal solution bottle and gently banged on the lower side of the container several to expel air bubbles trapped by the copper cathode.
After the insertion of the probe, the solution level was checked to ensure that reached it the bottleneck. Filling the solution to the bottleneck ensured that electrodes were covered. The meter was then switched on by pressing the MENU key to select the Calibration option, which gave the Rapid Cal option. After the readings were stable, the Calibrating screen displayed 100 %. OK was then pressed and subsequently ESC. It was calibrated at the start of

every field day to ensure consistent results between all readings. Rapid Cal solution simultaneously calibrates EC at 2570µS/cm, pH at 7.00, and turbidity at zero.

2.4.3 Dipper-T Meter

It was used to measure the water level. It is a manual meter that does not require calibration. At the start of each field day, it was checked that the batteries are charged.

2.4.4 Biological contamination measurement

Assessment of microbial contamination hazard was concerned with the presence of pathogens. For several reasons, however, pathogens are usually not studied directly. There are numerous pathogen types; they frequently occur in low concentrations, and they are often only detectable with time-consuming, costly molecular analyses that do not differentiate "dead, viable or infectious microorganisms" (Petrova *et al*., 2015).

Consequently, instead of detecting pathogens themselves, the study was focused on quantifying or detecting the presence of microorganisms or chemicals that indicate faecal contamination and, therefore, potential pathogen presence. This indicator approach has been common for around a century (Petrova *et al*., 2015), but the relationships between indicators and pathogens are not fully understood because it is difficult to compare the two directly, and such comparisons are rare (Ferguson *et al*., 2012).

2.5 Analysis of dissolved ions

The instrument was fitted with a specific lamp of the particular ion to analyze its concentration. The device was calibrated using prepared standardized solutions obtained from dilution of the standard stock solution of 1000 ppm to desired levels. Oxy-acetylene gas was used for flaming purposes for all ions.

2.6 Determination of Physical Parameters of Water

Temperature, turbidity, total dissolved solids, electrical conductivity, dissolved oxygen, salinity, and pH were measured on-site at each sampling station.

2.6.1 Temperature / Electrical Conductivity

On-site analysis of EC/temperature was done using a conductivity meter which was used to measure conductivity. The conducting cells were initially standardized using recommended standards with pre-determined readings. For every analysis level, the probe cells were washed thoroughly using sublimed water; then, control was conducted for the experiment. The conductivity cells were then immersed into the analyte, then calibrated reading for EC and temperature recorded simultaneously in degrees Celsius and micro Siemen units.

2.6.2 Turbidity

A turbid meter was used *in situ* (Nephelometric). The sample cell was filled with sample water to the line (about 15 mL) to handle the sample cell by the top. It was then capped. The cell was wiped with a soft, lint-free cloth to remove water spots and fingerprints. A thin film of silicone oil was applied and wiped with a soft cloth to obtain an even film over the entire surface. The instrument was then turned on. The sample was inserted in a sample cell in the instrument cell compartment so that the orientation mark aligned with the raised orientation mark in front of the cell compartment. Pressed read and the instrument displayed the turbidity readings.

2.6.3 Total Dissolved Solids

TDS for 12 samples of water was determined using the gravimetric method as indicated by (Teshome 2020). A 100 ml filtrate was poured in a dried, pre-weighed porcelain container, evaporated to dryness inside an oven maintained at 105ºC for 1 hour 30 minutes for standardized dryness. Finally, the resultant residue was transferred to desiccators to cool to standard dryness to attain constant weight. The constant weight attained was calculated as the TDS.

2.6.4 Dissolved Oxygen

DO was analyzed using a DO-meter probe in the aquaread meter. A pre-rinsed probe was immersed approximately 1.25 inches into the 12 samples, and stabilized readings were taken during analysis. The stabilized readings were read after waiting for the meter to stabilize on the digital screen (Teshome, 2020).

2.6.5 Salinity

Water salinity is measured by passing an electric current between the two electrodes of a salinity meter in sample water (Corwin & Yemoto, 2020). The electrical conductivity of the water sample is determined by the amount and composition of dissolved salts. Salts increase the ability of a solution to conduct an electrical current, so a high EC value indicates a high salinity level (Peralta & Costa, 2013).

2.6.6 Potential of Hydrogen (pH)

A potentiometric pH measure was carried out on-site using a calibrated pH meter. For every analysis level, the probes were extremely cleaned by the use of water immediately every reading was finished and dipped 1.25 inches inside the sample, and then standardized measures were recorded.

2.7 Bacteriological Analysis

The 12 samples were analyzed for their bacteriological quality. The bacteriological analysis involved presumptive, confirmatory, and completed tests. Presumptive test analysis was done to obtain total coliforms, while confirmatory test analysis was conducted using brilliant green broth to obtain faecal coliforms. Samples were collected in sterilized bottles. Care was taken not to touch the inside of the lid's bottle rim and not to allow the water to splash off hands or other bottle surfaces. The containers were filled, leaving a half-inch of air space between the top of the bottle and the collected water (Ho *et al*., 2019).

2.7.1 Presumptive Analysis for total coliform

The absence or presence of total coliforms was determined by multiple tube fermentation processes using Mac Conkeybroths. The double and single strength broth preparations were injected with loopful samples and stored in an incubator at 37°C for 24 hours, after which the findings were interpreted for the presence or absence of total coliforms based on lactose fermentation and gas production (Rojas *et al*., 2020).

The analysis from the results was read against standards. Positive indicators of Mac Conkey broth changing from purple to yellow due to lactose formation indicated the presence of total coliform. This was also shown by the production of gas inside the Durham tube or turbidity. Negative results indicated the absence of the gas and purple colour persistence (Haylamicheal and Moges, 2012).

2.7.2 Confirmatory Analysis

Faecal Coliform Bacteria Test Analysis

The analysis was done only for the samples that tested positive for total coliforms. The analysis was done using brilliant green broth preparations, as shown in figure 3.6. A loop is full of samples that indicated positive total coliforms were transferred onto respective brilliant green broth and enumerated after overnight incubation at 44.5°C. The results were read and interpreted based on gas production inside the Durham tubes. The test results were read against known positive standards such that faecal coliform indicated gas production inside the Durham tubes or turbidity of the broth.

Use of Aqua genx Test Kits

The most probable number (MPN) concentrations of E. coli were determined using compartmental bag test (CBT) kits in accordance with the procedures recommended by the manufacturer (Hawes *et al*., 2015). MPN testing involves multiple presence/absence tests on different volumes of the same sample. Statistical tables are used to estimate E. coli concentrations based on the combination of results. Fresh CBT II kits, purchased in the month prior to sampling, were used. The growth medium (which contains chromogenic substrate: 5-Bromo-4-chloro-3-indolyl-beta¬D- glucuronic acid) was stored in a refrigerator but never frozen.

Hand sanitiser was used prior to collecting each sample, and the inside and openings of the bags were not touched. The sample water was pumped/poured into a plastic jug and then immediately poured into the Thio bags. This was done because the jar allowed better pouring to collect exactly 100mL and keep the outside of the bag clean and dry. The jug was regularly sanitized with ethanol and triple rinsed with the sample water immediately before collecting each sample. Samples were stored out of direct sunlight immediately after collection. They were incubated at 40℃ for at least twenty-four and no more than thirty hours. The transport container and incubator were sanitized with ethanol between sample batches.

2.8 Determination of dissolved ions in Water

Atomic absorption spectrometry was used. A Perkin-Elmer Model analyst 200 Atomic Absorption Spectrophotometer equipped with a single element hollow cathode lamp and 10 cm air–acetylene burner was used to determine the metals ions. Standard solutions of known metal concentrations were prepared in water with a matrix similar to the sample. For samples containing high and variable concentrations of matrix materials, the major metal species in the sample and the dilute standard was made in the same way.

Standard additions methods were used if the sample matrix was complex and components could not be matched accurately with standards. All data were reported as ppm metal (i.e. milligrams metal per litre). Samples were filtered before use and the sample aspirated into the flame. Since the spectrometer uses a different lamp for each metal to be analyzed, a complete analysis of one metal was done (calibration curve and duplicate sample measurements) before commencing the analysis of another metal. Metals to be determined by AAS included manganese, iron, sodium, potassium, and calcium.

2.9 Data Analysis

The level of physicochemical parameters, bacterial content, major cations, and anions was analyzed before and after passing the water samples through the filter. These levels were then compared to those allowed by the WHO to gauge the efficiency of the sieve in the purification of water. Statistical analysis was performed by SPSS software version 21. Variations among the sampling locations were compared through one-way ANOVA. Tukey's post hoc test for several comparisons was conducted on statistically significant data. Variations amongst the sampling unfiltered and filtered water samples were analyzed using paired t-test. Correlation between selected physicochemical parameters ($p<0.05$) in the 18 water samples was conducted using Pearson's correlation (r). The findings were presented in tables and figures.

3. Results and discussion

The study was aimed at investigating the effectiveness of an activated carbon ceramic filter in water purification. This involved testing surface and underground water for physicochemical, microbial properties, and dissolved ions before and after filtration using the activated carbon ceramic filter. The water sources were from Fihoni (open well /Hand pump), Kingwede (borehole/underground), and Majikuko (Surface/ River) areas of Msambweni Sub-County, Kwale County.

3.1: Physical Properties of Water in Msambweni

The standard error of the mean, mean±SE, levels of the different physical properties of water samples obtained from Fihoni (open well /Hand pump), Kingwede (borehole/underground), and Majikuko (Surface/ River) sampling sites are presented in table 4.1. They included temperature, turbidity, Dissolved Oxygen (DO), electrical conductivity (EC), pH, total dissolved solids (TDS), and salinity.

Table 3.1: Mean±SE, standard deviation from the mean of the Levels of Physical water sample characteristics from Majikuko, Kingwede, and Fihoni Areas

Site ±SE	Mean XX	Temp (^{0}C)	Trb (NTU)	TDS (mg/L)	DO	Salinity	pH	EC
Majikuko	BF	22.92±0.87	5.25±0.01	51.12±31.85	5.94±0.48	5.17±0.56	7.37±0.15	0.87±0.03
	AF	20.90±0.86	1.17±0.01	50.13±30.84	4.75±0.38	4.18±0.54	5.87±0.01	0.33±0.06
p-value	<0.001							
Kingwede	BF	22.72±1.15	4.99±0.01	68.62±66.93	7.48±0.33	3.85±0.78	7.27±0.01	0.18±0.01
	AF	20.47±1.12	1.13±0.01	67.77±65.54	6.80±0.32	2.89±0.75	6.85±0.01	0.08±0.00
p-value	<0.001							
Fihoni	BF	23.24±1.22	30.00±1.00	62.81±14.53	4.21±0.96	4.42±0.67	7.46±0.02	0.28±0.01
	AF	22.23±1.10	0.88±0.01	62.73±13.53	3.83±0.89	4.12±0.57	6.25±0.01	0.02±0.00
WHO Standards		<25.0	< 5.0	Max. 500	>5.0	Max.250.0	6.5-8.5	<1.50
p-value	<0.001							

Water samples tested from the three sampling points exhibited a significant difference in the physical properties before and after filtration (p<0.001), as indicated by the T. test. AF-After Filtration; BF-Before Filtration; Temp.-Temperature, Trb-Turbidity, NTU-Nephelometric Turbidity Unit, TDS-Total Dissolved Solid, DO-Dissolved Oxygen, and EC-Electrical Conductivity.

The data in Table 4.1 indicates the observable properties values of the water samples before and after filtration were all within the acceptable range according to WHO regulations, of below 25°C for temperature, turbidity below 5.0 NTU, TDS below 1,500mg/L, DO above5.0, salinity below 250, PH between 6.5-8.5 and EC below 1.50. However, the turbidity and DO were beyond the recommended limits at (30.00±1.00 NTU) and DO (4.21±0.96 mg/L) from water samples collected from Fihoni.

The mean±SE ranged from 22.72±1.15-23.24±1.220C (Temperature); 4.99±0.01-30.00±1.00 NTU (Turbidity), 51.12±31.85-68.62±66.93 mg/L (TDS), 4.21±0.96-7.48±0.33 mg/L (DO2), 3.85±0.78-5.17±0.56 mg/L (salinity), 7.37±0.15-7.46±0.02 (pH) and 0.18±0.01-0.87±0.03 mg/L (EC). These levels decreased significantly after filtration of the water samples using the activated carbon, with the water samples from Fihoni registering the lowest levels in EC of 0.02±0.00 µS/cm. as seen in figures 3.1 to 3.7 below

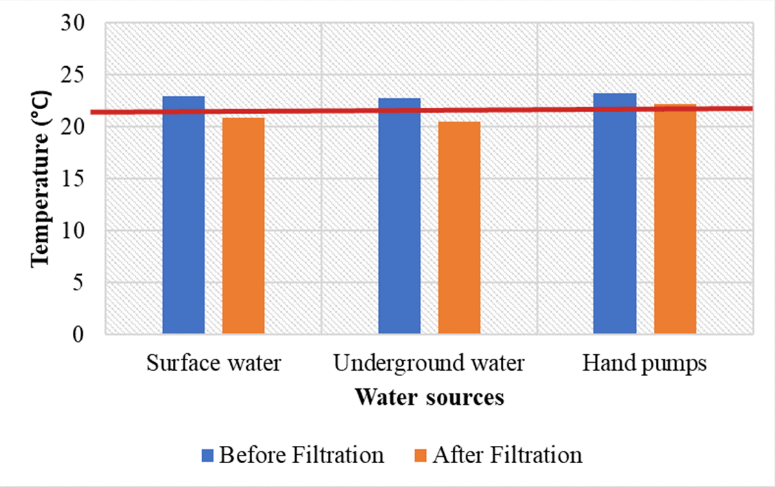

Figure 3. 1: Average Temperature levels for water samples before and after filtration

All the temperature values from all samples were below the WHO guideline of 25°C for both filtered and unfiltered samples. The temperatures of filtered water were lowest at each sampling point. The temperature for each sample dropped after filtration through the activated carbon ceramic filter. Water placed in earthen pots is evaporated from minuscule pores it has as it is made of mud particles. This evaporation of water produces a cooling effect. Some of the heat energy that is generated is used in the process of evaporation. Hence, water stored in earthen pots tends to become cooler (Kaurwar *et al*., 2017).

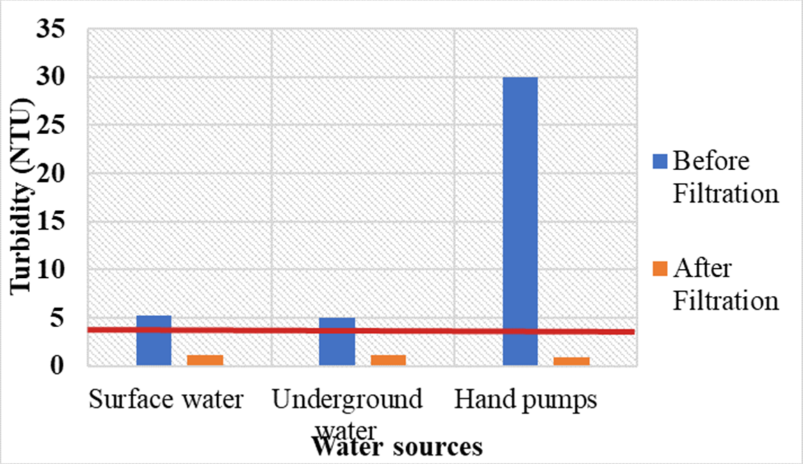

Figure 3. 2: Average Turbidity levels for water samples before and after filtration

The study revealed that there were high turbidity levels above the 5 NTU recommended by WHO for water samples from the hand pump and surface water. This can be attributed to clay, silt, finely dissolved organic and inorganic materials. The turbidity levels dropped when the samples were filtered to within recommended values.

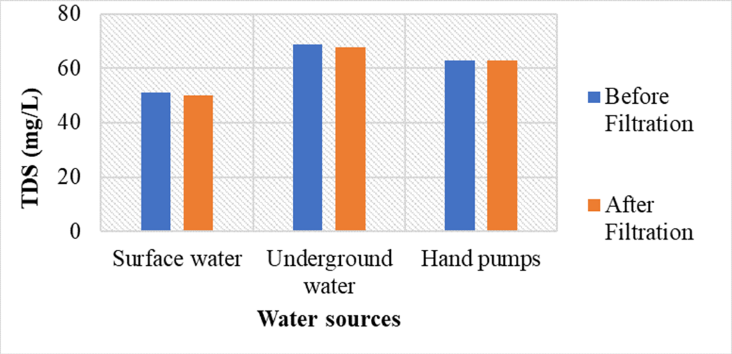

Figure 3. 3: Average TDS for water samples before and after filtration

The WHO standard for total dissolved solids (TDS) is < 500 mg/L. All samples before and after filtration were within limits. The results show that the activated carbon ceramic filter has no significant effect on the TDS.

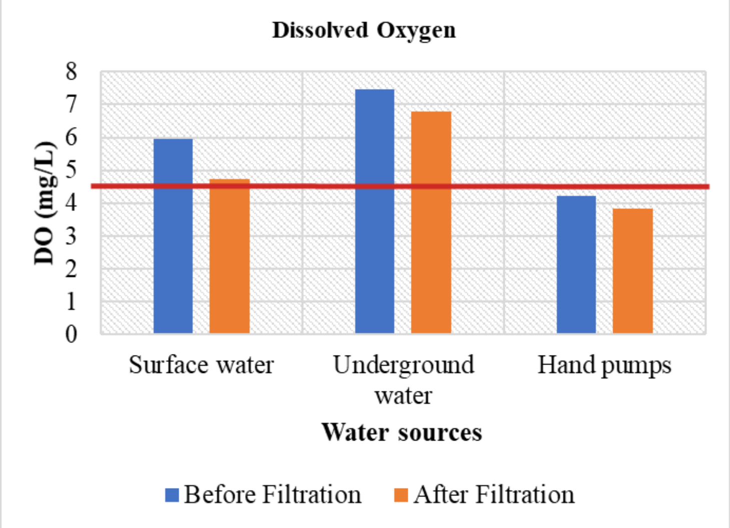

Figure 3. 4: Average DO for water samples before and after filtration

The WHO recommended values of dissolved oxygen (DO) are to be >5.0mg/L. Unfiltered water from hand pumps had lesser DO. This is a natural phenomenon in underground water. The levels also dropped slightly after filtration

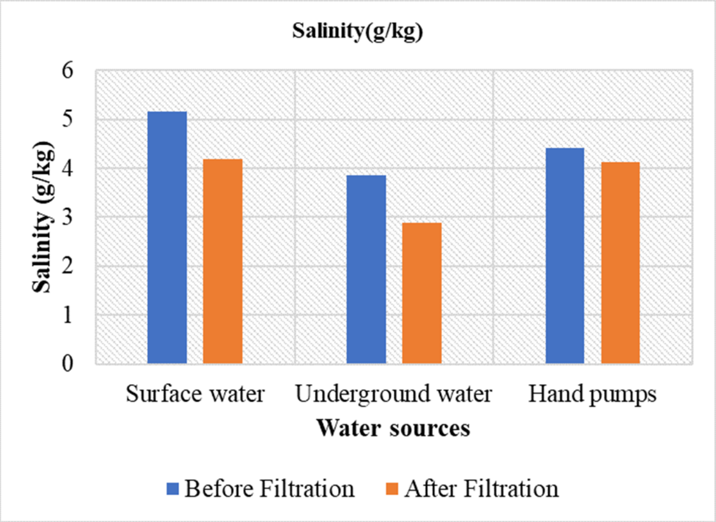

Figure 3. 5: Average salinity levels for water samples before and after filtration

The WHO recommended salinity levels in drinking water is supposed to be < 250. g/kg. All the samples were within recommended levels, with filtered samples even being much lesser.

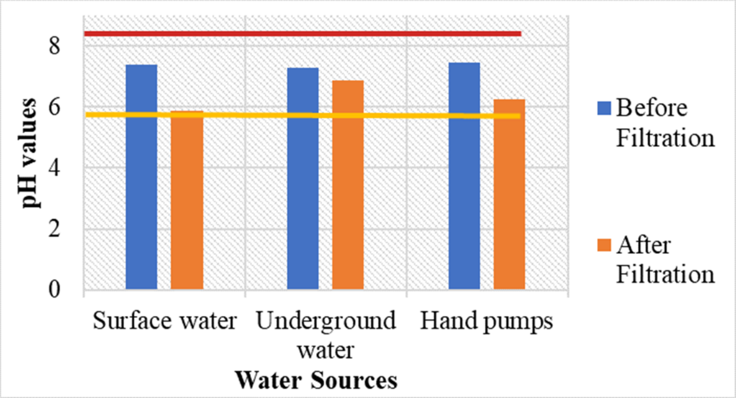

Figure 3. 6: Average PH values for water samples before and after filtration

The water samples from the three sites before filtration were all within the WHO guidelines. The filtered samples slightly dropped outside the PH range of 6.5-8.5 showing slight acidity.

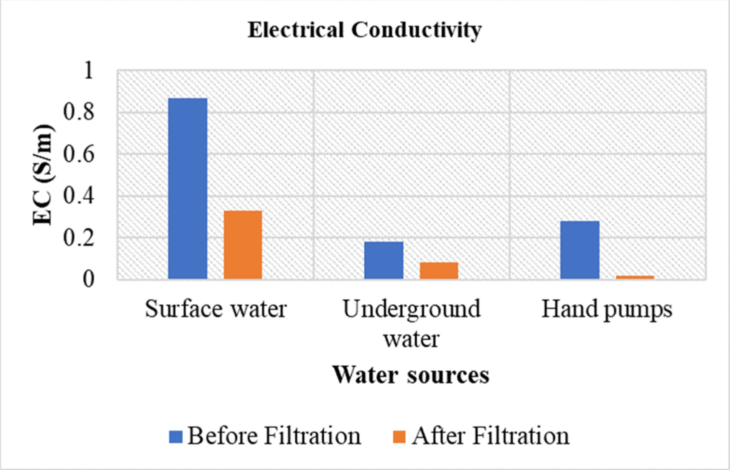

Figure 3. 7: Average EC for water samples before and after filtration

The samples had electrical conductivity (EC) less than 1.50 as recommended by WHO. The EC even dropped further after filtration.

The differences in the samples collected at Fihoni can be attributed to the removal of the ions by the activated carbon ceramic filter hence their low concentration in the water samples. Differences between the sites showed that Fihoni and Kingwede had the highest levels of turbidity and TDS of (30.00±1.00 NTU) and TDS (68.62±66.93 mg/L), respectively. The high turbidity in water samples obtained from the Fihoni area could be due to the availability of suspended materials such as planktons, bacteria, and dissolved organic.

The presence of high inorganic substances can also be the reason as to why there was a variation. The results are supported by Rojas *et al*. (2020), who noted similar findings. The t-test showed that the average figures of the physical parameters significantly differed before and after the filtration of the water samples ($p < 0.001$). The results can be attributed to the increased efficiency of the ceramic filters due to the small pores in the added clay. The study results corroborate Petrova *et al*. (2015) on the efficacy of ceramic filters.

Comparison between the three sites (Majikuko, Kingwede, and Fihoni) showed that water samples from Kingwede had a significantly higher level of TDS before (68.62±66.93) and after filtration (67.77±65.54). The findings can be associated with massive pollution within the area because of titanium mining activities. The results concur with (Beaulieu, Pick & Gregory-Eaves, 2013), who notes that one of the significant predictors of water standards is the number of human practices in a given area.

The high levels of TDS can be associated with elevated water temperature and low pH. Excessive temperature is caused by several aspects ranging from the transfer of heat from the atmosphere, active solar radiation, turbidity, and river confluence (Dugdale, Hannah & Malcolm, 2017). Elevated temperature limits tolerance levels of biological organisms and accelerates the solubility of toxic substances. Therefore, it implies that high water temperatures recorded in this study can be correlated with heavy metal loads such as lead (Bhardwaj, Gupta & Garg, 2017).

In this study, water pH was within the acceptable limits (between 6.5 and 8.5) before and after filtration. The pH decreased from 7.46±0.02 to 6.85±0.01 before and after samples of water from Fihoni was filtered. The alkaline pH can be due to the discharge or seepage of industrial pollutants containing silicates and phosphates into the underground water sources, as suggested by (O'Connor *et al*., 2018). High water pH above the maximum permissible levels is unfit because it potentially affects people and animals indirectly. High water pH causes inflammation and irritation of human mucous membranes, exposing them to more opportunistic illnesses (Agustin, 2016).

Table 3. 2: T-test of physicochemical Properties of Samples of the Water

Test Variable	Filtration	N	Mean	Std. Deviation	Std. Error Mean	T	Sig. (2-tailed)
Temp	Unfiltered	6	23.43	0.224	0.075	-1.602	0.129
	Filtered	6	21.84	1.887	0.962	-1.602	0.148
PH	Unfiltered	6	6.33	0.144	0.048	-9.404	0
	Filtered	6	7.12	0.21	0.07	-9.404	0
DO	Unfiltered	6	9.06	0.36	0.12	4.519	0
	Filtered	6	6.1	1.933	0.644	4.519	0.002
EC	Unfiltered	6	250.89	251.19	83.73	-1.38	0.186
	Filtered	6	463.56	388.013	129.338	-1.38	0.19
TDS	Unfiltered	6	168.22	167.489	55.83	-1.315	0.207
	Filtered	6	301	252.364	84.121	-1.315	0.21
Salinity	Unfiltered	6	0.09	0.101	0.034	-1.342	0.198
	Filtered	6	0.19	0.196	0.065	-1.342	0.204
Turbidity	Unfiltered	6	1.09	0.912	0.304	-3.919	0.001
	Filtered	6	14.82	10.471	3.49	-3.919	0.004

The results from Table 4.3, where n is the number of tests done, indicated that there was an insignificant mean variation between the filtered and unfiltered underground and surface water temperature, i.e. 0.148>0.05. The mean difference showed between the pH of the filtered and unfiltered underground and surface water was found to be statistically significant (0.000<0.05). This was supported by a T- statistic, which was more significant than the critical value (-1.602>-1.96).

The mean difference indicated between the dissolved oxygen of the filtered and unfiltered underground and surface water was likewise found to be statistically significant (0.000<0.05). The contrast of the water qualities can be attributed to the fact that ceramic filters remove ions and cations responsible for water pH. The findings are similar to Roohul *et al.* (2012).

However, the mean difference between the electrical conductivity of the filtered and unfiltered underground and surface water was found not to be significant. This was indicated by a p-value exceeding 0.05. The results also showed an insignificant mean difference between the filtered and unfiltered underground and surface water salinity. The results are attributed to the possibility that the water in the area has few dissolved salts, which are responsible for electrical conductivity and salinity. Ponce (2014) made similar observations. This was indicated by a p-value of 0.204.

The results, however, reported a significant mean difference in the turbidity of the filtered and unfiltered underground and surface water (0.004<0.05). The mean difference in the findings could be a result of anthropogenic activities that affect the water turbidity. Dai *et al*. (2018) made similar observations due to social activities such as mining and agriculture.

3.2 Microbial Quality of Water in Msambweni

The Mean±SE levels of the total coliforms (CFU/100 ml) and faecal coliforms (MPN) in water sampled from Fihoni (open well /Hand pump), Kingwede (borehole/underground), and Majikuko (Surface/ River) areas of Msambweni Sub-County, Kwale County were presented in table 4.4. The initial concentrations of E. coli and total coli from the three water sites used for the microbial removal test were found to be 100 % effective. The result of this study agrees with the finding of Petrova *et al.* (2015), who reported that ceramic filters could remove microorganisms efficiently.

During ceramic filters firing, the burnouts leave smaller pores of about 1-micron size, which filter out the most harmful microbes. Microorganisms with large sizes are blocked within the pore and refrained from flowing through the ceramic element (Bulta & Micheal, 2019). Also, Aliyu, Usman and Audu (2019) reported that ceramic water filters have good efficiency in removing microbial from bacterially contaminated water sources. When microorganisms pass through the pores of ceramic filters, there might be strong suffocation on their path due to the path's tortuosity. At the same time, they compete for feeding, which reduces the number of microbial after filtration (Alemayehu, 2018).

Table 3. 3 Mean±SE Total Coliforms (CFU/100ml) and Faecal Coliforms (MPN)

Sampling site		Faecal *E. Coli* (CFU/100 ml)	Total coliform (CFU/100 ml)
Majikuko	BF	5.00±0.00	25.00±0.00
	AF	ND	ND
	p-value	<0.001	<0.001
Fihoni	BF	3.00±0.00	18.00±0.00
	AF	ND	ND
	p-value	<0.001	<0.001
Kingwede	BF	1.00±0.00	12.00±0.00
	AF	ND	ND
	p-value	<0.001	<0.001
WHO standards		NIL	NIL

A T-test indicated that there was a significant difference in the biological properties of water before and after filtration (p<0.001). AF-After Filtration; BF-Before Filtration; CFU-Colony Forming Unit; MPN-Most Probable Number; ND-Not Detected.

Table 3.4 shows how the total coliforms and faecal *E. coli* were distributed in the water obtained from the three sampling locations, namely Fihoni (open well /Hand pump), Kingwede (borehole/underground), and Majikuko (Surface/ River). Water samples from the three locations tested positive for total coliforms and Faecal *E. coli*. The results are similar to those conducted by Swanson *et al.* (2018). The levels of Faecal *E. coli* and total coliform before filtration ranged between 1.00±0.00 to 5.00±0.00 and 12.00±00 to 25.00±0.00, respectively, which were well above the WHO standards (WHO, 2017). These levels, however, decreased significantly to WHO permissible levels after filtration.

The total coliform and faecal *E. coli* levels were significantly higher in Majikuko (surface water), followed by the Fihoni (hand pump) then Kingwede (underground) water, which might be a result of large volumes of surface run-off. The surface water site was used as cattle drinking and bathing points for humans at different sites along the stream. The shallow underground water (hand pumps) was also microbially contaminated because of the proximity to latrines. The animal and human wastes contribute to increased levels of both total coliform and Faecal *E. coli* (Purohit *et al*., 2017). This can also be attributed to human activities such as washing clothes and defecation areas for humans (WHO, 2017). The low levels in underground water were due to minimal contamination because the surface water gets filtered out as it recharges the aquifer below the ground.

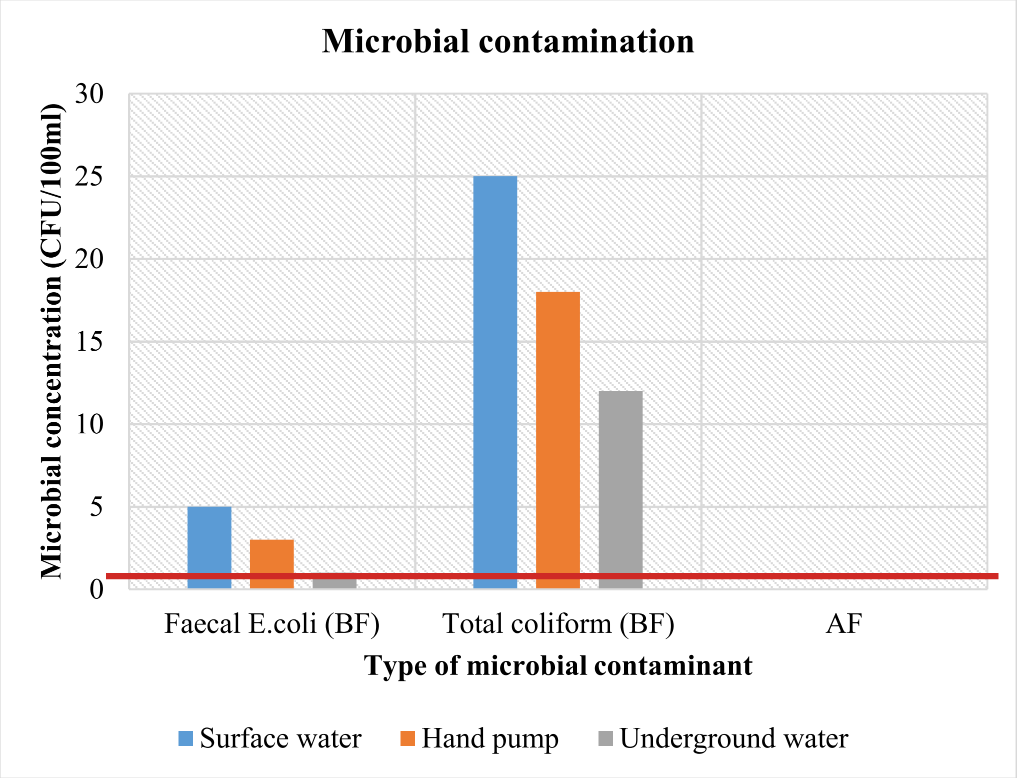

Figure 3. 8: Average microbial contamination in the water sources

3.3.1 Descriptive Results for Total Coliforms and Faecal *E. coli*

The mean of faecal *E. Coli* CFU/100 ml) detected in the underground and surface water was higher in the unfiltered water as compared to the mean faecal *E. coli* (CFU/100 ml) detected in filtered underground and surface water that is (2.83 v 0) as shown in the table below.

Table 4.4: Descriptive results for Total Coliforms (CFU/100ml) and faecal Coliforms (CFU/100ml)

Test Variable		N	Mean	Std. Dev	Std. Error	95% C.I L.B	Min U.B	Max	For Min
Feacal *E. coli* (cfu/100 ml)	Unfiltered	6	2.83	1.472	0.601	1.29	4.38	1	5
	Filtered	6	0	0	0	0	0	0	0
	Total	12	1.42	1.782	0.514	0.28	2.55	0	5
Total Coliforms (cfu/100 ml)	Unfiltered	6	14.67	5.888	2.404	8.49	20.9	9	25
	Filtered	6	0	0	0	0	0	0	0
	Total	12	7.33	8.627	2.49	1.85	12.8	0	25

The mean of total coliforms (CFU/100 ml) detected in the underground and surface water was higher in the unfiltered water as compared to the mean faecal *E. coli* (CFU/100 ml) detected in filtered underground and surface water that is (14.67 v 0). The variation of the total coliform count is due to the effectiveness of the ceramic filter in the removal of bacteria from the water. The findings are supported by Bulta & Micheal, 2019).

3.3.2 Test for Equality of Means for Total Coliforms and faecal *E. coli*

The results showed in Table 4.5 underscored various mean differences and their significance. The mean difference between Faecal *E. coli* (CFU/100 ml) found in unfiltered and filtered underground as well as surface water was statistically significant (0.001< 0.05).

Table 3 5:T-test for Total Coliforms (CFU/100ml) and faecal Coliforms (MPN)

Test Variable	Filtration	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
Feacal E. Coli (cfu/100 ml)	Unfiltered	6	2.83	1.472	0.601	4.715	0.001
	Filtered	6	0	0	0	4.715	0.005
Total Coliforms (cfu/100 ml)	Unfiltered	6	14.7	5.888	2.404	6.102	0
	Filtered	6	0	0	0	6.102	0.002

The mean difference between total coliforms (CFU/100 ml) in the filtered and unfiltered underground as well as surface water was also found to be statistically significant. According to Farrow *et al*. (2018), ceramic water filters can reduce a significant number of bacteria from the water. The findings are consistent with this since a high variation was noted between unfiltered and filtered water samples.

3.4 Ionic Properties of Water in Msambweni

The ionic properties of water sampled from Fihoni (open well /Hand pump), Kingwede (borehole/underground), and Majikuko (Surface/ River) areas of Msambweni Sub-County of Kwale County for selected ions (Na^+, Ca^{2+}, Mg^{2+}, HCO_3^-, K^+, Cl^- and SO_4^{2-}) are shown in Table 4.7

Table 4. 6: Ionic properties of water samples from Majikuko, Kingwede, and Fihoni Areas

Sampling site		Na^+	K^+	Ca^{2+}	Mg^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
Majikuko	BF	64.20±0.20	55.33±0.60	63.70±0.26	11.70±0.10	225.67±0.58	98.67±0.06	28.60±0.10
	AF	30.50±0.10	18.60±0.10	6.30±0.10	6.15±0.01	<LOD	64.00±1.00	15.80±0.10
P-value					<0.001			
Kingwede	BF	11.33±1.53	1.17±0.06	23.23±0.06	1.04±0.01	55.17±1.04	10.00±1.00	8.06±0.01
	AF	8.53±0.06	6.38±0.01	4.07±0.01	2.05±0.01	<LOD	7.25±0.01	5.71±0.01
P-value		0.031	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Fihoni	BF	15.43±0.15	7.37±0.01	37.20±0.10	4.47±0.01	132.67±0.58	12.87±0.06	2.76±0.01
	AF	2.86±0.02	3.46±0.01	1.99±0.01	0.35±0.01	<LOD	3.05±0.02	3.24±0.01
P-value					<0.001			
WHO standards		Max. 200	<100	<75	<30	<200	<250	250

The amounts (mg/L) of the mineral ions before filtration (BF) ranged from 1.04±0.01 in Kingwede for Mg^{2+} to 225.67+0.58 for HCO_3^- in the water samples obtained from Majikuko. After filtration, these levels significantly decreased to 0.35±0.01 for Mg2+ and 30.50+0.10 for HCO3- in Fihoni and Majikuko water samples. The levels were as per WHO's maximum recommended levels. The t-test also indicated negligible variations in the amounts of all the mineral ions between the three sampling locations.

The concentration (mg/L) of Ca^{2+} from the study areas ranged from 23.23±0.06 (Kingwede) to 63.70±0.26 (Majikuko) before filtration. The acceptable levels of Ca^{2+} for potable water are stipulated as 75 mg/L (WHO, 2017). According to the recommendation, the underground and surface water from these areas are suitable for human consumption. The most significant source of Ca^{2+} in the groundwater and surface water sources arises from the exchange of ions between rocks and minerals in these areas, as suggested by (Roohul *et al.,* 2012).

Further, the results may be an indication of the presence of $CaCO_3$, $CaSO_4$, $CaMg\ (CO_3)_2$ in the soil. Magnesium ion (Mg^{2+}) concentration (mg/L) is excessively found in surface 11.70±0.10 (Majikuko) compared to underground samples of water from the areas of study ranging between 1.04±0.01 (Kingwede) and 4.47±0.01 (Fihoni). Table 4.7 shows that magnesium concentration in the three sample sites is within acceptable WHO standards of less than 300 ppm. The Mg^{2+}could perhaps have the same origin as Ca^{2+}.

Sodium ions (Na^+) concentration (mg/L) in-underground and surface water sources before filtration ranged from 11.33±1.53 (Kingwede) to 64.20±0.20 (Majikuko).

WHO (2017) stipulates the maximum permissible level should be at 200 mg/L. Higher sodium ion (Na^+) concentration brings hypertension, congenital illnesses, kidney complications, and nervous disorders (Penerbit, 2014). The low Na^+ value in the underground and surface water is probably caused by the slow chemical breakdown of feldspars or under-utilization of the sub-surface sources. The findings are in line with (Harrison *et al.*, 2016).

Potassium ions (K^+) concentration in underground and groundwater sources varied between 1.17±0.06 (Kingwede) and 55.33±0.60 (Majikuko) mg/L. Hydrogen carbonate (HCO_3^-) existed abundantly, and the level varied between 55.17±1.04 to 225.67±0.58 mg/L from the sample of water fetched at Kingwede and Majikuko, respectively. The maximum allowable level for (HCO_3^-) is 300 mg/L; thus, the sub-surface water from the study location is potable, as suggested by WHO (2017). The amount of Cl^- in sub-surface and surface water varied from 10.00±1.00 to 98.67±0.06 mg/L. The acceptable level of Cl^- for potable water is recommended to be 250 mg/L (Chen *et al.*, 2017).

Chlorides are less harmful when they occur in small amounts, but at amounts exceeding 250 mg/L, it tastes salty with some odour. They cause hypertension and trigger heart failure (Liu & Dudley, 2020). The high amount of Cl^- in ground and surface water sources is contributed by home effluents and infiltration in sub-surface soil layers in arid areas, as suggested by (Ponce 2014). It was also found that the amount of SO_4^{2-} ions ranged from 2.76±0.01 (Fihoni) to 28.60±0.01 (Majikuko) mg/L. This was discovered to be below the maximum recommended level of 250 mg/L (WHO, 2017). Samples containing excessive amounts of SO_4^{2-} in potable water cause breathing problems (Annapoorna & Janardhana, 2015).

A T-test revealed significant variations in the chemical properties of water before and after filtration ($p< 0.001$) (AF-After Filtration; BF-Before Filtration; LOD-Limit of Detection). The findings confirm the efficiency of the ceramic filter in filtering various minerals in the water. The results are supported by other similar studies such as (Ponce 2014). The levels of dissolved ions were reduced when the water samples were filtered through the activated carbon ceramic filter.

3.4.1 Chemical Properties of the water samples in the study area

Table 3. 7: Descriptive results of chemical properties of the water Samples

Test Variable	Samples	N	Mean	Std. Dev	Std. Error	95% confidence interval (CI) for Mean		Min	Max
						L.B	U. B		
Ca^{2+}	Unfiltered	6	43.22	17.53	7.16	24.82	61.61	23	64.00
	Filtered	6	4.05	2.02	0.82	1.93	6.17	1.54	6.50
	Total	12	23.63	23.66	6.83	8.60	38.67	1.54	64.0
Mg^{2+}	Unfiltered	6	5.99	5.10	2.08	0.63	11.34	1	12.80
	Filtered	6	2.64	2.40	0.98	0.13	5.16	0	6.00
	Total	12	4.32	4.18	1.21	1.66	6.97	0	12.80
K^{+}	Unfiltered	6	22.25	28.06	11.46	-7.20	51.7	1	61.52
	Filtered	6	8.45	6.2	2.53	1.95	14.96	3	19.00
	Total	12	15.35	20.67	5.97	2.22	28.49	1	61.52
Na^{+}	Unfiltered	6	28.56	25.35	10.35	1.96	55.16	9.81	64.00
	Filtered	6	12.80	12.23	4.99	-0.03	25.63	1.98	30.00
	Total	12	20.68	20.68	5.97	7.54	33.82	1.98	64.00
Cl^{-}	Unfiltered	6	39.53	43.19	17.63	-5.80	84.85	10	99.00
	Filtered	6	23.20	28.11	11.47	-6.30	52.7	3	64.00
	Total	12	31.36	35.77	10.33	8.63	54.09	3	99.00
SO_4^{2-}	Unfiltered	6	13.70	13.12	5.36	-0.07	27.46	3	31.89
	Filtered	6	8.21	5.36	2.19	2.58	13.84	3	16.00
	Total	12	10.95	9.98	2.88	4.61	17.29	3	31.89

The analysis results revealed that the mean calcium cation was higher in the unfiltered underground and surface water than in the filtered underground and surface water (43.22 v 4.05). The results also indicated that the mean Magnesium cations exceeded unfiltered underground and groundwater contrary to filtered underground and surface water. This was denoted by the mean score of 5.99 and 2.64, respectively. Likewise, the mean potassium cations exceeded unfiltered underground and surface water contrary to the filtered underground and surface water (28.06 v 6.20). The findings show the role of ceramic water filters.

Further, the results indicated a higher mean sodium cation was in the unfiltered underground and surface water as compared to the filtered underground and surface water (28.56 v 12.80). The mean presence of chloride ions was also found to be higher in the unfiltered underground and surface water as compared to the filtered underground and surface water (39.53 v 23.20).

Also, sulfate presence in the underground and groundwater exceeded the unfiltered sub-surface and groundwater contrary to filtered underground and surface water (13.70 v 8.21). According to Penerbit (2014), the filters comprise tiny pores that prevent organic and inorganic particles (larger than 0.5 microns) from passing through. The results can, therefore, be explained in concurrence to the author. Water through ceramic filters has to pass through an intricate maze (Annapoorna & Janardhana, 2015). The process explains why there was a variation between the filtered and unfiltered water samples.

3.4.2 Means of Chemical traits of Water Samples fetched from Majikuko, Kingwede, and Fihoni Areas

The results showed a significant mean variation in calcium cations of the filtered and unfiltered underground and surface water (0.000< 0.05). The other cations, however, were found to be insignificant.

Table 3. 8: T-test of Chemical Properties of Water Samples from Majikuko, Kingwede, and Fihoni Area

Test Variable	Filtration	N	Mean	Std. Deviation	Std. Error Mean	t	Sig. (2-tailed)
Ca^{2+}	Unfiltered	6	43.22	17.532	7.157	5.436	0.000
	Filtered	6	4.05	2.018	0.824	5.436	0.003
Mg^{2+}	Unfiltered	6	5.99	5.102	2.083	1.453	0.177
	Filtered	6	2.64	2.398	0.979	1.453	0.189
K^{+}	Unfiltered	6	22.25	28.063	11.457	1.176	0.267
	Filtered	6	8.45	6.196	2.53	1.176	0.288
Na^{+}	Unfiltered	6	28.56	25.348	10.348	1.371	0.200
	Filtered	6	12.8	12.229	4.992	1.371	0.211
Cl^{-}	Unfiltered	6	39.53	43.189	17.632	0.776	0.456
	Filtered	6	23.2	28.106	11.474	0.776	0.459
SO_4^{2-}	Unfiltered	6	13.7	13.119	5.356	0.948	0.365
	Filtered	6	8.21	5.361	2.188	0.948	0.376

The mean difference between the presence of magnesium cations, potassium cations, sodium cations, chlorides, and sulfate anions in the filtered and unfiltered underground and surface water were found to be statistically insignificant, i.e. (0.177, 0.267, 0.200, 0.456 and 0.365 accordingly) as shown in the table 4.12. The findings concurred with (Storti *et al.*, 2017). According to the authors, ceramic filters tend to show considerable variation in calcium between filtered and unfiltered water. The differences occur because of the combination of chemicals occurring when water seeps through the ceramic pores.

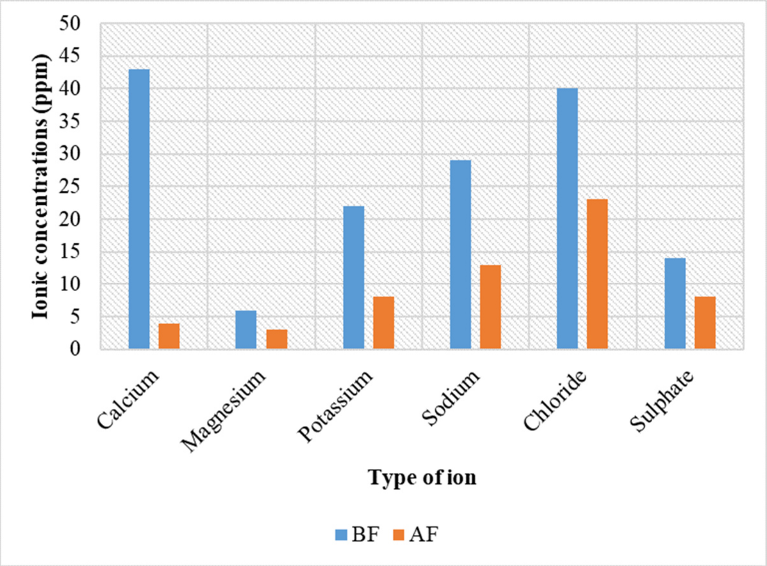

Figure 3. 9: Average levels of dissolved ions in water samples before and after filtration

The result of this study showed that ceramic filters had good removal efficiency of Mg^{2+} and Ca^{2+} that cause the hardness of water (figure 4.9). The removal of calcium and magnesium ions might be due to the ion exchange on the ceramic surface and precipitation formation as oxides and hydroxides of these cations. The central cations in clay structure, aluminium and silicon with higher charge might be replaced with a lower charge like magnesium and calcium by leaving a net negative charge.

The WHO guideline values are given for the concentration of calcium 75 mg/L and magnesium 30 mg/L in drinking water (WHO 2017).

3.5 Hypothesis Testing

Multiple linear regressions were applied in testing the hypotheses. Acceptance/rejection criteria were that if the p-value is below 0.05, the H1 is not rejected, but if it's above 0.05, the H1 fails to be accepted.

3.5.1 Hypothesis Testing for Physico-Chemical Parameters

From Table 4.3 above, the findings of the significance levels informed the hypothesis. The hypothesis was that there was no significant improvement of both chemical and physical parameters of drinking water when an activated carbon ceramic filter was used in water purification. Findings in Table 4.3 above showed the p-value for temperature to be $0.148>0.05$, p-value for pH was $0.000<0.05$, p-value for dissolved oxygen $0.000<0.05$, p-value for electrical conductivity $0.186>0.05$ the p-value for salinity $0.204>0.05$ while the p-value for turbidity $0.004<0.05$.

The results indicated that the hypothesis for pH, dissolved oxygen, and turbidity the alternative hypothesis upheld; hence there was a significant improvement in turbidity, dissolved oxygen, and pH of drinking water when an activated carbon ceramic filter was used in water purification. However, there was no significant improvement in temperature, electrical conductivity, and salinity of drinking water when an activated carbon ceramic filter was used in water purification.

3.5.2 Hypothesis Testing for Bacteriological Water Contaminants

The results in Table 4.6 showed the p values of faecal *E. coli* (MPN) (CFU/100 ml) to be ($0.001<0.05$) and Faecal coliforms (MPN) (CFU/100 ml) ($0.001<0.05$) were statistically significant; hence the alternate hypothesis was upheld. Thus, there is a notable reduction of water contaminants in drinking water when an activated carbon ceramic filter is used in water purification.

3.5.3 Hypothesis Testing for Water Dissolved Ions

The findings in table 4.9 indicated that only calcium cations had a notable correlation with water filtration using an activated carbon ceramic filter. i.e. $0.000< 0.05$. This indicated that the alternate hypothesis was upheld. Thus, there was a major improvement in calcium cations of drinking water when an activated carbon ceramic filter was used in water purification. However, there was no significant improvement of magnesium, potassium, sodium, chlorides, and bicarbonate and sulfate ions in drinking water when an activated carbon ceramic filter was used in water purification.

4. Conclusion

The water samples' physical properties (TDS, temperature, DO, turbidity, salinity, electrical conductivity (EC) and pH) before and after filtration were determined. All the parameters ranged within the recommended limits set by

(WHO 2004) guidelines for drinking water except turbidity (30.00±1.00 NTU) and DO2 (4.21±0.96 mg/L) in water samples obtained from Fihoni. These levels decreased significantly after filtration using the activated ceramic carbon filter with the water samples from Fihoni registering the lowest levels of 0.02±0.00 µS/cm for EC.

Total and Faecal coliforms were all above the permissible limits before filtration. The number of coliforms was almost constant at all sites; however, Majikuko and Kingwede recorded the highest number of faecal and total coliforms, respectively. The pathogenic bacterial isolated were *Escherichia coli*, *Shigella spp*, and *Vibrio cholerae.*

The levels (mg/L) of the mineral elements before filtration ranged from 1.04±0.01 in Kingwede for Mg^{2+} to 225.67±0.58 for HCO_3^- in the water samples obtained from Majikuko. After filtration, these levels significantly decreased to 0.35±0.01 for Mg^{2+} and 30.50±0.10 for HCO_3^- in Fihoni and Majikuko water samples. These figures were within the WHO recommended limits.

The study shows that the majority of the parameters did not exceed the permissible limits of potable water. Some parameters were elevated in specific sampling sites, while for others, it was the reverse. The water samples in all the sampling sites were heavily polluted with coliforms. These levels significantly decreased after filtration using the activated carbon ceramic filter. Pollutant levels after filtration reported here were considerably lower than those in earlier studies of Diani and Mivumoni, respectively.

In Msambweni, the abstraction still seems not to have had an effect on the aquifer. There are no signs of seawater intrusion even when companies; like Base Titanium and KISCOL are abstracting more than 40,000m^3 per day. The findings indicate that the fabricated ceramic filter effectively reduces various physical and chemical parameters and bacteria that undermine the water quality.

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