Water Quality Research Journal

Water Quality Research Journal Vol 58 No 4, 264 doi: 10.2166/wqrj.2023.009

Development and evaluation of filter for canal water potability

V. Tiwari[a], J. P. Singh[a,*], P. Sahota[b], N. N. Singh[a] and K. Singh[c]

[a] Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana, India
[b] Department of Microbiology, Punjab Agricultural University, Ludhiana, India
[c] Department of Soil Science, Punjab Agricultural University, Ludhiana, India
*Corresponding author. E-mail: jpsingh@pau.edu

ABSTRACT

A low-cost portable water filter having a capacity of 15 l for an average small family size was designed, developed, and fabricated for canal water potability. The volume and thickness of filter media were computed and found to be 4,544 cm^3 and 5.6 cm, respectively. The provision for injection of sodium hypochlorite solution was made for the removal of bacterial contaminants and calibrated as 1.5 mL for 15 l of water to maintain the required level of residual chlorine content (2–5 ppm) which was supplied through the pumping unit. The adsorbed contaminants on the filter media could be removed by placing it in 3 l of boiled water for 2 min. The experiment was conducted to determine the settlement duration of suspended solids in canal water and found to be 8 h, thereafter allowing it for filtration. The performance of the developed filter was evaluated by analyzing water quality parameters of the canal water before and after filtration. The values of biological oxygen demand (BOD), chemical oxygen demand (COD), MPN, TDS, pH, and residual chlorine of filtered water were found to be within the permissible limit. The cost of the developed filter was estimated to be INR 1,300 which is economically viable, technically feasible, and easily portable.

Key words: bacteriological, canal water, charcoal, filter media, physicochemical, potability

HIGHLIGHTS

- A portable water filter of height 34.4 cm, and diameter 33.2 cm having a 15-l capacity was developed and evaluated.
- Physicochemical and biological water quality parameters of filtered water were within the permissible limit.
- Filter media and filter body can be exposed to sunlight (UV rays) for disinfection and detachable for washing.
- Supplies hygienic water with low operation and maintenance costs.

INTRODUCTION

Water is a precious natural commodity used by living and non-living things. There are about 1.4 billion km^3 of water on the earth's planet, out of which about 97% of the earth's water is seawater. It is estimated that worldwide 69% of water is used for irrigation out of which 15–35% is unsustainable (Kumar *et al.* 2010). Ground water may become contaminated due to improper disposal of agricultural, industrial, and domestic waste. Groundwater quality is primarily an environmental concern not only for health reasons but also for its effect on crop production. There are various pollutants, such as iron, copper, lead, zinc, cadmium, arsenic, and salinity in groundwater above permissible limits; these have wide-ranging effects on human, animal, plant, and aquatic lives. The coliform group of bacteria is the principal indicator of the degree of contamination and water quality. According to the World Health Organization (WHO), there are at least 5 million deaths per year due to the use of unsafe drinking water and at least 1.4 billion do not have access to drinking water (Mathys 2000). As per the WHO estimates, about 1.1 billion people are drinking unsafe water globally and the vast majority of diarrheal disease in the world (88%) is attributable to unsafe water, sanitation, and hygiene. Bain *et al.* (2014) conducted a study from low- and middle-income countries published between 1990 and August 2013 that assessed drinking water for the presence of *Escherichia coli* or thermo-tolerant coliforms (TTC). The southern part of Punjab, India comprising 34% area of the state is facing severe groundwater quality problems due to brackish water (Jain & Kumar 2007) which is neither fit for irrigation nor for drinking purposes. This region is well occupied with a dense canal network that supplies good quality water throughout the year. This canal water may be used for drinking after removing contaminants through proper filtration techniques. The goal of the present study is to develop a low-cost portable water filter. The novelty of this filter is UV ray exposure to filter media with zero water wastage. The purification of canal water is the foremost requirement, particularly for drinking water based on the purification principle and process.

The methods used for water purification include physical processes, such as filtration, sedimentation, and distillation; biological processes (slow sand filters or biologically active carbon); chemical processes (flocculation and chlorination); and the use of electromagnetic radiation (ultraviolet light), etc. (Chopparapu *et al.* 2020; Wang 2021; Wikipedia 2023). Several methods lower the TDS of water such as boiling and heating tap water with and without $NaHCO_3$, absorption by food-grade activated carbon (AC) (Jacobsen 2004; Pradeep *et al.* 2016), and battery-powered electrolysis (Ilhan *et al.* 2008; Agostinho *et al.* 2012; Rusydi 2018).These sustainable technologies are innovative, simple, and developed with locally available materials. There are a few filtration units used for irrigation and drainage purposes but not fit for domestic use. There are many types of water filters in the market with the ability to purify contaminated water, viz. aquaguard/aqua fresh, reverse osmosis (RO) system, ultra UV water purifier, gravity-based water purifier, high bottled drinking water, etc., but affordable only to the high economic group of society (Tiwari 2012). Technologically advanced filters have no real application in developing countries without the capability to sustain them (Mc Allister 2005). The marketed water filters are fixed type in houses and do not have provision for UV ray exposure to filter media which facilitates waterborne bacteria/pathogens. The study has to be conducted to find a simple, workable, and low-cost method for the purification of surface water for its potability to the common people. The study on nano fitter media for the instant purification of surface water is required for the development of a low-cost portable water filter bringing the turbidity of water within permissible limits for drinking purposes. Organizations such as the United Nations (UN) and WHO are currently pushing the water filter industry to develop sustainable solutions to empower many rural nations with the ability to filter their water in cheaper, more environmentally friendly ways. Prasad (2002) developed a low-cost water filter that meets the requirement of quality water in rural India. The case brings out how even a simple-looking concept for water filtration and disinfectant has to go through several well-defined steps for a successful introduction into the field. Robert (2003) conducted a study on the existing ceramic water filter technologies, production processes, and methods for bringing a low-cost ceramic filter to market in Nepal. A red-clay grog disk and candle filters coated with colloidal silver performed the best in terms of microbiological removal efficiency (>98%) and flow rate (ranging from 641 ml/h/candle (Ceradyn) to 844 ml/h/candle (Gravidyn)). The point of use (POU) household water treatment technology improves the quality of their water by treating it in the home and *E. coli* was reduced by using a bio-sand filter (Stauber *et al.* 2006). Harshfield *et al.* (2009) studied appropriate water purification and distribution systems considering the design and construction process for a slow sand filtration system to provide clean drinking water to most households in the community. The media properties, water requirements, filter cycle time, water dosage volume, water production rate, water temperatures, and practical application of bio-sand filter (BSF) were studied (Kubare & Haarhoff 2010). Stewart-Wade (2011) conducted a study on slow sand filtration which provides an effective and relatively inexpensive means of controlling pathogens in recirculating irrigation water. It uses both physical and biological pathogen control mechanisms. A study on the common indigenous water filtration technique using four different bamboo charcoals (Bhaluka, Jati, Makal, and Bijuli) separately for iron removal (Baruah *et al.* 2011) reveals that all four types of bamboo charcoal could effectively remove iron from water. Shirey *et al.* (2012) studied the community structure of the bacteria associated with three granular activated carbon (GAC) and two anthracite filters over 12 months to monitor changes in community composition and identified that GAC filters exhibited the greatest degree of bacterial community variability over the sampling period, while anthracite filters showed a lower degree of variability and less change in community composition. Gupta & Nair (2012) carried out a study to observe a further reduction in organic load by using a sand-associated charcoal filter, which indicated considerable improvements in the removal of chemical oxygen demand (COD) and BOD. The US Environment Protection Act, the World Health Organization (WHO), and numerous academic studies identify GAC as the best available technology for the control of many agrichemicals and synthetic organic chemicals in drinking water (Anon 2015). Charcoal is an effective filter media because it is characterized by its large pore size which makes it a possible medium for adsorbing bacteria and organic matter similar to AC in filtration capabilities (Agbanobi 1999). Lakshmikandhan & Ramadevi (2019) investigated Bicarbonate-Treated Acacia Catechu Carbon (BTACC) and removed 98% Pb(II) from the aqueous solution. Chlorination is the process of a chemical disinfection method that uses various types of chlorine or chlorine-containing substances for the oxidation and disinfection of the potable water source. Sodium hypochlorite disinfects the water and greatly reduces the prevalence of waterborne pathogens viz., bacteria, viruses, and amoeba (Somani *et al.* 2011). The quantification of several microbial indicators in aquatic systems is required to estimate the biological quality of such systems. The coliform bacteria have been used as traditional indicators worldwide. The number of colony-forming units of all bacterial types decreased when both the NaOCl concentration and exposure times increased (Coronel *et al.* 2011). The farmers are using canal water for irrigation and domestic purposes; however, canal water also gets contaminated by human, animal, and environmental pollution and contains physicochemical and microbiological impurities. The coliform group of bacteria has remained the cornerstone of national drinking water regulation. Sahota & Pandove (2010) conducted epidemiological surveillance of 110 samples in Ludhiana City tested with a Bacteriological Water Testing Kit (BWTK) and found that about 66% of samples were bacteriologically non-potable. Pandove & Sahota (2015) conducted a study of water supply through three different water utilities (Municipal Corporation, hand pumps, and submersible pumps) from different localities of Ludhiana City and found that concentrations of Pb, Cu, Fe, Cr, K, Na, Co, and Ca (21 drinking water samples) were below permissible limits described by WHO and BIS. Zinc was detected in 95.45% of drinking water samples (0.001–0.14 mg/l) and boron was detected in 85.71% of drinking water samples (0.002–0.133 mg/l) whereas arsenic was detected in 19.04% of the water samples (0.006–0.01 mg/l) and nickel (Ni) in 57.14% of water samples (0.0091–0.047 mg/l). The coliform contamination in Yamuna river water at Okhla barrage, Delhi flowing through membrane filtration technique was estimated and found the maximum number of total coliforms/*E coli* bacteria followed by Nigambodh ghat and Wazirabad barrage (Kaur & Mehra 2012). The lakes, rivers, and springs (surface water bodies) are important sources of freshwater (Bhateria & Jain 2016). People are dependent on groundwater for the regular water supply due to poor quality and insufficiency in surface water resources. In this context, lakes are one of the most important water resources and they have been used as a source of water supply for human and animal consumption (Yogendra & Puttaiah 2008). The nutrients enter into the lake from the disposal of human excreta and agricultural wastes which are rich in nitrogen, phosphorous, and potassium leading to the growth of algae and eutrophication in lake water (Carlson 1977). The quality of lake water is evaluated using various physicochemical and biological parameters selected on the Designated Best Use (DBU) of the water body (lake) for various purposes. The Water Quality Index (WQI) is an important tool used for designating the quality of lake water. The complete analysis of water quality comprising physical, chemical, biological, and toxicological components determines all the potential uses of the water body (Vasistha & Ganguly 2020). Mohamed *et al.* (2014) reported the WQI values of the Ismailia Canal, Nile River Egypt, and found good to poor for drinking and aquatic life utilization, and excellent for irrigation utilization. Metal index (MI) and pollution index (PI) were calculated to assess the contaminations of the canal water with the metals (Al^{+3}, Cd^{+2}. Cu^{+2}, Fe^{+2}, Mn^{+2}, Ni^{+2}, Pb^{+2}, and Zn^{+2}) and the MI and PI values of the canal water was found dangerous at most sites, particularly for drinking and fisheries utilizations. The water quality analysis of Sirhind Feeder Canal, Rajasthan Feeder Canal, and Indira Gandhi Canal of Indian Punjab from 25 selected locations was compared with the BIS 10500:2012 standards and CPCB standards for Designated Best Use (DBU) and found within acceptable limits with respect to most of the physical and chemical parameters. Water samples from these canals were also found within acceptable limits with respect to all the heavy metals (arsenic, chromium, cadmium, copper, iron, nickel, lead, and zinc) indicating the absence of industrial pollution in canal water and pesticide analysis of the canal water samples were also found to be below the detection limit (Anon 2020). Shakya & Singh (2010) reported the chemical analysis of canal water and groundwater of the Faridkot district of southwest Punjab, India, and the values of pH, EC, Co_3^-, HCo_3^-, residual sodium carbonate (RSC), and sodium adsorption ratio (SAR) of the groundwater were found to be very high in comparison with canal water, which is not suitable for irrigation as well as domestic use. Most people depend upon groundwater sources that have problems with hardness, calcium, nitrate, phosphate, fluoride, salinity, sodicity, DO, BOD, COD, heavy metals (copper and zinc), and excess MPN count. The concentration of salinity, sodicity, fluoride, and uranium in groundwater was found to be above the permissible limit in most parts of southwest Punjab and other heavy metals showed temporal variations in their concentration and do not occur consistently. In addition, pesticide residues have also been found to occur in groundwater. Enhancement of safe canal water supply for drinking purposes is recommended to alleviate health problems besides installing reverse osmosis plants in the area for removing uranium, fluoride, and other toxins from groundwater (Singh 2013). The groundwater of southwestern districts of Indian Punjab is brackish and is neither suitable for domestic use nor agriculture. People are using canal water for irrigation and domestic purposes in this region. Canal water is chemically and bacteriologically contaminated by humans, animals, and environmental pollutants, which is not suitable for drinking purposes. Canal water could be a feasible and viable solution for drinking water in problematic (salinity, sodicity, fluoride, etc.) areas of the southwestern district of Punjab, India after removing contaminants. The treatment of canal water to remove physicochemical and microbiological contaminants is required to access safe drinking water. However, the marketed water filters are costly, fixed type, and affordable to rich people only. The objective of the study is to develop a low-cost portable water filter for canal water potability for small family sizes to make it easily available and affordable to the common people.

MATERIALS AND METHODS

Fabrication of filter for canal water potability

The capacity of the water filter was worked out by considering an average of five-member family sizes. As per WHO, the water requirement for drinking is 3 l per person per day. The total daily water requirement for the average five-member family size was computed to be 15 l. A portable water filter of 15-l capacity for canal water potability has been designed, developed, and fabricated consisting of a transparent plastic container, metal sieve, muslin cloth, filter media, and manually operated pumping unit. The height and diameter of the plastic container were 34.4 and 33.2 cm, respectively. The metal sieve of 8 cm depth was kept at the top of the container on which the filter media was placed and packed in a cotton cloth (Figures 1 and 2) with a

Figure 1 | Components of water filter.

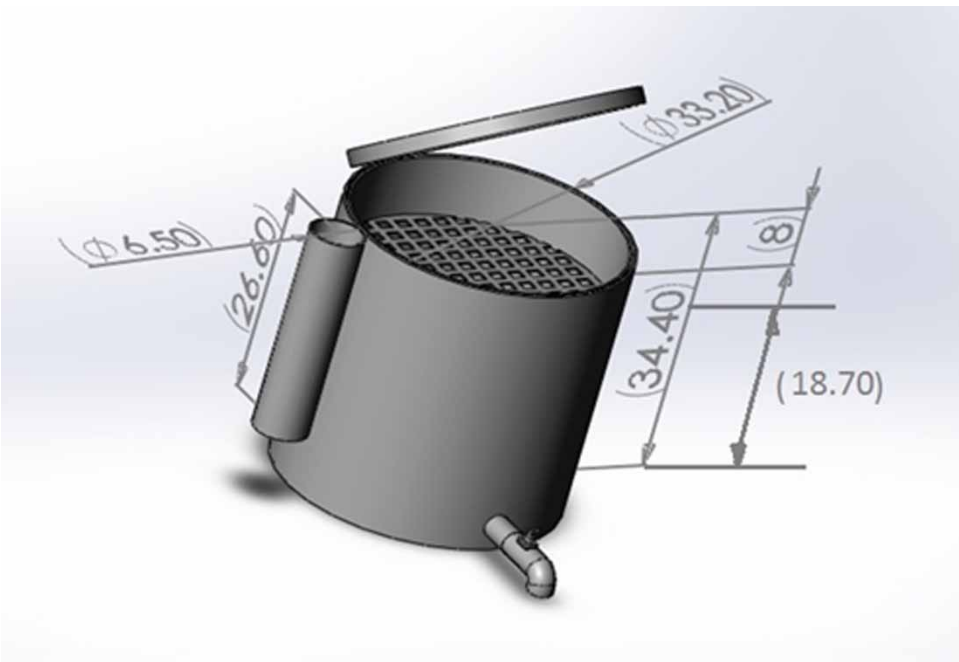

Figure 2 | Dimensions of developed filter (cm).

water ponding capacity of 2.5 l. The provision for opening the filter body from the top has been made, which can be exposed to UV rays of sunlight for disinfection. The pumping unit was fixed outside of the filter body at a depth of 3.1 cm from the top of the container which contains a plastic bottle of 500 ml capacity for sodium hypochlorite solution. The length and diameter of the pumping cylinder are 26.6 and 6.5 cm, respectively (Figure 2). The dosage of sodium hypochlorite solution was calibrated to be 1.5 ml for a 15-l storage water (0.1 ml per liter water). A tap was placed at the height of 3.2 cm above the bottom of the container for the outlet of the filtered water with a discharge rate of 40 ml/s. The sodium hypochlorite solution has been supplied with a discharge rate of 0.5 ml per pumping at the bottom of the metal sieve of the filter body through a chlorination pipe having a length of 75.3 cm and a diameter of 0.3 cm. The storage capacity of the developed filter is found to be 15.32 l with an internal diameter and height of the container of 33.2 and 18.7 cm, respectively. The dead storage capacity of the filter body was kept at 1 l, which is the portion below the outlet (tap) of the water storage container. The dead storage is provided for the settlement of fine residue in water, which has to be removed from time to time.

Selection of filter materials

The best filter media was selected amongst charcoal, alum, and sand after testing its efficacy by analyzing the water quality parameters. The experiment for removal of total suspended solids (TSS) through charcoal and sand filter media was also conducted with different wash load concentrations viz., 500, 1,000, 1,500, and 2,000 ppm, respectively, for the settlement durations of 6, 8, 10, and 12 h, respectively.

Computation of volume and thickness of filter media

The volume of the charcoal media was computed using the Ergun equation (Barrett *et al.* 1991) as shown in the following equation

$$\frac{h}{L}=\left[\frac{150\mu(1-\varepsilon)^2}{\rho.g.d^2.\varphi^2.\varepsilon^3}\right].V_{\mathrm{D}}+\left[\frac{1.75.(1-\varepsilon)}{g.d.\varphi.\varepsilon^3}\right].V^2 \quad (1)$$

where h is the head loss through media bed (m); L is the depth of media bed (m); ε is the media bed porosity (–); φ is the average surface area sphericity (–); d is the geometric grain diameter (m); g is the gravitational acceleration (m/s^2); ρ is the density of water (kg/m^3); μ is the dynamic viscosity of water (kg/m/s); V is the filtration rate (m/s); V_{D} is the water dosage volume (m^3).

Equation (1) consists of laminar (first term) and turbulent (second term) flow. The flow in the filtration unit is predominantly turbulent due to the high filtration velocity and the relatively large grain size. Thus, the laminar term in Equation (1) can be ignored and given as

$$\frac{h}{L}=\left[\frac{1.75(1-\varepsilon)}{g.d.\varphi.\varepsilon^3}\right].V^2 \quad (2)$$

$$V_{\mathrm{media}}=\frac{V_{\mathrm{s}}}{h/L} \quad (3)$$

where $V_{\mathrm{media}}=L.A$; $V_{\mathrm{s}}=A.h$; V_{media} is the volume of filter media (m^3); V_{s} is the surface volume for the filtration unit (m^3); A is the surface area of the media (m^2).

Substituting the value of h/L from Equation (2) into Equation (3), we get:

$$V_{\mathrm{media}}=\left[\frac{g.d.\varphi.\varepsilon^3}{1.75(1-\varepsilon)}\right]\cdot\frac{V_{\mathrm{s}}}{f(\mathrm{UC})V^{\,2}} \quad (4)$$

where $f(\mathrm{UC})$ is the function of the uniformity coefficient.

The thickness of media (h) could be computed by the simple equation for the volume of a cylindrical container with a circular base as;

$$h=\frac{V_{\mathrm{media}}}{(\pi r^2)} \quad (5)$$

and

$$\text{Sphericity} = \frac{\text{de}}{\text{dc}} \tag{6}$$

where de is the diameter of a sphere of the same volume as the object; dc is the diameter of the smallest circumscribing sphere. r is the radius of the circular container.

Analysis of water quality parameters

The physicochemical and bacteriological water quality parameters of canal water samples from the Giderbaha block of Muktsar district, Punjab, India were analyzed as per WHO guidelines in the laboratory of the Department of Soil Science and Microbiology, Punjab Agricultural University, Ludhiana, Punjab, India. The recommended procedure for analyzing water quality parameters viz., MPN (most probable number) analysis, pH, TDS, BOD, and COD was followed and tested in these laboratories.

The microbiological quality of water was analyzed for the presence of total coliforms and fecal coliforms through MPN analysis using standard methods (IS-10500-1991 BIS, New Delhi, India) and BWTK (Sahota *et al.* 2010) (Figure 3). The MPN test (Anon 1992) is a statistical method based on the random dispersion of microorganisms per volume in a given water sample. In this method, measured volumes of water are added to a series of tubes containing a liquid indicator growth medium. The media receiving one or more indicator bacteria show growth and a characteristic color change. The color change is absent in those receiving an inoculum of water without indicator bacteria. It is used for the detection and estimation of coliform in water samples. A commonly used medium is MacConkey broth which contains the indicator bromocresol purple. The MPN of coliforms in 100 ml of the water sample can be estimated by the presence of a number of *E. coli*. The BWTK (Figure 3(a)) contains a better combination of fermentable sugars like dextrose, sucrose, and lactose that promote the growth of emerging pathogens, injured coliforms in addition to total coliform, fecal coliforms, and *E. coli*. BWTK can be designated autoanalysis because a color change from blue (Figure 3(a)) to yellow (Figure 3(c)) reflects positive due to a change in pH produced by the target microbe (s). No change in color indicates an absence of microbial contaminants (Figure 3(b): Negative). No equipment is required other than an incubator if faecal coliform at 44.4 °C is to be detected.

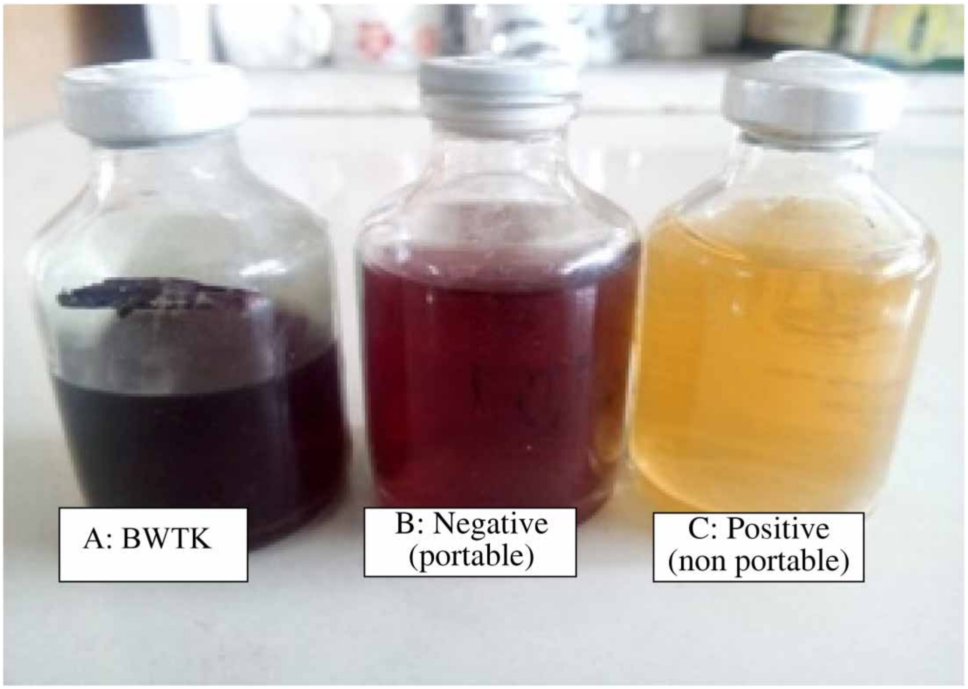

Figure 3 | Bacteriological water testing kit (BWTK).

Specific color (blue to yellow) changes denote the presence of the target microbe (s) (Sahota *et al.* 2010). The procedure to use BWTK is to open the kit near the water source and the water sample to be tested or screened for bacteriological potability should be aseptically dispensed in kit bottles up to the calibrated mark (approximately 15 ml). The bacterial contamination is indicated when the content of the kit bottle shows a change in color, turbidity, sediments, pellicle, and popping of lid within 12 h.

The residual chlorine content in the water sample was determined by a starch-iodide titration method using a sodium thiosulfate solution (0.01 N) reagent. The mineral contents in the canal water sample were analyzed using an inductively coupled argon plasma (ICAP) machine. The pH and TDS of the water sample were measured with a pH meter and TDS meter, respectively.

The BOD is determined by measuring the dissolved oxygen (DO) content of the water sample before and after incubation at 25 °C for 3 days by the Winkler method (Winkler 1888). The method depends on the oxidation of manganous hydroxide (divalent compound) by the oxygen dissolved in the water, resulting in the formation of a tetravalent compound. When the water containing the tetravalent compound is acidified then the free iodine is liberated from the oxidation of potassium iodide. The free iodine is equivalent chemically to the amount of DO present in water samples. The BOD of the canal water was determined by taking 5 ml of canal water sample into a 1 l volumetric flask with a dilution factor of 200 and adding 1 ml each of calcium chloride ($CaCl_2$), phosphate buffer, ferric chloride ($FeCl_3$), and magnesium sulfate ($MgSO_4$). Aerated distilled water was added into the same flask (volumetric flask) to make the final volume 1 L. Three BOD bottles (250 ml) were filled with the diluted sample from the volumetric flask up to the rim without leaving any air space out of this, two bottles were placed in an incubator at 25 °C to determine the final value of DO and the third BOD bottle was immediately analyzed for initial DO. The initial DO was determined by injecting 2 ml of $MnSO_4$ and KI through the pipette below the water surface along the sides of the wall in the third BOD bottle and shaking well. The brown precipitates were formed indicating the presence of oxygen in the bottle and kept aside for a few minutes allowing the precipitates to settle down, then 2 ml of concentrated H_2SO_4 was added into the same BOD bottle and shaken well to dissolve the precipitates. 50 ml of this solution was taken into a conical flask and titrated against $Na_2S_2O_3$ using a few drops of starch $(C_6–H_{10}–O_5)_n$ as an indicator. The change of blue color titrant to colorless was observed as the endpoint. The final DO of the remaining two BOD bottles was determined similarly after incubating at 25 °C for 3 days. The BOD of the canal water sample was obtained as; (Initial DO – Final DO) × Dilution Factor.

The chemical oxygen demand (COD) test is an indirect measure of the number of organic compounds in water with a known excess of potassium dichromate ($K_2Cr_2O_7$), an oxidizing agent titrated with ferrous ammonium sulfate (FAS) to determine the amount of $K_2Cr_2O_7$ consumed and the oxidizable matter is calculated in terms of oxygen equivalent. The COD of the canal water was determined by adding 5 ml of potassium dichromate ($K_2Cr_2O_7$) and 15 ml of concentrated sulfuric acid into a duplicate digestion tube filled with a canal water sample of 25 ml each. The digestion tubes were plugged and autoclaved at 15 psi for 15 min. The content of the digestion tube was cooled after autoclaving and the final volume was made to 70 ml by adding distilled water. The content of the digestion tube was titrated against standard FAS using a ferroin indicator. The endpoint was recorded as a change in color from yellowish green to wine red. The COD was calculated with a standard formula (Tiwari 2012).

RESULTS AND DISCUSSION

A water filter for canal water potability was fabricated, developed, and tested by analyzing the physicochemical and bacteriological parameters of canal water for pre-monsoon, during-monsoon, and post-monsoon before and after filtration. The filter media volume, capacity, and dimension of the water filter body for the average family size have been worked out. The concentration and dosage of sodium hypochlorite solution have been calibrated and the filter media has been tested for removal of suspended solids.

Selection of filter media

Charcoal filter media was selected amongst the charcoal, alum, and sand after testing its efficacy separately and with alternative layer combinations by analyzing water quality parameters. The pH, TDS, and MPN of the water filtered from the alum, charcoal, and sand were analyzed. The MPN of coliforms in 100 ml of filtered water through charcoal filter media was found to be lowest 150 MPN and TDS 115 ppm than the other two filter media alum and sand, which was found to be within permissible limits with neutral pH of 7.2 (Table 1). This table indicated that the pH value of filtered water was below the normal

Table 1 | Water quality parameters of filtered water from various filter media

	Filter media		
Water quality parameter	**pH**	**TDS (ppm)**	**MPN (cfu)**
Alum powder	5.1	641	460
Charcoal	7.2	115	150
Sand	6.9	511	210

and the TDS was above the permissible limit through alum powder and sand media. However, the alum powder was dissolved in filtered water during filtration rather to remove contaminants. The experiment on combination showed that the filtered water through the alternative layers with different thicknesses of charcoal, alum, and sand was found to be of poor quality. The TDS and MPN values of charcoal filter media were found to be lower than those of alum and sand.

Thus, charcoal was found to be the best filter media for treating various physicochemical and bacteriological water quality parameters in comparison to alum powder and sand (Table 1). The charcoal filter media is also a good absorbent for the removal of contaminants, controlling parasites, and removing odors, and the same was selected for the development of a water filter

Estimation of volume and thickness of filter media

The volume of filter media (charcoal) was computed using the Ergun Equation (4). The value of the porosity of the media was computed to be 0.45 through particle volume (8.5 ml) and total volume (19 ml). The value of sphericity was computed to be 0.30 by substituting the value of d_i (2.3 cm) and d_c (7.5 cm), respectively, in Equation (6). The diameter of locally available charcoal was found to be 1.2 mm, the uniformity coefficient (UC) 1.9 (Anon 2015), and the value of f(UC) was obtained to be 4.2 (Figure 4).

The filtration rate of charcoal was found to be 15 m/h (Crittenden *et al.* 2012). The volume of charcoal filter media was computed to be 4,544 cm^3 by substituting all the above values in Equation (4) for 15 l of storage water. The thickness of the charcoal filter media was estimated by using Equation (5) and found to be 5.6 cm. An experiment was also conducted to verify the computed thickness of filter media by analyzing the water quality parameters of filtered water through this media. The value of TDS and pH of filter water through charcoal filter media of thickness 5.6 cm was found to be 108 ppm and 8.1 (Table 2) which is within the permissible limit. It is indicated that the thickness of the charcoal filter

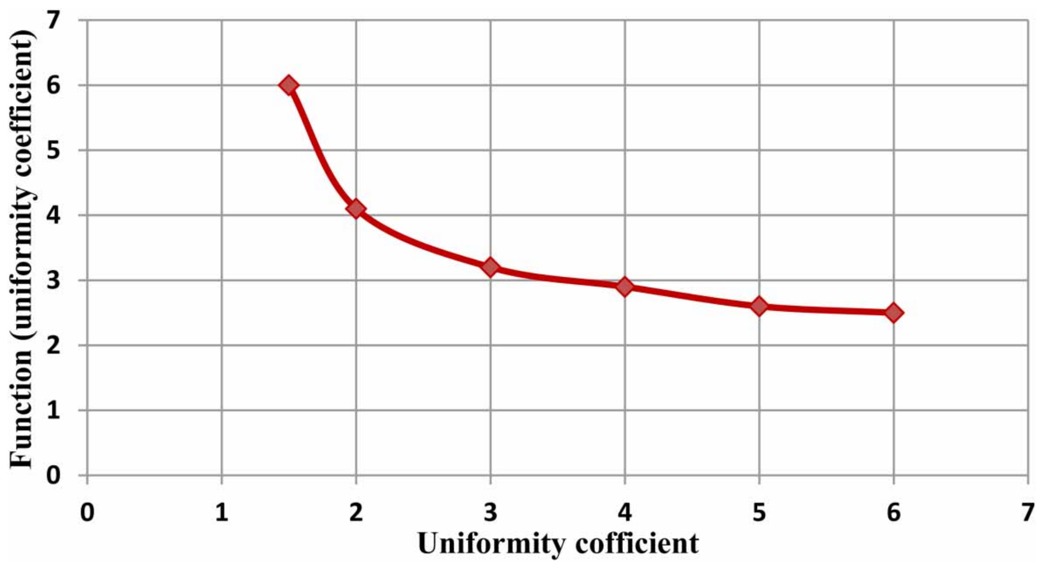

Figure 4 | Graphical representation of f(UC).

Table 2 | Water quality parameter of filtered water through charcoal filter media

Filter media thickness (cm)	Water quality parameter TDS (ppm)	pH
5.6	108	8.1

media is appropriate for the filtration of canal water for drinking. The same media thickness was chosen for the fabrication of the water filter.

Testing of filter media for removal of suspended solids

The charcoal and sand filter media was selected for testing of its efficacy for the removal of suspended solids from canal water. The different concentrations of wash load viz., 500, 1,000, 1,500, and 2,000 ppm were prepared in the laboratory and allowed to pass through sand and charcoal filter media. The TSS of water filtered from sand and charcoal for each wash load was analyzed (Table 3). Table 3 reveals that the values of suspended solids in filter water through charcoal filter media were found less than sand.

Settlement of suspended solids

An experiment was carried out for the duration of settlement of suspended solids for higher wash load concentration in water. The water sample of higher wash load concentrations (2,000 ppm) was kept for 6, 8, 10, and 12 h duration for the settling of suspended solids (Table 4). Table 4 depicts that the value of suspended solids decreased with the increase in settlement duration. The value of TSS in water for the minimum time of settlement (8 h) was found to be 20.4 ppm which is within the permissible limit of 25 ppm (Table 4 and Figure 5).

Calibration of dosage of sodium hypochlorite (NaOCl) for chlorination

The amount of sodium hypochlorite solution (5% NaOCl) was calibrated for 15 l capacity of water filter by conducting minimum inhibitory concentration tests with different concentrations of NaOCl solution viz., 1, 2, 3, 4, and 5 ppm. The simulation studies by maximizing contamination of water bacteriologically to 2,400 MPN/100 ml and filtering the same through a fabricated filter following the protocol (Table 5) indicated that the MPN value (total coliforms) of contaminated water after injection of NaOCl solution (2–10 ppm) was detected for all the contact time (1–19 h). However, the MPN value for a

Table 3 | Sediment residue retained in filtered water through filter media

Concentration of wash load (ppm)	Sediment residue retained in filtered water (percent)	
	Sand	Charcoal
500	31	25.2
1,000	36	30.4
1,500	36.9	30.2
2,000	32.3	26.9

Table 4 | Total suspended solids (TSS) in settled water at different time intervals from 2,000 ppm wash load water

Time interval (hours)	TSS (ppm)	TSS (%)
6	28.2	1.4
8	20.4	1.0
10	20	1.0
12	19.3	0.95

Figure 5 | Before and after 8 h of settlement of suspended solids.

Table 5 | Minimum inhibitory concentration of 5% sodium hypochlorite solution

	MPN value for different contact time			
NaOCl (ppm)	**0 h**	**1 h**	**18 h**	**19 h**
1	2,400	Detected	Detected	Detected
2	2,400	Detected	Detected	Detected
3	2,400	Detected	Detected	Detected
4	2,400	Detected	Detected	Detected
5	2,400	N.D.	N.D.	Detected

5 ppm concentration of 5% NaOCl solution after 1–18 h of contact time was not detected (Table 5). The filtered water after the resident time of 18 h was observed to be re-contaminated.

Thus, a 5 ppm concentration of 5% NaOCl solution was selected for disinfecting water for up to 18 h of contact time. The volume of 5% sodium hypochlorite solution for 15 l of water with 5 ppm concentration was computed and found to be 1.5 ml using the normality equation (($N_1V_1 = N_2V_2$). The sodium hypochlorite solution in the half-liter capacity of the pumping unit of the developed filter may work for 330 days for a 15-l water requirement per day. The sodium hypochlorite solution has to be refilled whenever the pumping cylinder gets empty. The cost of refilling sodium hypochlorite solution is Rs 30 per 500 ml.

Performance evaluation of developed water filter

The performance of the developed water filter was evaluated by analyzing various bacteriological and physicochemical water quality parameters before and after filtration of the canal water samples for the pre-monsoon, during-monsoon, and post-monsoon season(s). The performance of filter media was evaluated and the cost of the developed water filter has also been worked out.

Analysis of canal water quality parameters before and after filtration

The values of BOD, COD, TDS, residual chlorine, pH, and MPN of canal water during the pre-monsoon period were found to be 175 ppm, 310 ppm, 117 ppm, 0.1 ppm, 7.9, and 1,100 MPN, respectively (Table 6). The values of BOD, COD, and MPN were found to be much higher than the permissible limit. The mineral contents in the water sample were found to be within the permissible limit for drinking water. However, the chlorine content was found to be 0.1 ppm which is less than the required limit (0.2–0.5 ppm). The physicochemical and bacteriological analysis of canal water indicates that this water is not suitable for drinking purposes without filtration. The same canal water was then filtered through

Table 6 | Analysis of canal water before and after filtration

	Pre-monsoon		During-monsoon		Post-monsoon		
Water quality parameters	**Values before filtration**	**Values after filtration**	**Values before filtration**	**Values after filtration**	**Values before filtration**	**Values after filtration**	**Permissible limit**
BOD (**ppm**)	175	4.2	52	3.9	24	2.1	3
COD (ppm)	310	9.6	117	7.6	85	4.5	7
MPN /100 ml	1,100	<3	2400	<3	2400	<3	<3
pH	7.9	8	8.1	8.2	8.1	8.2	6.5–8.5
TDS (**ppm**)	117	169	110	146	86	106	500
Residual chlorine (**ppm**)	0.1	0.2	0.1	0.2	0.1	0.2	0.2–0.5
Arsenic (**ppm**)	0.006	0.004	0.0051	0.003	0.0041	0.003	0.05
Cadmium (**ppm**)	0	0	0.0002	0.0002	0.0002	0.0002	0.01
Chromium(ppm)	0.006	0.004	0.0049	0.0035	0.0040	0.0032	0.05
Lead (**ppm**)	0.002	0.003	0.004	0.0053	0.005	0.006	0.05
Sulphur (**ppm**)	6.569	8.331	8.1	10.86	8.9	12.52	200
Magnesium(**ppm**)	11.6	12.94	13.71	10.41	14.85	10.50	30
Iron (**ppm**)	0.09	0.05	0.0091	0.0077	0.0082	0.0052	0.3
Calcium (**ppm**)	76.65	74.26	17.65	16.23	15.45	13.2	75
Copper (**ppm**)	0.001	0.001	0.002	0.001	0.002	0.001	0.05

the developed water filter and water quality parameters of the filtered water were analyzed. The values of BOD, COD, TDS, residual chlorine, pH, and MPN were found to be 4.2, 9.6, 169, 0.2 ppm, 8.0, and <3 MPN/100 ml, respectively, which are within the permissible limit (Table 6). However, the coliforms in filtered water were not detected and the value of residual chlorine was increased from 0.1 to 0.2 ppm which fulfills the requirement for drinking water. The decrease in values of BOD, COD, and MPN and the increase in chlorine content of filtered water indicated that the activated charcoal filter media and sodium hypochlorite solution removed the physicochemical and bacteriological contaminants of the canal water and enhanced the required chlorine content in filtered water. However, the TDS of filtered water was increased to 169 ppm from 117 ppm due to the residue content of charcoal and sodium hypochlorite.

The values of BOD, COD, TDS, residual chlorine, pH, and MPN of canal water during the monsoon period were found to be 52 ppm, 117 ppm, 110 ppm, 0.1 ppm, 8.1, and 2,400 MPN, respectively (Table 6). The table indicated that the value of BOD, COD, and MPN was found to be much higher than the permissible limit which is not fit for drinking purposes. The mineral contents in the water sample were found to be within the permissible limit during monsoons for drinking water. However, the chlorine content was found to be 0.1 ppm which is less than the required limit. The presence of heavy metals in canal water was not found during this season. The water quality parameters of the filtered water through the developed filter were analyzed. The values of BOD, COD, TDS, residual chlorine, pH, and MPN were found to be 3.9 ppm, 7.6 ppm, 146 ppm, 0.2 ppm, 8.2, and <3 MPN/100 ml, respectively, which are within the permissible limit (Table 6). The value of TDS of filtered water has been increased to 146 ppm due to the residue of charcoal and sodium hypochlorite.

The physicochemical and bacteriological parameters of the post-monsoon canal water were analyzed. The values of BOD, COD, TDS, residual chlorine, pH, and MPN were found to be 24 ppm, 85 ppm, 86 ppm, 0.1 ppm, 8.1, and 2,400 MPN, respectively (Table 6). During post-monsoon, the mineral contents in the water sample were observed to be within the permissible limit. However, the chlorine content was found to be 0.1 ppm which is less than the required limit. The values of BOD, COD, and the presence of coliforms in water samples was much higher than the permissible limit for drinking purposes. The values of BOD, COD, TDS, residual chlorine, pH, and MPN of filtered canal water were found to be 2.1 ppm, 4.5 ppm, 106 ppm, 0.2 ppm, 8.2, and <3 MPN/100 ml, respectively (Table 6) which are within the permissible limit. The value of residual chlorine was increased from 0.1 to 0.2 ppm which fulfills the requirement for drinking water and the TDS of filtered water increased from 80 to 106 ppm due to the residual content of

Table 7 | Bacterial contaminants in filter media placed in boiled water for different time

Time for keeping packed charcoal in boiling water	Number of colonies
Control	40×10^5 MPN/100 mL
1 min	3×10^5 MPN/100 mL
2 min	Not detected
3 min	Not detected

Table 8 | Cost estimation of developed water filter

Components	Amount (Rupees)
Plastic container (15 l capacity)	400
Pumping unit	300
Metal sieve	400
Charcoal	100
Tap	100
Total	INR1,300

charcoal and sodium hypochlorite which is within the permissible limit. The removal of pollutants from charcoal filter media was carried out for its reuse.

An experiment was also conducted to remove contaminants from filter media by placing used charcoal in 3 l of boiled water at the end of the day for different time intervals. The results indicated that the *E. coli* was not detected when filter media was kept in the boiled water for 2–3 min which made it free from contaminants (Table 7). The optimized time for used charcoal filter media to be kept in boiled water was found to be 2 min at 80 °C.

The cost of different components of the developed filter was computed and the total cost of the water filter was found to be Rs 1,300 per set (Table 8). The water filter is affordable to a low economic strata of people. The water filter is technically feasible, economically viable, and portable.

CONCLUSIONS

A low-cost portable water filter of 15-l capacity for canal water potability has been designed, developed, and fabricated, consisting of a transparent plastic body. The height and diameter of the water filter were worked out to be 34.4 and 33.2 cm, respectively. The metal sieve of 8 cm depth was kept at the top of the container on which the filter media was placed. The thickness and volume of filter media were computed using the Ergun equation and found to be 5.6 cm and 4,544 cm^3, respectively. The concentration and dosage of sodium hypochlorite solution have been calibrated and found to be 1.5 ml for 15 l of water supplied through the manually operated pumping unit. The developed water filter was tested by analyzing the physico-chemical and bacteriological parameters of canal water for pre-monsoon, during-monsoon, and post-monsoon season(s). All the water quality parameters of filtered water were found to be very low and within the permissible limit for drinking purposes. The filter media has been tested for the removal of suspended solids and the duration of settlement of suspended particles was found to be 8 h. The charcoal should be kept in 3 l of boiled water for 2 min daily to make it free from contaminants. The cost of the developed filter was estimated to be about INR 1,300 which is economically viable, technically feasible, and easily portable. The novelty of the developed water filter is replaceable filter media and exposure to UV rays to kill bacteria/pathogens available on filter media with zero wastage of water. The filter body is completely transparent through which major impurities can easily be observed, detachable for washing and manually operated which reduces the operation cost. However, there are several marketed water filters, which are costly, fixed type, and not affordable to the low economic strata of society.

ACKNOWLEDGEMENTS

This work is supported by the Department of Science and Technology (DST), Ministry of Science and Technology, Government of India, New Delhi funded project 'Biomonitoring of indicator and emerging pathogens in drinking water and remedial measures' under Water Technology Initiatives Project. The authors are very thankful to the funding agency DST.

AUTHOR CONTRIBUTIONS

Dr J. P. S. and Dr P. P. S. conceptualized the whole article and developed the methodology. Mr V. T. and Ms N. N. S. collected the data and did the fieldwork. Mr V. T., Ms N. N. Singh, Dr P. P. S. and Dr K. S. collected the sample and rendered support in data analysis. Dr J. P. S., Dr P. P. S., Mr V. T. and Ms N. N. Singh interpreted the results. Dr J. P. S., Dr P. P. S. and Ms N. N. S. wrote the initial draft. Dr J. P. S. and Dr P. P. S. revised the data after review.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Agbanobi, R. O. 1999 Using granulated wood charcoal as a filter medium. *Journal of Environmental Quality* **28** (3), 1038–1040.

Agostinho, L. C. L., Nascimento, L. & Cavalcanti, B. F. 2012 Water hardness removal for industrial use: Application of the electrolysis process. *Journal of Cancer Science & Therapy* **01** (09), 460. doi:10.4172/scientificreports.460.

Anonymous 1992 *American Public Health Association Standard Methods for the Examination of Water and Wastewater*, 18th edn. American Public Health Association, Washington, DC.

Anonymous. 2015 *Granular Activated Carbon. Drinking Water Treatment Database*. Environmental Protection Agency, United States.

Anonymous 2020 *Water Quality Monitoring of Canals, Central Water Commission (CWC)*. Available from: http://www.indiaenvironmentportal.org.in/content/469812.

Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T. & Bartram, J. 2014 Fecal contamination of drinking water in low- and middle-income countries: A systematic review and meta-analysis. *PLoS Medicine* **115**, 1–23.

Barrett, J. M., Bryck, J., Collins, M. R., Janonis, B. A. & Logsdon, G. S. 1991 *Manual of Design for Slow Sand Filtration*. American Water Works Association (AWWA) Research Foundation, Denver, CO, pp. 1–288.

Baruah, B. K., Medhi, C. & Misra, A. K. 2011 Indigenous water filtration technique in rural areas of Assam: A study on iron removal by bamboo charcoals. *The IUP, Journal of Chemical Engineering* **3** (2), 61–67.

Bhateria, R. & Jain, D. 2016 Water quality assessment of lake : A review. *Sustainable Water Resources Management* **2** (2016), 161–173.

Carlson, R. E. 1977 A trophic state index for lakes. *Limnology and Oceanography* **22** (2), 361–369.

Chopparapu, R., Sambattula, K. R., Edara, D. K., Dasari, R., Sycam, V., Srivalli, G. & Chennaiah, M. B. 2020 A review article on water purification techniques by using fiber composites and biodegradable polymers. *AIP Conference Proceedings* **2247**, 040007. https://doi.org/10.1063/5.0004069.

Coronel, O. C., Gomez, L. M. R., Munoz, A. H., Falcon, A. P. M., Rodriguez, G. A. & Vanditurbe, U. 2011 Chlorine disinfection of *Pseudomonas aeruginosa*, total coliforms, *Escherichia coli* and *Enterococcus faecalis*: Revisiting reclaimed water regulations. *Water Science and Technology* **64** (11), 2151–2157.

Crittenden, J. C., Trussell, R. R., Hand, D. W., Howe, K. J. & Tchobanoglous, G. 2012 *Adsorption. Water Treatment: Principles Design*. John Wiley & Sons, Inc, Hoboken, NJ, pp. 1191–1192.

Gupta, V. V. & Nair, B. 2012 Using sand associated charcoal filter for removal of organic load in wastewater. *International Journal of Global Technology Initiative* **1** (1), 2277–6591.

Harshfield, E., Jamec, A., Makhado, O. & Ramarumo, E. 2009 Water purification in South Africa: Ethical analysis and reflections on collaborative community engagement projects in engineering. *International Journal for Service Learning in Engineering* **4** (1), 1–14.

Ilhan, F., Kurt, U., Apaydin, O. & Gonullu, M. T. 2008 Treatment of leachate by electrocoagulation using aluminum and iron electrodes. *Journal of Hazardous Materials* **154** (1–3), 381–389.

Jacobsen, E. K. 2004 Water filtration. *Journal of Chemical Education* **81** (2). https://doi.org/10.1021/ed081p224A.

Jain, A. K. & Kumar, R. 2007 *Water Management Issues – Punjab, North-West India. Proc Indo-US Workshop on Innovative E-Technologies for Distance Education and Extension/Outreach for Efficient Water Management*. ICRISAT, Patancheru/Hyderabad, Andhra Pradesh, India.

Kaur, S. & Mehra, P. 2012 Bacteriological contamination in pre-monsoon, monsoon and post-monsoon season at selected sites of river Yamuna at Delhi, India. *Global Journal of Modern Biology and Technology* **2** (1), 13–15.

Kubare, M. & Haarhoff, J. 2010 Rational design of domestic biosand filters. *Journal of Water Supply* **59** (1), 1–15.

Kumar, R., Singh, B., Hundal, H. S., Singh, K. & Singh, Y. 2010 *Geospatial Quality of Underground Water of the Punjab*. Bulletin, Department of Soil Science, Punjab Agricultural University, Ludhiana, India.

Lakshmikandhan, K. & Ramadevi, A. 2019 Removal of lead in water using activated carbon prepared from Acacia catechu. *Water S A* **45** (3), 374–382.

Mathys, A. 2000 *Water Supply in Underprivileged Areas. New World Water*. Sterling Publications Limited, London, pp. 32–34.

Mc Allister, S. 2005 *Analysis and Comparison of Sustainable Water Filters*. *Tech Report*. Department of Mechanical Engineering, University of Wisconsin, Madison, USA.

Mohamed, E. G., Ali, M. H., Ibrahim, A. A., Ayman, H. F. & Seliem, M. E. 2014 Evaluation of surface water quality and heavy metal indices of Ismailia Canal, Nile River, Egypt. *The Egyptian Journal of Aquatic Research* **40** (3), 225–233.

Pandove, G. & Sahota, P. 2015 Physico-chemical characteristics of drinking water. *Mintage Journal of Pharmaceutical and Medical Sciences* **4** (2), 4–8.

Pradeep, G. G., Sukumaran, K. P., George, G., Muhammad, F. & Mathew, N. 2016 Removal of dissolved solids in waste water using activated carbon from coconut shell. *Journal of Research* **2** (07), 5–7.

Prasad, V. C. S. 2002 Low-cost domestic water filter: The case for a process-based approach for the development of a rural technology product. *Water SA* **28**, 139–148. ISSN 0378-4738.

Robert, D. 2003 *Development of a Ceramic Water Filter for Nepal*. M. E. Thesis, University of British Columbia, Canada.

Rusydi, A. F. 2018 Correlation between conductivity and total dissolved solid in various type of water: A review. In *IOP Conference Series: Earth and Environmental Science*, p. 118.

Sahota, P. & Pandove, G. 2010 Biomonitoring of indicator and emerging pathogens in piped drinking water in Ludhiana. *Report and Opinion* **2** (1), 14–21.

Sahota, P., Pandove, G., Achal, V. & Vikal, Y. 2010 Evaluation of a BWTK for detection of total coliforms, *E. coli* and emerging pathogens from drinking water: Comparison with standard MPN method. *Water Science and Technology* **62** (3), 676–683.

Shakya, S. K. & Singh, J. P. 2010 New drainage technologies for salt-affected water logged areas of southwest Punjab, India. *Current Science* **99** (2), 204–212.

Shirey, T. B., Thacker, R. W. & Olson, J. B. 2012 Composition and stability of bacterial communities associated with granular activated carbon and anthracite filters in a pilot scale municipal drinking water treatment facility. *Journal of Water and Health* **10** (2), 244–255.

Singh, K. P. 2013 Water quality and health issues in South-West Parts of Punjab State, India. *Water and Health, Springer India* 385–397.

Somani, S. B., Ingole, N. W. & Kulkarni, N. S. 2011 Disinfection of water by using sodium chloride (NaCl) and sodium hypochlorite (NaOCl). *Journal of Engineering Research and Studies* **2** (4), 40–43.

Stauber, C. E., Elliott, M. A., Koksal, F., Ortiz, G. M., Digiano, F. A. & Sobsey, M. D. 2006 Characterisation of the biosand filter for *E. coli* reductions from household drinking water under controlled laboratory and field use conditions. *Water Science and Technology* **54**, 1–7.

Stewart-wade, S. M. 2011 Plant pathogens in recycled irrigation water in commercial plant nurseries and greenhouses: Their detection and management. *Irrigation Science* **29**, 267–297.

Tiwari, V. 2012 *Development of Filter for Potable Water in Rural Areas*. M. Tech. Thesis, Punjab Agricultural University, Ludhiana, India.

Vasistha, P. & Ganguly, R. 2020 Water quality assessment of natural lakes and its importance: An overview. *Materials Today: Proceedings* **32** (2020), 544–552. Available from: https://www.researchgate.net/publication/339531564.

Wang, B. B. 2021 Research on drinking water purification technologies for household use by reducing total dissolved solids (TDS). *PLoS ONE* **16** (9), e0257865. https://doi.org/10.1371/journal.pone.0257865.

Wikipedia 2023 *Water Purification*. Available from: https://en.wikipedia.org/wiki/Water_purification.

Winkler, L. W. 1888 The determination of dissolved oxygen in water. *Berichte der Deutschen Chemischen Gesellschaft* **21**, 2843.

Yogendra, K., Puttaiah, E. T., 2008 Determination of water quality index and sustainability of urban water body in Shimoga town Karnataka. In: *Proceedings of TAAL 2007: The 12th World Lake Conference* (Sengupta, M. & Dalwani, R., eds). Springer, New Delhi, pp. 342–346.

First received 3 May 2023; accepted in revised form 4 November 2023. Available online 17 November 2023