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Simulation and evaluation of water sterilization devices

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ABSTRACT

Treatment of water before consumption is needed to ensure that water quality and purity is achieved. Consuming untreated water can lead to waterborne diseases (such as diarrhea, cholera, and typhoid fever, etc.). It is unbelievable to know that a higher volume of earth water is unsuitable for human consumption because of naturally occurring activities (such as an earthquake, hurricane, and typhoon, etc.) or some human activities (such as throwing sewage, industrial waste, harmful fertilizer, and litter, etc.). This study aims to analyze water sterilization devices using the fuzzy PROMETHEE multi-criteria decision-making method. This method aid the therapist to obtain the most efficient and outstanding therapy that best address the symptoms shown by the patient. The method implements groundwork for constituting a decision-problem, recognizing and evaluating its differences and co-action, and further features the leading alternatives and the reason behind it. The method is applied while evaluating and comparing several criteria such as safety, cost, efficiency, capacity, maintenance, and power consumption. To successfully implement this method, weight, and preference functions were utilized. The weight is set based on the importance of each criterion. With the decision lab, visual PROMETHEE program, the result indicating the most preferred device is gotten. The result shows ultraviolet sterilizer as the most preferred water sterilization device based on the assigned weight and criteria. This decision can, however, be adapted furthermore by assigning different weights and criteria of choice. With this study, it is important to note that the technique used is an efficient tool in multiple criteria decision making for water safety.

Keywords: Alternatives; Decision-making; Multi-criteria; PROMETHEE; Sterilization; Waterborne

1. Introduction

Water occurs naturally on earth and its sources range from the deep ground (groundwater), lakes, reservoir, river, canals, rainwater, and surface water. Drinkable water has a pH of 7 (neither acidic nor alkaline). Water sterilization is the process of getting rid of harmful chemicals, biological contaminants, suspended solids, and gases from water. Asides drinking, sterilization is done for other purposes such as fulfilling the requirement for industrial, pharmacological, chemical, and medical applications. Several methods utilized for sterilization of water include filtration, sedimentation, and distillation, slows and filters, flocculation, chlorination, and ultraviolet light. Many regions around the world do not have easy access to fresh drinking water, because of the uneven distribution of freshwater in time and space. A large number

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of areas are facing water scarcity and stress. Water treatment is the process of making water more portable and suitable or useful, as by purifying, clarifying, softening or deodorizing it. Substances removed during these processes include but are not limited to algae, viruses, bacteria, suspended particles, and naturally and industrially occurring minerals such as iron, calcium, sodium, and manganese. Water technology options include self-supply designs, a community-scale point of use [1]. Supply of potable water to people remains a crucial task provided for by the communities, and designing a water supply framework needs to pursue the standards of building science and besides needs specialized information and user experience. Several communities employ different ways to sterilize water for consumption depending on the constituent of the water. Surface water such as those taken from the streams, lakes, and rivers needs more treatment than those taken from groundwater. The treatment of water requires chemical, physical, and sometimes biological processes to remove contaminants and get the fresh expected water. All these processes can be achieved through the devices which have been innovated to apply all these means to treat water into fresh water with respect to obtaining high efficiency to cover the public needs.

2. Devices

2.1. Ultraviolet sterilizer device

Minute living organisms such as bacteria and viruses are everywhere around us. Many are beneficial while some are hazardous and can cause extreme difficulties in the general health of humans. An ultraviolet sterilizer is used to stop and alter the spread of these organisms thereby stopping their expansion. Because virtually all microscopic organisms are susceptible to ultraviolet rays, the device can successfully eliminate hazardous micro-organisms using ultraviolet radiation. The device is also used in some instances to stop free-floating algae. The ultraviolet light has no residual effect on humans [2] and does not stay in water once the water is sterilized. Therefore, if ultraviolet rays miss any microorganism while sterilizing, that outstanding microorganism can replicate and pollute the water. Ultraviolet sterilizer device utilizes liquid crystal display and ultra-high temperature alarm. The device contains sterilization information recording and printing. This method poses no hazard, overdosing or expansion of risky synthetic substances or chemicals. After sterilization, the water has neither a chlorine taste nor a corrosion problem. The device does not change hard water to sweet or soft water.

2.2. Brackish water reverse osmosis system RO-500

Brackish water is virtually a mix of freshwater and saltwater. This water is saltier than fresh water; however, it is not as salty as seawater. Therefore, it has a moderate level of dissolved minerals and salt. The presence of these impurities makes the water less desirable or unsuitable for consumption. The device utilizes water purification technology called reverse osmosis which clears away macroparticles, molecules, and ion present in water utilizing a semipermeable layer. Here, to get rid of osmotic pressure guided by the chemical potential difference of the solvent, the applied pressure is used [3]. The overwhelming evacuation instrument in membrane filtration is size exclusion [4]. As minerals are expelled, water gets de-mineralized, thus water taste is influenced. Apart from the removal of mineral and salt, the device can evacuate poisons such as lead, mercury, fluoride, and arsenic. The device can also expel ordinarily discovered cryptosporidium in the lake, stream, and open water. Useful minerals such as calcium, iron, magnesium, and sodium are usually removed by this device thereby causing mineral inadequacy in the body. The device cannot eliminate viruses; hence, it is preferred to be used together with ultraviolet sterilizer. Though the system takes too long to sterilize water and it's costlier to maintain, it remains the best device to treat water hardening.

2.3. Electro-deionization system

Electro-deionization (EDI) system removes impurities and deionizes water using machinery that utilizes electricity, resin, and ion exchange membranes. This system utilizes a polishing and chemical treatment method to reverse osmosis (RO). Hence, it is different from other sterilization technology. It delivers high unadulterated water in a consistent stream, finishes evacuation of broken up inorganic particles and requires not too many programmed valves or complex control groupings that need supervision by an administrator. Water requires filtration pre-treatment and the device has low control utilization; hence, there is a need to fulfill the expanding interest for high immaculateness water which can be accomplished by utilizing EDI gear. The EDI procedure replaces ordinary deionization (DI) mixed resin beds to create deionized water. EDI has become the resolution for some applications, it has brought down working costs and less repairing's support requesting, making EDI the financially savvy arrangement [5].

2.4. H_2Ozone 80

The utilization of ozone is the main and best innovation for giving brilliant drinking water. The environmentally-friendly manner by which it works is preferably suited for manageable water treatment. It is generally utilized for drinking water treatment because of its amazing sanitization and oxidation characteristics [6]. The ozone used in the device has more grounded germicidal properties than chlorination. It also has an exceptionally solid oxidizing power with short response time. The treatment process does not add synthetic substances to the water. Ozone has more noteworthy purification adequacy against microorganisms and infections compared to chlorination. Furthermore, the oxidizing properties can likewise decrease the convergence of iron, manganese, sulfur and diminish or dispense with taste and scent issues. Ozone oxidizes iron, manganese, and sulfur in the water to frame insoluble metal oxides or natural sulfur. These insoluble particles are then evacuated by post-filtration. Natural particles and synthetic substances will be wiped out through either coagulation or compound oxidation [7]. Ozone is a green innovation with numerous ecological benefits. It diminishes our reliance on generally utilized, destructive synthetic concoctions, for example, chlorine and wipes out their risky disinfectant results. The main side-effect made by ozone applications is oxygen which is reabsorbed into the air. Just like the ultraviolet sterilizer device, ozonation gives no germicidal or sterilization remaining to hinder or counteract regrowth.

2.5. Packaged membrane bio-reactor system

Membrane bioreactor system (MBR) technology materializes as a better sterilization method for wastewater over the activated sludge process which is a traditional technology used for over a century. Furthermore, MBR remains one of the leading technologies in the sterilization of wastewater and a combination of traditional sterilization system and liquid–solid separation system [8,9]. Conventional initiated slime wastewater treatment plants depend on stretched out air circulation times to decrease the biochemical oxygen demand of the wastewater to a suitable discharge concentration. They likewise depend on gravity or mechanical elucidation to accomplish the required total suspended solids evacuation concentration. MBR is the best in class, exceptionally proficient wastewater treatment advancements, performing altogether superior to conventional bioreactors in alleviating waste streams with a high natural substance. This is because of MBR's capacity to keep up a high concentricity of high-impact microorganisms that tend to drain quicker in conventional bioreactor frameworks [5]. MBR series submerged membrane hollow fiber sheet is exceptionally prepared for membrane bio-response in different sewage and wastewater treatment application.

2.6. Industrial seawater reverse osmosis desalination systems

Desalination innovation has been around for the majority of the most recent century. Desalination innovation has brought new water and thus modern and business advancement to zones of the world that generally may have stayed ineffective. Not just has advancement been upgraded by this innovation in any case, more significantly, the health and welfare of numerous individuals have been enhanced by the supply of sterile new supplies [10]. The definition of desalination, for the most part, is thought to be the creation of new water (freshwater) from seawater. Distillation-type desalination frameworks require a lot of energy to create new freshwater and, as a result of these, exclusive where minimal effort energy is accessible is distillation monetarily achievable for applications.

3. Materials and methods

The proposed method for this study is the fuzzy PROMETHEE method. This method utilizes a multi-criteria decision-making algorithm to prioritize alternatives based on two important data; the weight and preferential function. Different preference functions (P_j) are available on PROMETHEE for calculating the priority value of each criterion. The preference function defines the difference between the evaluations with two alternatives (a and a_i) in relation to a specific criterion and a preference degree ranging between 0 and 1. The preference functions for practical purposes that can be used at the discretion of the decision-maker include; usual function, *v*-shape function, level function, *u*-shape function, linear function, and Gaussian function. A detailed description of the preference functions used in their ranking and how to decide on which function best suits a scenario was discussed by Brans et al. [11]. Generally, *v*-shape and linear preference functions are mostly used for data with quantitative measure, while the usual shape and level preference functions are mostly used for qualitative data. Gaussian preference function is recommended in a scenario where there are quantitative and qualitative data [11–13]. It grades several alternatives options depending on their effectiveness over a series of criteria. Here, the alternatives include various devices used for the sterilization of water. Fuzzy PROMETHEE uses the fuzzy linguistic scale to obtain the weights based on the importance of the criteria to designate weights to the performance indicators. Fuzzy PROMETHEE is preferred over other multi-criteria decision-making methods because it can handle both qualitative and quantitative criteria simultaneously, it can deal with fuzzy relations, vagueness, and certainties and finally because it provides the user maximum control over the weights of the criteria. Fuzzy PROMETHEE has been used in evaluating cancer treatment techniques, analysis of breast tumor treatment methods, evaluating cancer treatment alternatives, analysis of image reconstruction algorithms in nuclear medicine, evaluating nuclear medicine imaging devices, evaluating *x*-ray based medical imaging devices and evaluation of sterilization methods for medical devices [14–19]. Fuzzy PROMETHEE needs evaluation on the weights of the criteria considered as well as the preferential function while correlating the input of the alternatives [20]. Different preference functions designate the difference between the evaluations gathered based on criteria and could be used in order of the chosen criteria. The preference function is between 0–1. Functions used to achieve the PROMETHEE method include Gaussian, level, usual, *U*-shape, and *V*-shape functions.

4. Discussion and results

To effectively compare various sterilization devices based on notable criteria, the triangular fuzzy scale was utilized (Table 1) to get the significance of each criterion and then employ to Yager index to forecast the weight of each criterion. The criteria are prioritized based on their importance.

After collecting the necessary data, the Gaussian preference function was utilized for each criterion as presented in Table 2 since it is based on the standard deviation of the criteria while giving the preference to the alternative. The function of the Gaussian preference function is:

$$P(d) = \begin{cases} 0, d \le 0 \\ 1 - e^{\frac{d^2}{2s^2}}, d > 0 \end{cases}$$

where "d" denotes the difference between the alternative related to their corresponding criteria and "s" denotes the standard deviation of the data for each criterion.

After which the visual PROMETHEE decision lab program was applied. The acquired outcomes are presented in Table 3. We also used the *V*-shape function for safety, cost, efficiency, capacity, and power consumption.

Table 1
Linguistic scale for importance

Linguistic scale for evaluation	Triangular fuzzy scale	Importance of criterions
Very high (VH)	0.75, 1, 1	Safety
Importance (H)	0.5, 0.75, 1	Cost, efficiency
Medium (M)	0.25, 0.50, 0.75	Capacity, maintenance
Low (L)	0, 0.25, 0.5	Power consumption
Very low (VL)	0, 0, 0.25	–

Table 2
Visual PROMETHEE application for the cancer treatment alternatives

Criteria	Cost ($)	Capacity (GDP)	Efficiency	Power consumption	Safety	Maintenance
Preference						
(Min./Max.)	Min.	Max.	Max.	Min.	Max.	Min.
Weight	0.75	0.50	0.75	0.25	1.00	0.50
Preference Fn.	Gaussian	Gaussian	Gaussian	Gaussian	Gaussian	Gaussian
Evaluations						
Ultraviolet sterilizer	6,500	700	Moderate	Low	High	Moderate
Brackish water reverse osmosis system	100,000	650,000	Low	High	High	Moderate
Electro-deionization system	5,600	80	Low	High	High	Moderate
H_2Ozone 80	16,500	140	High	Moderate	Very high	Very high
Packaged membrane bio-reactor system	10,000	75,000	Very high	Very low	Very high	Very high
Industrial seawater reverse	500,00	340,000	Very high	High	High	Moderate

Table 3
Complete ranking for glucometer in the management of diabetes

Ranking	Device	Positive outflow ranking	Negative outflow ranking	Net flow
1	Ultraviolet sterilizer	0.2361	0.0868	0.1493
2	Brackish water reverse osmosis system	0.2061	0.1420	0.0641
3	Electro-deionization	0.2313	0.1686	0.0627
4	Industrial seawater reverse	0.2153	0.1738	0.0415
5	H_2Ozone 80	0.1231	0.2769	–0.1538
6	Packaged membrane bio-reactor system	0.1132	0.2769	–0.1637

The result obtained from Table 3 shows that ultraviolet sterilizers with the lowest price, lowest maintenance cost and lowest power consumption top the list of alternatives and therefore will be more efficient and useful. Moreover, the positive and negative side of every measure was resolved and appear in Fig. 1. The criteria for ultraviolet are on the positive side when contrasted with industrial seawater reverse seawater desalination and H_2Ozone 80.

To justify the robustness of our study, a sensitivity analysis was carried out. Here, two alternatives (packaged MBR and H_2Ozone 80) with already known outranking results were selected, investigated and analyzed. After analysis, packaged MBR once again outranked H_2Ozone 80 thereby showing the robustness of the ranking solution. The outcome of the ranking solution can be obtained in Table 4.

5. Conclusion

Using a multi-criteria decision-making technique such as fuzzy PROMETHEE to evaluate water treatment devices has demonstrated that the conduct of fuzzy input data and PROMETHEE outranking approach works well in handling uncertainty and can assist governments, organizations and individuals in making the best decision as regards safe water provision whether for consumption, industrial or clinical use. The study was able to show the simplicity and

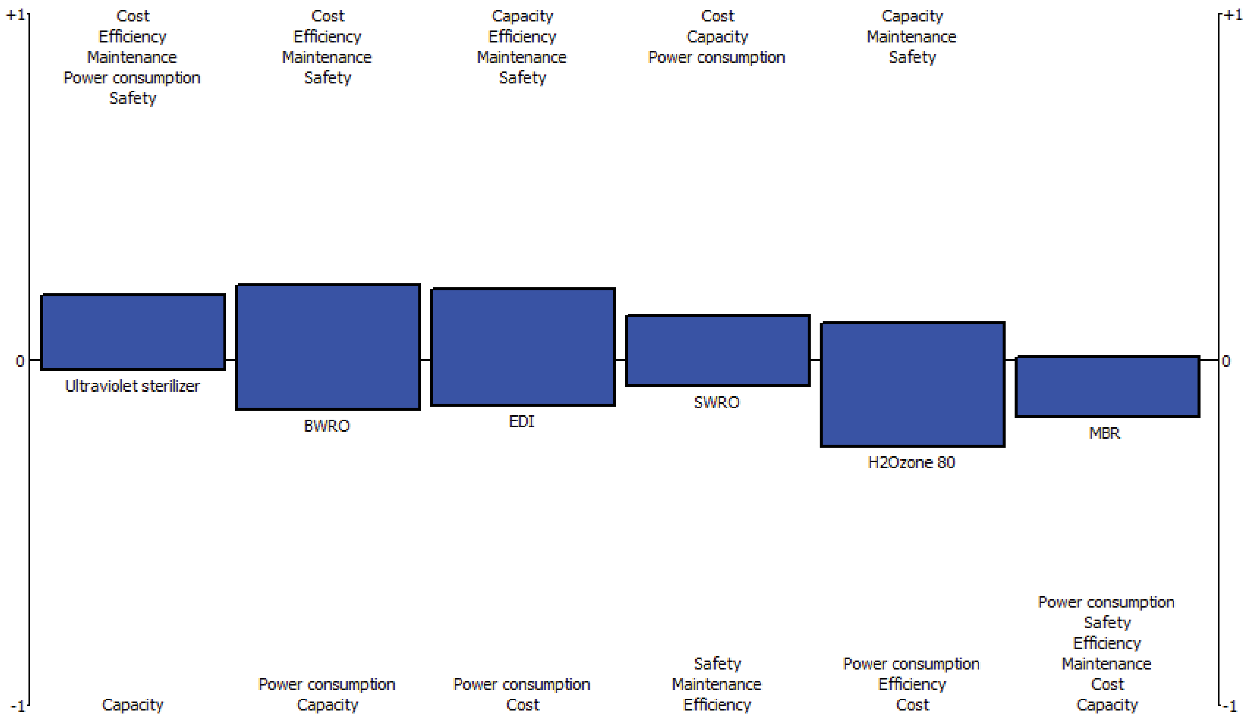

Fig. 1. PROMETHEE evaluation result.

Table 4
Complete sensitivity analysis

Ranking	Device	Positive outflow ranking	Negative outflow ranking	Net flow
1	Packaged membrane bio-reactor system	0.5142	0.0000	0.5142
2	H_2Ozone 80	0.0000	0.5142	–0.5142

feasibility of the proposed technique for multi-criteria decision-making problems in water safety. The current study can be updated and advanced by including more treatment approaches and criteria.

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