MITIGATING DRINKING WATER SCARCITY THROUGH ULTRAFILTRATION TECHNOLOGY IN COASTAL SETTLEMENTS OF SOUTH KALIMANTAN, INDONESIA

MITIGAÇÃO DA ESCASSEZ DE ÁGUA POTÁVEL POR MEIO DA TECNOLOGIA DE ULTRAFILTRAÇÃO EM ASSENTAMENTOS COSTEIROS DO SUL DE KALIMANTAN, INDONÉSIA

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Abstract

This study addresses the critical theme of drinking water scarcity in South Kalimantan's coastal settlements, driven by seawater intrusion that causes high salinity and severe microbial contamination. The primary goal is to evaluate the effectiveness of an integrated three-stage water treatment system to mitigate this water crisis. The methodology involved implementing a single-flow system comprising Fiber Reinforced Plastic (FRP) pre-filtration, Ultraviolet (UV) sterilization, and Reverse Osmosis (RO) technology. Water quality was systematically assessed across physical, chemical, and biological parameters strictly adhering to the Indonesian Ministry of Health standards (Permenkes No. 2/2023). Samples were analyzed at four specific stages: raw well water, post-FRP filter, post-UV sterilization, and the final RO product. The conclusions demonstrate that the system successfully transformed hazardous brackish water into safe, high-quality potable water. Initial raw water tests showed high TDS (308 mg/L) and extreme microbial pollution (>200 CFU/100 mL). While FRP and UV stages were insufficient individually for total purification, the RO stage acted as the critical final purifier, drastically reducing TDS to 32 mg/L and ensuring absolute sterility (0 CFU/100 mL). This integrated technological intervention reliably prevents severe health risks associated with salinity and waterborne diseases in vulnerable coastal communities.

Keywords: Coastal Communities. Reverse Osmosis. Seawater Intrusion. Ultraviolet Sterilization. Water Treatment.

Resumo

Este estudo aborda o tema crítico da escassez de água potável nos assentamentos costeiros de Kalimantan do Sul, causada pela intrusão de água do mar, que resulta em alta salinidade e grave contaminação microbiana. O objetivo principal é avaliar a eficácia de um sistema integrado de tratamento de água em três etapas para mitigar essa crise hídrica. A metodologia envolveu a implementação de um sistema de fluxo único composto por pré-filtragem com plástico reforçado com fibra (FRP), esterilização por luz ultravioleta (UV) e tecnologia de osmose reversa (RO). A qualidade da água foi avaliada sistematicamente em parâmetros físicos, químicos e biológicos, em estrita conformidade com as normas do Ministério da Saúde da Indonésia (Permenkes nº 2/2023). As amostras foram analisadas em quatro estágios específicos: água bruta do poço, pós-filtro FRP, pós-esterilização UV e o produto final de RO. As conclusões demonstram que o sistema transformou com sucesso a água salobra perigosa em água potável segura e de alta qualidade. Os testes iniciais da água bruta mostraram alto TDS (308 mg/L) e poluição microbiana extrema (>200 UFC/100 mL). Embora as etapas de FRP e UV fossem insuficientes individualmente para a purificação total, a etapa de RO atuou como o purificador final crítico, reduzindo drasticamente o TDS para 32 mg/L e garantindo esterilidade absoluta (0 UFC/100 mL). Essa intervenção tecnológica integrada previne de forma confiável os graves riscos à saúde associados à salinidade e às doenças transmitidas pela água em comunidades costeiras vulneráveis.

Palavras-chave: Comunidades Costeiras. Osmose Reversa. Intrusão de Água do Mar.

Esterilização por Ultravioleta. Tratamento de Água.

1 INTRODUCTION

Drinking water is defined as water that, with or without prior treatment, meets health requirements and is safe for direct consumption. Safe and adequate drinking water services are recognized as a fundamental Human Right and constitute one of the primary targets within the Sustainable Development Goals (SDGs) (United Nations, 2015). The Government of Indonesia previously issued the Decree of the Minister of Health No. 907/Menkes/SK/VII/2002 about Drinking Water Quality Requirements and Supervision (Minister of Health, 2002). In 2010, the regulations regarding drinking water quality requirements were updated through the Regulation of the Minister of Health of the Republic of Indonesia No. 492/Menkes/Per/IV/2010. This regulation incorporated implementing guidelines for the supervision of drinking water that fulfills health requirements (Minister of Health, 2010). Enhancing water quality can be achieved through water treatment technologies utilizing filtration, sedimentation, aeration, decontamination, disinfection, and other methods capable of achieving water quality that meets the Environmental Health Quality Standards (Minister of Health, 2023).

The demand for clean water presents a critical global challenge, particularly in the coastal regions of developing nations. Climate change and rising sea levels have exacerbated seawater intrusion into groundwater and surface water sources. Coastal communities continuously face the dual risks of water scarcity and high environmental vulnerability (Mora *et al*., 2018). Especially in tropical regions, these conditions are aggravated by extreme seasonal fluctuations between droughts and floods (Barendrecht *et al*., 2024; Marengo & Espinoza, 2016). Studies on drinking water quality in Indonesia indicate that while microbial contamination is severely prevalent, chemical contamination generally remains within the limits set by the applicable Decree of the Minister of Health of the Republic of Indonesia (Irianti *et al*., 2024). However, a case study in Bekasi City, Indonesia, found that the parameters for pH, E. Coli, and total coliform exceeded quality standards (Dianty *et al*., 2022).

The primary problem with raw drinking water sources in coastal areas is the phenomenon of seawater intrusion (Abd-Elaty & Zelenakova, 2022; Chowdhury, 2022; Karuppaiah & Gopal, 2023). Seawater intrusion occurs due to the encroachment of seawater into fresh groundwater aquifers (Abd-Elaty & Polemio, 2023; Basack *et al*., 2022; Chowdhury, 2022). The main causes of seawater intrusion include excessive groundwater extraction leading to a decline in the groundwater table (Armanuos *et al*., 2022; Chen *et al*., 2024; Perumal *et al*., 2024); sea-level rise causing saltwater seepage inland (Abd-Elaty & Polemio, 2023; Bosserelle *et al*., 2022; Isiaka *et al*., 2023); and the degradation of mangrove ecosystems, which naturally serve as a barrier against seawater intrusion rates (Akram *et al*., 2023; Basack *et al*., 2022; Nair *et al*., 2023). The limited availability of drinking water sources in coastal areas forces communities to adapt in burdensome ways. They must incur higher costs to purchase drinking water (Khan *et al*., 2023; Nurhayati *et al*., 2024; Shohel *et al*., 2024); the use of brackish water or contaminated groundwater for drinking risks causing skin diseases, diarrhea, and other illnesses (Rakib *et al*., 2019; Shammi *et al*., 2019; Wahyono *et al*., 2019); and this ultimately worsens the welfare of coastal communities, who predominantly belong to the lower-middle economic class (Ashrafuzzaman *et al*., 2023; Korfali & Jurdi, 2010; Nurfadilah & Hamzah, 2025).

Raw water originating from groundwater, rivers, and lakes still heavily contains physical pollutants, pathogenic microorganisms, and dissolved chemical substances that pose health risks (Alaqarbeh *et al*., 2022; Mishra, 2023; K. Sharma *et al*., 2023). Therefore, an effective water treatment system is necessary to transform raw water into drinking water that complies with health quality standards. Filtration is the process of passing water through a porous medium to filter out particles (Aziz *et al*., 2024; Ibrahim *et al*., 2022; Rahaman *et al*., 2024). The filtration process represents the physical and chemical separation stage in an effective water treatment system (Bera *et al*., 2022; Castro-Jiménez *et al*., 2022; Li *et al*., 2022).

Filtration technology has evolved from conventional methods to highly efficient systems capable of rapidly and effectively removing suspended particles and turbidity from raw water. The combination of filtration, ultraviolet (UV), and Reverse Osmosis (RO) technologies has been widely adopted due to its ability to filter pollutants at the molecular level, eradicate viruses/bacteria, and eliminate chemical contamination

(Ihekweme *et al.*, 2023; Nugrahadi *et al.*, 2023; Parveen & Malviya, 2022). Activated carbon filtration media serves to absorb organic substances and remove odors, tastes, and colors frequently found in polluted raw water (Alver *et al.*, 2022; Castiglioni *et al.*, 2022; Rahman *et al.*, 2023). Single and double filtration systems have been applied in peat water treatment in South Kalimantan, yielding results that meet the standards set by the Minister of Health (Nugrahadi *et al.*, 2023, 2024; Wianto *et al.*, 2024).

The bodily impact of consuming water affected by seawater intrusion (brackish water with a salt content of 1,000 - 10,000 mg/L) involves various human health disorders. Excessive salt intake through drinking water can trigger numerous ailments, including kidney disorders, hypertension, dehydration, digestive issues, and electrolyte imbalances. For the community of Pagatan Besar Village residing in a coastal environment, ensuring the fulfillment of clean water needs is imperative. This study focuses on the successful production of high-quality drinking water that complies with the regulations of the Minister of Health. The study employs a single-flow filtration system utilizing a combination of filtration, ultraviolet, and reverse osmosis. This process ensures the elimination of physical, chemical, and biological contaminants, resulting in drinking water that meets the requirements of the Minister of Health Regulation No. 492/Menkes/Per/IV/2010.

2 MATERIALS AND METHODS

Indonesia is an archipelagic country with a coastline length of 6,771.92 km (Sui *et al.*, 2020), which is continually increasing annually (Yang *et al.*, 2023). Coastal areas sourcing raw water are highly vulnerable to seawater intrusion, rendering the brackish/saline water unusable for drinking and daily necessities. This situation is not merely an environmental issue but poses a significant threat to national water security and the survival of millions residing along the coastlines.

The implementation site for the ultrafiltration process aimed at improving drinking water quality is in Pagatan Besar Village, South Kalimantan Province, Indonesia (see Figure 1). Pagatan Besar Village is a coastal area highly susceptible to seawater intrusion, featuring numerous river estuaries that result in high amounts of dissolved sediments.

Figure 1

Location of the application of the filtration process converting brackish water into high-quality drinking water

The Regulation of the Minister of Health Number 492/Menkes/Per/IV/2010 is the primary regulation in Indonesia governing Drinking Water Quality Requirements. Since 2023, this regulation has been updated/replaced by Permenkes No. 2 of 2023 concerning the Implementing Regulations of Government Regulation Number 66 of 2014 regarding Environmental Health, which establishes broader environmental health quality standards. This regulation was enacted to ensure that the water consumed by the public is safe and does not cause health disturbances (Minister of Health, 2010, 2023).

Drinking water is defined as water that, through processing or without processing, meets health requirements and can be consumed directly. Drinking water is declared safe if it meets the requirements of being free from E. Coli bacteria and total Coliform bacteria (0 per 100 ml of sample); satisfies the maximum limit requirements for chemical contents such as iron, fluoride, chloride, manganese, as well as toxic substances (mercury, arsenic, etc.); and is odorless, tasteless, colorless (maximum 15 TCU), has a temperature variance of $\pm3°C$ from the ambient air temperature, and a maximum turbidity of 3 NTU. The regulation also sets the maximum limit for Total Dissolved Solids (TDS) at 500 mg/L. If water affected by intrusion possesses a salt content that causes the TDS value to exceed this limit, the water is legally unfit for consumption. The regulation also guarantees that the produced drinking water is safe for health; mandates regular water quality testing; and enforces compliance with external supervision conducted by the Regency/City Health Office (Minister of Health, 2023).

Due to the regulations from the Minister of Health, drinking water must be tested to ensure compliance. Drinking water testing based on the Minister of Health's regulations is as follows:

2.1 Temperature testing

The principle of water temperature testing involves measurement using a calibrated water thermometer (typically a mercury or digital thermometer). This test must be conducted directly in the field (in situ) because water temperature rapidly changes to match the surrounding air temperature when transported to a laboratory. The equipment typically uses a mercury thermometer with a Celsius ($°C$) scale and a minimum accuracy of 0.1°C or according to analytical accuracy requirements (SNI 06-6989.23, 2005). Based on the latest standards of Permenkes No. 2 of 2023, the temperature threshold for drinking water is a $\pm3°C$ difference from the ambient air temperature.

2.2 Total dissolved solids (TDS) testing

TDS testing specifically for drinking water utilizes the Gravimetric method. The basic principle involves filtering the water sample through filter paper to separate suspended solids. The filtrate (filtered water) is then evaporated to dryness and heated at a temperature of 180°C until a constant weight is achieved. The weight of the remaining residue is calculated as TDS (SNI 3554, 2015). The calculation formula is:

$$TDS \ content \ (mg/L) = \frac{(W_1 - W_0) \times 10^6}{V} \qquad (1)$$

keterangan:

- W_1 = Weight of the dish + dry residue (grams)
- W_0 = Weight of the empty dish (grams)
- V = Volume of the evaporated sample (mL)
- 10^6 = Conversion factor to mg/L

Based on the latest standards of Permenkes No. 2 of 2023, the maximum threshold for TDS in drinking water is <300 mg/L.

2.3 Turbidity testing

Water turbidity testing employs a Nephelometer to ensure the water does not contain excessive suspended particles that could harbor pathogens (bacteria/viruses). This method is based on comparing the intensity of light scattered by the water sample with the intensity of light from a standard suspension under identical conditions (SNI 06-6989.25, 2005). Based on the latest standards of Permenkes No. 2 of 2023, the maximum threshold for drinking water turbidity is <3 NTU.

2.4 Color testing

Testing water color is crucial for distinguishing between water that appears turbid due to particles (apparent color) and water that is genuinely colored due to dissolved

organic substances (true color). Water color is determined by visually comparing the color of the water sample against a standard solution with a known concentration. The unit used is Pt-Co (Platinum-Cobalt) units, often referred to as TCU (True Color Units) (SNI 06-6989.24, 2005). Based on Permenkes No. 2 of 2023, the maximum color limit for drinking water is 15 TCU/Pt-Co. In coastal areas, water often appears yellow or brown, indicating a high Pt-Co value due to the presence of humic/fulvic acids (organic substances) or dissolved metals (such as iron), which can interfere with the effectiveness of disinfectants (chlorination) during water treatment.

2.5 Odor testing

Odor testing still relies on the human sense of smell (organoleptic). Odor testing must be conducted as soon as possible after the sample is taken, as odor-causing compounds are highly volatile or alterable by temperature and light (SNI 06-6989.24, 2005). Based on Permenkes No. 2 of 2023, the standard for drinking water requires it to be Odorless.

2.6 pH testing

Testing water pH is highly important because unstable pH can affect the taste of the water and the effectiveness of the disinfection process. Testing is conducted using the potentiometric method, which measures the electrical potential difference between a glass electrode and a reference electrode immersed in the water sample using a pH meter (SNI 3554, 2015). Based on Permenkes No. 2 of 2023, the health standard is within the range of 6.5 - 8.5. Water affected by marine intrusion often experiences a pH shift. If the pH is too low (acidic), the water becomes corrosive to pipes; if too high (alkaline), the water tends to taste bitter or cause scaling.

2.7 Nitrate (NO_3^-) testing

The method used for nitrate testing is UV-Vis Spectrophotometry or cadmium reduction. The principle is to measure the light absorbance by nitrate compounds in the

sample. Because nitrate absorbs light at ultraviolet wavelengths (around 220 nm), its concentration can be determined by comparing the sample's absorbance value against a standard calibration curve (SNI 3554, 2015). Based on the health standards of Permenkes No. 2 of 2023, the maximum limit for nitrate in drinking water is 50 mg/L. High nitrate levels are highly dangerous for infants (Blue Baby Syndrome), as the blood's ability to carry oxygen is drastically reduced.

2.8 Nitrite (NO_2^-) testing

The method used is Spectrophotometry based on the principle of forming a purplish-red azo compound. Nitrite in the water sample reacts with sulfanilamide in an acidic medium (pH 2.0 – 2.5) to form a diazonium salt compound. The salt is then coupled with N-(1-naphthyl)-ethylenediamine dihydrochloride (NED) to form a purplish-red azo compound. The intensity of the color formed is directly proportional to the concentration of nitrite in the water. This color is then measured using a Spectrophotometer (SNI 3554, 2015). Permenkes No. 2 of 2023 sets the standard nitrite level to not exceed 3 mg/L.

2.9 Hexavalent chromium (VI) testing

Hexavalent Chromium (VI) is a highly toxic and carcinogenic heavy metal, frequently found in metal plating or leather tanning industrial waste that contaminates groundwater. The testing principle involves the reaction between hexavalent chromium (VI) and diphenylcarbazide compounds in an acidic environment. The reaction forms a red-purple complex compound. The intensity of the color formed is directly proportional to the Chromium concentration in the water, which is then measured using a Spectrophotometer (SNI 6989.71, 2009). Based on health standards in Permenkes No. 2 of 2023, the maximum limit for hexavalent chromium (VI) in drinking water is <0.01 mg/L.

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2.10 Dissolved iron (Fe) testing

Testing for dissolved iron (Fe) levels in water is conducted using Atomic Absorption Spectrophotometry (AAS), which is highly accurate for detecting heavy metals frequently found in coastal areas. The working principle involves aspirating the water sample into a flame (air-acetylene). The iron metal in the sample decomposes into neutral atoms. These atoms absorb light radiation from a specific iron hollow cathode lamp (HCL) at a wavelength of 248.3 nm. The amount of light absorbed is proportional to the iron concentration in the sample (SNI 6989-84, 2019). The environmental health standards of Permenkes No. 2 of 2023 require the maximum iron level in drinking water to be 0.2 mg/L.

2.11 Dissolved manganese (Mn) testing

The testing procedure for dissolved manganese (Mn) levels in water uses flame Atomic Absorption Spectrophotometry (AAS). The filtered water sample (to isolate the dissolved phase) is aspirated into a flame (air-acetylene mixture). The manganese metal in the sample is atomized. Light from a manganese Hollow Cathode Lamp is absorbed by the manganese atoms. The amount of light absorbed (absorbance) is proportional to the manganese concentration in the sample (SNI 6989-84, 2019). Manganese is frequently found in high concentrations in coastal or swamp groundwater, which, if exceeding thresholds, can cause water to appear brownish, smell fishy, and leave black stains on household appliances. Based on the latest health standards in Indonesia, Permenkes No. 2 of 2023, the maximum limit for Manganese (Mn) in drinking water is 0.1 mg/L.

2.12 Residual chlorine (Cl_2) testing

Residual chlorine testing is conducted to ensure that water that has undergone disinfection (chlorination) still retains a sufficient amount of free chlorine to eliminate pathogens during distribution, yet not excessively so as to endanger health. Based on commonly used standard operating procedures utilizing manual equipment, the Eligibility

Standard (Permenkes No. 2 of 2023) for drinking water passing through a piping system requires a residual chlorine level of 0.2 - 0.5 mg/L.

2.13 Dissolved arsenic (As) testing

Testing for arsenic (As) in this standard is crucial because arsenic is a toxic heavy metal that is carcinogenic (cancer-causing) if consumed even in minute quantities. The method commonly used according to the standard is Atomic Absorption Spectrophotometry (AAS) (SNI 3554, 2015). Based on health regulations (Permenkes No. 2 of 2023), the maximum arsenic level in drinking water is 0.01 mg/L.

2.14 Dissolved cadmium (Cd) testing

Testing for cadmium (Cd) levels in water is conducted using the Atomic Absorption Spectrophotometry (AAS) method employing an air-acetylene flame (SNI 06-0644, 1989). According to Permenkes No. 2 of 2023, the maximum threshold for cadmium in drinking water is exceedingly small, specifically 0.003 mg/L. Cadmium is a highly toxic heavy metal often found as an industrial pollutant in coastal areas.

2.15 Dissolved lead (Pb) testing

The testing procedure for dissolved and total lead (Pb) metal levels in water uses an Atomic Absorption Spectrophotometer (AAS) with an air-acetylene flame (SNI 06-6989.8, 2009). The Maximum Limit according to Permenkes No. 2 of 2023 for lead (Pb) content in drinking water is 0.01 mg/L. Exceeding this threshold is highly dangerous due to its accumulative nature within the body, which can damage the nervous system, inhibit red blood cell formation, and impair brain development in children. Lead is a highly toxic heavy metal often found in coastal regions resulting from industrial waste or port activities.

2.16 Fluoride (F) testing

The standard for testing fluoride (F) in drinking water utilizes Spectrophotometry. Its working principle is based on the reaction between fluoride and a color solution (reagent). Fluoride reacts with a zirconium-dye lake (SPADNS) to form a colorless complex compound (SNI 3554, 2015). The maximum permissible limit for F in drinking water is 1.5 mg/L based on Permenkes No. 2 of 2023. F content must be strictly monitored because, although beneficial for dental health in small amounts, excessive levels can cause fluorosis (damage to tooth enamel and bones).

2.17 Dissolved aluminum (Al) testing

Testing for aluminum (Al) levels in water is conducted spectrophotometrically using Eriochrome cyanine R reagent. Aluminum in a buffered environment (pH 6.0) reacts with Eriochrome cyanine R to form a purplish-red complex compound. The intensity of the color formed is proportional to the aluminum content in the sample, which is then measured at a wavelength (λ) of 535 nm using a UV-Vis Spectrophotometer (SNI 6989.34, 2009). The maximum limit for dissolved Al in drinking water based on Permenkes No. 2 of 2023 is 0.2 mg/L.

2.18 Water treatment

Drinking water treatment systems depend on whether the raw water source is groundwater or surface water. Drinking water treatment technology was developed centuries ago to protect public health from physical, chemical, and pathogenic bacterial contamination (Ray & Jain, 2011). The treatment of raw water into drinking water utilizes Ultrafiltration Technology divided into three stages: ultrafiltration, ultraviolet, and reverse osmosis (Figure 2).

Figure 2

Schematic diagram of the drinking water treatment system in three main stages
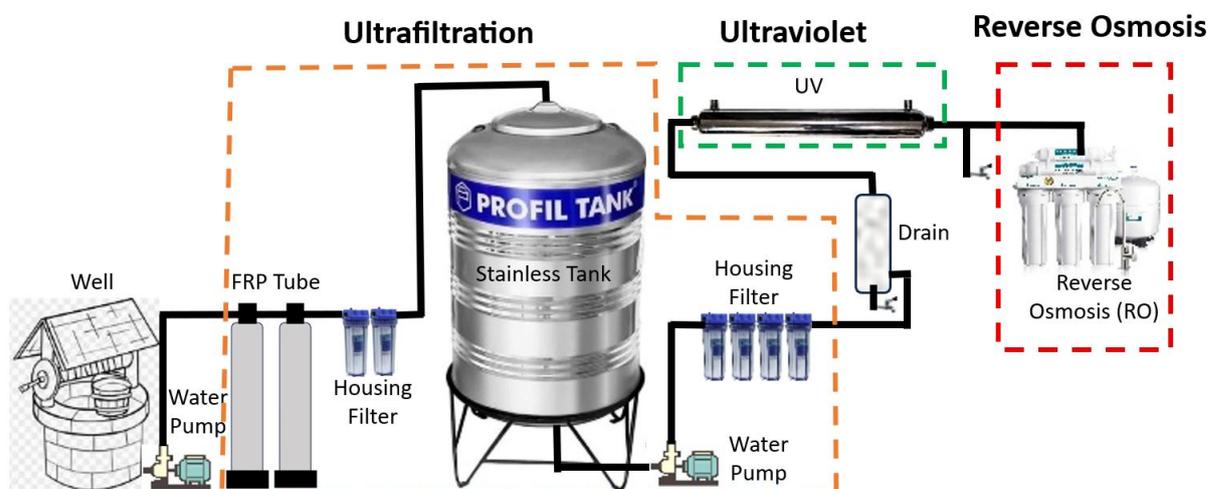
The raw water source originates from a dug well located 100 meters from the shoreline of Pagatan Besar Village, Indonesia. Coastal areas feature shallow groundwater tables and highly porous (easily absorbing water) sandy soil formations, making the raw water source highly susceptible to seepage from domestic waste. Physically, the water in this location is highly likely to be hard (high calcium/magnesium content).

Stage 1 of the drinking water treatment is ultrafiltration, which functions to separate contaminants without removing the natural minerals required by the body. The ultrafiltration system utilizes a semi-permeable membrane with very small pore sizes, ranging from 0.01 to 0.1 microns (Aziz *et al*., 2024; Nguyen, 2012). The working principle of ultrafiltration relies on water pressure to force water through the membrane walls with extremely tight pores acting as a mechanical barrier. The main components of the UF system are Fiber Reinforced Plastic (FRP) tubes and a filter housing. The FRP tubes contain silica sand, zeolite, and activated carbon media. The silica sand media serves to filter suspended particles (Teodosiu *et al*., 2018). The zeolite media functions to filter fine particles, bind ammonia, reduce lime content, and improve water clarity. The activated carbon media acts to absorb odors, unpleasant tastes, yellow discoloration, and chlorine substances (Sharma & Bhattacharya, 2017). The housing filter tube removes silica sand grains or carbon dust carried over, residual odors, colors, and remaining chlorine, ensuring they are absent, so the water is completely clear and odorless, and also acts as a protector for the Reverse Osmosis (RO) membrane.

Stage 2 in the water treatment involves an ultraviolet (UV) lamp tube aimed at killing or inactivating harmful microorganisms such as bacteria (E. coli, Salmonella), viruses, and parasites (Giardia, Cryptosporidium) (González *et al*., 2023; Minh Tran *et al*., 2022). Water from the UF process flowing through the UV lamp tube does not alter the taste, odor, or pH of the water, which is especially important for brackish water.

Stage 3, Reverse Osmosis (RO), is a highly effective technology used to treat drinking water with high salt content, making it suitable for processing brackish water. This type of filtration technology employs a filter membrane with pore sizes of 0.0001 microns. As a result of the filtration, only pure water can flow through, while particles such as salt and impurities are retained. The function of RO is to remove 95–99% of contaminants, eliminate odors and tastes caused by chlorine and other organic compounds, resulting in RO drinking water that possesses a fresher and more natural taste.

In this research, water sampling consisted of 4 water samples taken under different conditions, with each sample collected at a volume of 2 liters for physical and chemical testing. Water samples prepared for biological testing were placed in dark glass bottles. The first sample taken was raw water originating from the dug well. The second sample was taken after entering the FRP tube; the third sample was taken after passing through the FRP and UV tubes; and then the fourth sample was taken after passing through the FRP, UV, and RO tubes. Water quality testing was conducted at the BBTKLPP Laboratory (Center for Environmental Health Engineering and Disease Control) Banjarbaru based on drinking water standards from the Ministry of Health of the Republic of Indonesia Permenkes No. 2 of 2023.

3 RESULT AND DISCUSSION

The physical realization of the schematic diagram (Figure 2) and the installation results of the clean water to drinking water treatment system have been completely assembled (Figure 3). The installation results depict several stages of processing raw water into drinking water. The first stage involves rough cleaning and sterilization functioning as primary treatment (pre-treatment and ultrafiltration). The components consist of two large FRP tubes (filter media) containing silica sand, activated carbon, or

zeolite/manganese. Their function is to address the main problems of raw water (such as turbidity, odor, color, or high iron/manganese content). The series of blue filter housing components (cartridges) arranged in series serve to progressively filter fine particles (sediments) (potentially from sizes 5 to 1 micron).

The second stage involves flowing water through the ultraviolet (UV) sterilization component; in the upper long stainless steel tube lies the UV lamp. This ensures that bacteria and pathogens in the water are killed before the water is distributed or enters the RO stage. For the water to flow smoothly, a booster pump is necessary: it can be seen at the bottom to maintain stable water pressure through all the filters. The water exiting this system is physically clean (clear, odorless) and free of bacteria, suitable for clean sanitation needs or as RO feed water.

The third stage represents the final purification stage, utilizing a household-scale RO system. The RO tube components consist of an RO membrane functioning as the core filter separating pure water from dissolved contaminants (heavy metals, salts, lime) down to the molecular level. Other components include small white filters serving to improve the water's taste, making it fresh for drinking. The pressure tank component at the bottom functions to store the RO product water so the faucet can dispense water robustly when opened. The water exiting the small gooseneck faucet is pure drinking water (H_2O) ready for direct consumption without boiling.

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Figure 3

Assembled drinking water treatment equipment

The test results of processing brackish water into drinking water based on physical, chemical, and biological parameters with raw water samples from the coast of Pagatan Besar Village, South Kalimantan, Indonesia. Water that has passed through the FRP, UV, and RO tubes is shown in Table 1.

Table 1

Test results of water samples based on physical, chemical, and biological parameters

No.	Parameter	Unit	TEST RESULTS				Maximum Allowable Levels*
			Raw Water	FRP	UV	RO	
A	**Physical Test**						
1	Temperature	°C	24,0	24,0	24,0	24,0	Air Temperature ±3
2	TDS	mg/L	308	282	272	32	<300
3	Turbidity	NTU	<1,7	<1,7	<1,7	<1,7	<3
4	Colour	TCU	<5	<5	<5	<5	10
5	Odor	-	odorless	odorless	odorless	odorless	odorless
B	**Chemical Test**						
1	pH	-	8,12	7,90	7,85	7,55	6,5 – 8,5
2	Nitrate (NO_3-)	mg/L	11,83	27,88 0	20,11	0,90	20
3	Nitrite (NO_2-)	mg/L	0,0500	0,0138	<0,002	<0,002	3
4	Valentine Chromium (VI)	mg/L	<0,0017	<0,0017	<0,0017	<0,0017	0,01
5	Dissolved Iron (Fe)	mg/L	<0,138	<0,138	<0,138	<0,138	0,2

6	Dissolved Manganese (Mn)	mg/L	<0,046	<0,046	<0,046	<0,046	0,1
7	Residual Chlorine (Cl2)	mg/L	0,1	0	0	0	0,2 – 0,5
8	Dissolved Arsenic (As)	mg/L	<0,007	<0,007	<0,007	<0,007	0,01
9	Dissolved Cadmium (Cd)	mg/L	<0,001	<0,001	<0,001	<0,001	0,003
10	Dissolved Lead (Pb)	mg/L	<0,001	<0,001	<0,001	<0,001	0,01
11	Fluoride (F)	mg/L	1,40	1,03	0,36	0,31	1,5
12	Dissolved Aluminium (Al)	mg/L	<0,17	<0,17	<0,17	<0,17	0,2
C	**Biological Test**						
1	*Total Coliform*	CFU/100 mL	>200	4	0	0	0
2	*E. Coli*	CFU/100 mL	>200	0	0	0	0

The implementation of the brackish water to potable drinking water treatment system is designed integratively to meet environmental health quality standards in accordance with the Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023. The process stages begin with pre-treatment using filtration media in FRP tubes, functioning to effectively reduce physical particles and turbidity in the raw water. Furthermore, RO technology plays a crucial role as the main unit in filtering dissolved minerals and chemical pollutants down to the molecular level to significantly lower TDS levels. The disinfection process is then maximized through UV light exposure, which functions to completely eliminate dangerous microbiological contamination such as E. coli bacteria and total Coliform. The combination of these methods ensures the final output of drinking water production is hygienic, safe for consumption, and fully compliant with national food sanitation standards. Testing was conducted on four stages of samples: Raw Water, FRP filter output, UV sterilization output, and the final RO product. The purpose of the analysis is to ascertain the effectiveness of each treatment stage in reducing pollutant parameters until they meet safe drinking water quality standards.

Physical parameters indicate the aesthetic characteristics and comfort of water when consumed. TDS testing on raw water (308 mg/L) was slightly above the threshold set in the table (<300 mg/L), although taste-wise it might not be overly salty (mildly brackish category). The FRP and UV stages only slightly reduced TDS (to 272 mg/L), as this technology is not designed to separate dissolved salts. The RO stage demonstrated highly significant performance by drastically lowering TDS to 32 mg/L. This proves the RO membrane functions effectively in the desalination process, making the water

extremely clear and well below the maximum limit. Testing for turbidity, color, odor, and temperature parameters from raw water that already possessed good physical quality (turbidity <1.7 NTU and odorless). The treatment process maintained this quality up to the final stage, with all physical parameters in the RO tube meeting the requirements.

Chemical parameters focus on the content of dissolved substances that can endanger health if consumed long-term. The acidity parameter (pH) in raw water (8.12) was slightly alkaline. The RO process lowered the pH to 7.55. This reduction is reasonable because the RO membrane filters out pH-buffering mineral ions. The final value of 7.55 is within the ideal range (6.5 – 8.5). In Nitrate (NO_3-) testing, an anomaly occurred at the FRP stage where Nitrate spiked from 11.83 mg/L to 27.88 mg/L (exceeding the 20 mg/L limit). This was likely caused by the oxidation process of ammonia or organic matter accumulated inside the FRP filter media. However, the RO unit successfully drastically reduced Nitrate to 0.90 mg/L. Without the RO unit, the water would not meet requirements due to the high Nitrate content at the intermediate stage. The initial Fluoride content (1.40 mg/L) was almost approaching the threshold (1.5 mg/L). The RO unit effectively slashed the Fluoride level to 0.31 mg/L, providing a broader safety margin. Heavy metals (As, Cd, Pb, Cr, Fe, Mn, Al) across all heavy metal parameters in the raw water were already below the instrument's detection limit and below the quality standard.

Biological (microbiological) parameter analysis is the most critical parameter for acute safety (preventing diarrhea/gastrointestinal diseases). In the initial condition, the raw water was heavily polluted with total Coliform and E. Coli >200 CFU/100mL, making it dangerous if consumed directly. The FRP stage was able to eliminate E. Coli, but total Coliform was still detected (4 CFU). This indicated that physical filtration alone was insufficiently sterile; subsequently, the UV stage successfully killed the remaining bacteria, producing a count of 0 for Coliform and E. Coli. The RO unit acted as double protection, ensuring the final result remained at 0 CFU/100mL.

The performance of the water treatment unit started with the FRP tube effectively acting to clear initial physicals, but conversely raising nitrate levels (likely due to saturated filter media or biological processes occurring inside the tube), rendering the results at this stage unfit. The second stage through the UV tube was highly effective for bacterial sterilization but did not lower the high levels of TDS minerals and chemical

pollutants (nitrate). The final stage through the RO tube became the determinant for drinking water suitability because it could reduce TDS from brackish (308 mg/L) to pure fresh water (32 mg/L); discard the excess nitrate that bypassed the previous stage, and perfect the water's sterility.

The results of the physical parameter analysis on raw water samples on the coast of Pagatan Besar Village indicated a critical health risk, particularly related to high TDS levels and salinity caused by seawater intrusion phenomena. Consuming water with excessive salt content over the long term can trigger serious physiological functional disorders (Xeni *et al*., 2023), including an increased prevalence of high blood pressure (Wu *et al*., 2025; Xeni *et al*., 2023) and preeclampsia risk in pregnant women (Costopoulos *et al*., 2025), as well as placing an excessive workload on the kidneys (Luyckx *et al*., 2022). Furthermore, the high turbidity level in the water samples not only degraded aesthetic quality but also acted as a protective medium for pathogenic microorganisms (Shaikh *et al*., 2024), thereby increasing the potential for gastrointestinal irritation and decreasing the effectiveness of simple disinfection methods (Steadmon *et al*., 2023).

The interaction between coastal aquifers and local wetland characteristics indicated potential heavy metal contamination, specifically iron (Fe) and manganese (Mn), as well as pH instability (Gantayat & Elumalai, 2024). Chronic exposure to these chemical contaminants poses long-term, accumulative health threats (Niu *et al*., 2024); manganese content exceeding the threshold is neurotoxic, capable of hindering children's cognitive (Turck *et al*., 2023) and motor development (Dike *et al*., 2023), while extreme iron levels risk causing liver and pancreatic organ damage (Tian *et al*., 2023). This condition is exacerbated if the water pH tends to be saline, which can trigger corrosion in piping systems and dissolve other hazardous materials into drinking water, thereby creating systemic toxicity risks for the community (Farh *et al*., 2023).

The presence of bacteriological pollutant indicators in the raw water samples confirmed an acute threat in the form of water-borne diseases such as diarrhea, dysentery, and typhoid fever, which are leading causes of morbidity in vulnerable groups such as toddlers and the elderly. By combining all these parameters, it can be concluded that the raw water in Pagatan Besar Village is in the high-level health risk category and is unfit for direct consumption (without processing). This dictates the urgency of implementing

advanced water treatment technologies capable of molecular filtration and total disinfection to break the chain of disease transmission and guarantee public health safety sustainably.

4 CONCLUSIONS

Based on the laboratory test results referring to Permenkes No. 2 of 2023, the water sample at the final stage (RO product) is declared to meet the requirements (potable) physically, chemically, and biologically. The applied treatment system proved reliable in transforming raw water containing high bacteria and threshold TDS into safe, high-quality drinking water. Given the low TDS test values, the processed water is declared safe for the kidneys and does not contribute to hypertension risks, considering the salt content (salinity) has been successfully eliminated almost entirely. In chemical parameter testing, the processed water demonstrated excellent chemical stability for maintaining body acid-base balance and preventing gastric irritation. Concentrations of hazardous and carcinogenic heavy metals (such as arsenic, lead, cadmium, and hexavalent chromium) as well as organ-disrupting metals (such as iron, manganese, and aluminum) were at extremely low figures or below the instrument's detection threshold. This affirms that the long-term consumption of this water is safe from chronic toxicity risks, neurotoxic disorders, and liver function damage frequently threatening areas with poor groundwater quality. The combination of RO membrane filtration technology and UV sterilization proved capable of achieving absolute sterility levels, marked by 0 CFU/100 ml for Total Coliform and E. Coli parameters. This condition guarantees the water's safety from the risk of acute water-borne disease transmission such as diarrhea, dysentery, and typhus. However, it should be noted that the residual Chlorine value is 0 mg/L, which is normal for UV/RO systems.

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Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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