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Development and evaluation of solar PV powered brackish water desalination unit

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Abstract
The availability of fresh water has become a significant concern due to various factors, such as climate change, population growth, water contamination, and water usage policies. Two essential requirements for water treatment are the presence of brackish water and a reliable energy source, like solar energy. In India, there are approximately 3.9 million hectares of estuaries and 0.5 million hectares of mangrove areas that offer potential sources of brackish water. The Konkan region, known for its hilly terrain and abundant rainfall ranging from 2500 to 4000 mm annually, also benefits from 8-9 months of solar energy availability, with an average of 6.5 to 7.5 hours of sunshine per day from September to May. Three specific sites, namely Burondi, Harnai, and Tadil, were selected for brackish water collection and analysis. To differentiate between brackish water samples collected at different distances from the sea coast, labels such as Ws200, Ws300, and Ws400 were assigned. These labels corresponded to brackish water samples obtained at distances of 200 meters, 300 meters, and 400 meters from the sea coast, respectively. The analysis of brackish water samples included eight properties: pH, turbidity, TDS, total hardness, dissolved oxygen, chloride, calcium, and magnesium. Desalinated water samples were labelled as Ws200, Ws300, and Ws400 as per the corresponding distance of collection of brackish water samples. The output capacity for Ws200, Ws300, and Ws400 is 2.06 LPH, 2.40 LPH, and 2.82 LPH, respectively. For Ws200, Ws300, and Ws400, the energy consumption is 0.02717 kWh, 0.2760 kWh, and 0.2769 kWh, respectively. Ws200 has the highest specific energy consumption of 0.1319 kWh/lit., while Ws400 has the lowest of 0.0979 kWh/lit. Sample Ws400 has the highest overall desalination efficiency (14.33%), while sample Ws200 has the lowest (10.33%). Values obtained from the chemical analysis of the desalinated water, comply with the standards set by the Bureau of Indian Standards (BIS) and the World Health Organization (WHO) for drinking water. This suggests that the desalinated water meets the recommended guidelines for safe consumption.

Keywords: Brackish water, konkan, desalination, analysis, standards, safe

1. Introduction

The availability of fresh water has become a significant concern due to various factors. These include changes in climate patterns, population growth, contamination of existing water resources, and policies related to water usage. Additionally, the demand for fresh water has significantly increased due to rapid industrialization, global population growth, and unequal distribution of water resources. As a result, per-capita water usage in agricultural, industrial, and personal practices has increased. On Earth's surface, sea water accounts for 97.5% of water, while fresh water makes up only 2.5%. Out of this fresh water, approximately 70% is locked in icecaps, and 30% is found in underground aquifers. Only a small percentage of fresh water is available in rivers, reservoirs, and streams for human consumption and other uses. (Pandey P K, Upadhyay R., 2016) [16].

Unsafe and contaminated water consumption can lead to various diseases, sometimes resulting in death. In India, waterborne diseases impose a significant economic burden, estimated at around USD 600 million annually. To mitigate these issues, water treatment methods can be employed to ensure the safety of water and reduce the incidence of diarrheal and other waterborne diseases, especially in areas without a piped water system. Two crucial aspects for implementing water treatment are the presence of brackish water and a reliable source of energy, such as solar energy. The availability of brackish water needs to be assessed, and in India, there are approximately 3.9 million hectares of estuaries and 0.5 million hectares of mangrove areas. In Maharashtra state, the brackish water resources are limited to four coastal areas in the Konkan region, with a total area of 80,000 hectares of land.

The Konkan region experiences substantial rainfall, ranging from 2500 mm to 4500 mm. The Konkan region is known for its hilly terrain and receives a significant amount of rainfall, with an average annual rainfall ranging from 2500 to 4000 mm. The region also benefits from solar energy for a duration of 8-9 months, from September to May, with an average of 6.5 to 7.5 hours of sunshine per day. To ensure the availability of safe and clean drinking water by filtering and purifying brackish water, the operation of a solar-powered filtration system is necessary.

Small-scale solar-powered reverse osmosis desalination units can be highly beneficial for communities residing in remote and hard-to-reach areas. These units can provide safe freshwater for drinking and offer the following advantages:

1. Suitable for areas with saline water issues.
2. Ideal for areas without access to electricity.
3. Easy to operate and have minimal environmental impact.
4. Simple to maintain and repair. (Banat. *et.al*., 2012) [6].

2. Material and Methods

The present chapter consists of the stepwise methodology to accomplish the research work and is summarized under the following sub-heading.

1. Site selection, Sample collection and properties of brackish water
2. Development of solar PV powered brackish water desalination unit
3. Performance evaluation of developed unit
4. Properties of fresh water.

2.1 Site selection, sample collection and properties of brackish water

2.1.1 Site selection for samples of brackish water

Three sites selected for brackish water collection and further analysis *viz*; Burondi, Harne, Tadil where brackish water which is a combination of sea water and fresh water is available in the estuaries. The three sites *viz*; Burondi, Harnai, Tadil are located from Dapoli at distance of 16 km, 15.3 km, 7.1 km respectively.

2.1.2 Sample collection of brackish water

Brackish water samples were collected manually for the desalination study at each site. The samples from Burondi were labeled as B200 (200 m from the sea coast), B300 (300 m), and B400 (400 m). Similarly, samples from Harnai were labeled as H200, H300, and H400, and samples from Tadil were labeled as T200, T300, and T400, based on their respective distances from the sea coast.

2.1.3 Analysis of properties of brackish water sample

Nine brackish water samples (B200, B300, B400, H200, H300, H400, T200, T300, T400) were collected in 1-liter transparent bottles. The samples were placed in a protective box and sent to Garada Institute of Technology for analysis. To differentiate the brackish water obtained from different distances from the sea coast, the brackish water samples were represented as Ws200, Ws300, and Ws400. These labels corresponded to the brackish water obtained from brackish water samples collected at distances of 200 meters, 300 meters, and 400 meters from the sea coast, respectively. The analysis included eight properties: pH, turbidity, TDS, total hardness, dissolved oxygen, chloride, calcium, and magnesium. The analysis was conducted within 24 hours of sample collection

Table 1: Properties of brackish water sample and standard methods and instrument for determination

Sr. No.	Properties	Method / Instrument used
1.	pH	Electrical pH meter
2.	Turbidity	Turbiditimeter
3.	TDS	Gravimetric method
4.	Total hardness	EDTA titrimetric method
5.	Dissolved oxygen	Iodometric method
6.	Chloride	Argentometric method
7.	Calcium	EDTA titrimetric method
8.	Magnesium	Calculation method

(Manual of Methods of Analysis of Foods Water, Food Safety and Standards Authority of India Ministry of Health and Family Welfare, Government of India New Delhi, 2016)

3.2 Development of solar PV powered brackish water desalination unit

3.2.1 Components and their technical specifications

1. **Solar panels** Solar panels use photovoltaic (PV) cells to convert sunlight into electricity. This electricity powers a pump that forces water through filters in a media tank and also used by UV.
2. **Supporting frame:** Supporting frame provides space for attachment of different components of the desalination unit which are fixed or mounted on it.
3. **Electrical circuitary:** Electrical circuitary comprises of cables and switch. Cables from solar panels are connected to the pump motor and UV which provides pathway for produced electricity.
4. **Basin:** Basin provides temporary space for brackish water after pouring into it until the water passes through the pipe connected further to media tank.
5. **Pipe connections:** Pipes of varying length are provided for passing flow of water from basin, media filter tank, pre-carbon filter, sediment filter, RO membrane and lastly to fresh water collecting tank.
6. **Media Filters and RO Filter:** Media tank filled with sand, broken bricks and charcoal pieces. The sand used in the filters is hard and free from dust and clay. Broken bricks have high adsorption capacity. It also has high turbidity removal efficiency. Size of broken brick was 20-25 mm. Charcoal has good adsorption quality.
7. **Pump motor:** Pump motor is used to force the water from media tank to the sediment, pre-carbon filters and lastly through RO membrane.
8. **UV system:** UV system purify water by using ultraviolet rays to kill microorganisms present in the water.
9. **Fresh water tank:** Fresh water tank is used to store water filtered from various filters.

Table 2: Power of the appliances of solar PV powered desalianation unit

Sr. No.	Name of appliances	No. of appliances (A)	Power (W) (B)	Runtime (hr) (C)	Total power (A) × (B)	Units (Wh/day) (A) × (B) × (C)
1.	Pump	1	50.4	5	50.4	252
2.	UV system	1	24	5	24	120
					74.4	372

3.2.2 Solar panel sizing: Total daily load requirement = 372 Wh/day
Considering solar energy is available for 7 hours daily then,
Solar panel power
= Total load/daily sunshine hour

$$= \frac{372}{7}$$

= 53.14 W

Considering 30% loss in the system then,

$$= \frac{53.14 \times 30}{100}$$

= 15.94 W

Size of the panel was 53.14W+15.94W=69.08W
Two solar panels of 37W each available in department used.

Table 3: Technical specifications

Sr. No.	Components	Specifications
1.	Solar panel (Nos. 2)	P_{MAX} -37 WATT
		V_{OC} (Open circuit voltage) - 21.75 V
		I_{SC} (Short circuit current) - 2.12 A
		V_M (rated voltage) - 12V
		I_M (rated current) - 2 A
2.	Supporting frame	Material- - Mild Steel
		Length - 101 cm
		Breadth - 99.60 cm
		Height - 106 cm
3.	Filter pipe	Diameter - 0.25 inch
4.	Sediment filter	Maximum Flow - 1.00 GPM
		Maximum Pressure - 1.25 PSI
		Maximum Temperature - 100^0 F
		Service Life - 2500 GAL
5.	Pre-carbon filter	Maximum Flow - 1.00 GPM
		Maximum Pressure - 1.25 PSI
		Maximum Temperature - 1000 F
		Service Life - 2500 GAL
6.	RO membrane	Pore Size - 0.0001 micron.
7.	Pump motor	Volt - 24.00 VDC
		Ampere - 2.100 A
		Open Flow - 2.500 LPM
		Suction Height -2.500 M
		Throttle -1100 CC
8.	UV	UV rays wavelength – 254 nm wavelength
		Volt - 24.00 VDC

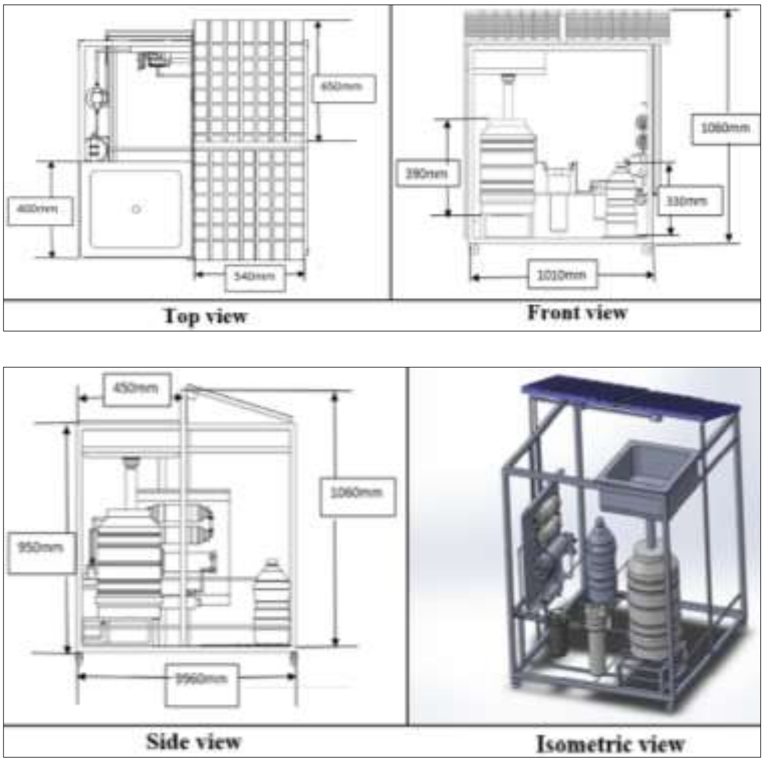

Fig 1: Schematic diagram of developed solar PV powered brackish water desalination unit

Fig 2: Developed solar PV powered brackish water desalination unit

3.3 Performance evaluation of developed solar PV powered brackish water desalination unit

1. **Input water, liter:** Solar PV powered brackish water desalination unit was provided with brackish water samples of 5 litre each like B200, B300, B400, H200, H300, H400, T200, T300, T400 as input water.
2. **Output water, litre:** Output water comprises of two parameters as following.
   - Desalinated water, litre
   - Waste water, litre
3. **Power produced by SPV, KW**

Power produced by SPV,

$$KW = \text{Current (I)} \times \text{Voltage (V)} \quad (1)$$

4. **Pump efficiency**

$$\text{Pump efficiency} = \frac{\text{Useful power output}}{\text{Total power input}} \times 100 \quad (2)$$

5. **Energy consumption, KWh**

Energy consumption,

$$KWh = \text{Power produced by SPV (KW)} \times \text{Time(hr)} \quad (3)$$

6. **Specific Energy Consumption (SEC), KWh/lit**

Specific Energy Consumption (SEC),

$$KWh/lit = \frac{\text{Energy consumption(KWh)}}{\text{Desalinated water (lit)}} \quad (4)$$

7. **Overall desalination efficiency, η_{de}:**

Overall desalination efficiency,

$$\eta_{de} = \frac{\text{Desalinated water (lit)}}{\text{Input water (lit)}} \times 100 \quad (5)$$

3.4. Properties of fresh water after desalination

The solar PV-powered brackish water desalination unit that was developed underwent testing using nine brackish water samples: B200, B300, B400, H200, H300, H400, T200, T300, and T400. Each sample had a volume of 5 liters. After the desalination process, the resulting desalinated water from each brackish water sample (B200, B300, B400, H200, H300, H400, T200, T300, and T400) was collected in bottles and securely placed in a protective thick box. These samples were then sent to Garada Institute of Technology, Lavel for further analysis to determine various properties such as pH, turbidity, total dissolved solids (TDS), total hardness, dissolved oxygen, chloride, calcium, and magnesium. To differentiate the desalinated water obtained from different distances from the sea coast, the desalinated water samples were represented as Ws200, Ws300, and Ws400. These labels corresponded to the desalinated water obtained from brackish water samples collected at distances of 200 meters, 300 meters, and 400 meters from the sea coast, respectively.

The analysis of the desalinated water samples for the aforementioned properties was conducted within 24 hours of collecting the desalinated water from the respective brackish water samples. This ensured that the properties of the desalinated water were determined promptly and accurately.

4. Results and Discussion

The results obtained in this study are presented and analysed under the following headings.

1. Determination of the properties of brackish water.
2. Performance evaluation of the desalination unit.
3. Analysis of the properties of desalinated water.

4.1 Determination of the properties of brackish water

Table 4: Properties of brackish water samples

Sr. No.	Properties	Ws200	Ws300	Ws400
1.	pH	6.89	6.81	6.78
2.	Turbidity(NTU)	Nil	Nil	Nil
3.	TDS (ppm)	69.33	51	40.66
4.	Dissolved Oxygen (ppm)	6	6	6
5.	Chloride (ppm)	40.06	34.26	26.53
6.	Calcium (ppm)	55.33	37.66	24.33
7.	Magnesium (ppm)	36	26.67	22.33
8.	Total hardness (ppm)	82.66	68.33	29.66

4.2 Performance evaluation of developed solar PV powered brackish water desalination unit

4.2.1 Output capacity

A solar PV powered brackish water desalination unit treated brackish water samples (Ws200, Ws300, and Ws400) in 0.25 hours. Each 5-liter sample underwent desalination, resulting in a combination of desalinated water and waste water. Figure 2 shows the variation in desalination output capacity for the samples. According to Table 5, the output capacity for Ws200, Ws300, and Ws400 is 2.06 LPH, 2.40 LPH, and 2.82 LPH, respectively. Ws400 had the highest output capacity (2.82 LPH), while Ws200 had the lowest (2.06 LPH), as shown in Table 5.

Table 5: Output capacity for brackish water samples

Sr. No.	Samples	Output capacity, LPH
1.	Ws200	2.06
2.	Ws300	2.40
3.	Ws400	2.82

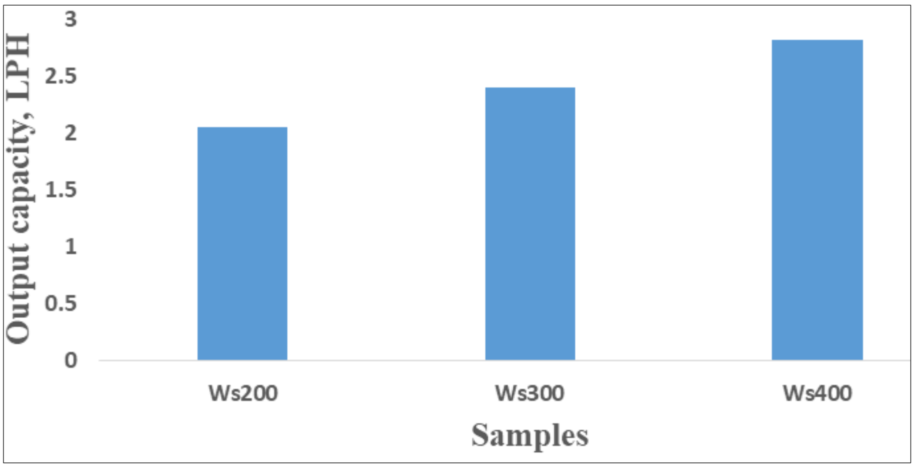

Fig 3: Variation of output capacity of brackish water samples

4.2.2 Energy consumption for desalination of brackish water

Energy consumption in brackish water desalination varies for different samples. For Ws200, Ws300, and Ws400, the energy consumption is 0.02717 kWh, 0.2760 kWh, and 0.2769 kWh, respectively (Table 6). Ws400 has the highest energy consumption (0.2769 kWh), while Ws200 has the lowest (0.02717 kWh). This difference is due to the greater quantity of desalinated water produced by Ws400. Figure 3 visually represents the variation in energy consumption for desalinating brackish water samples.

Table 6: Energy Consumption for desalination

Sr.no.	Samples	Energy consumption, kWh
1.	Ws200	0.2717
2.	Ws300	0.2760
3.	Ws400	0.2769

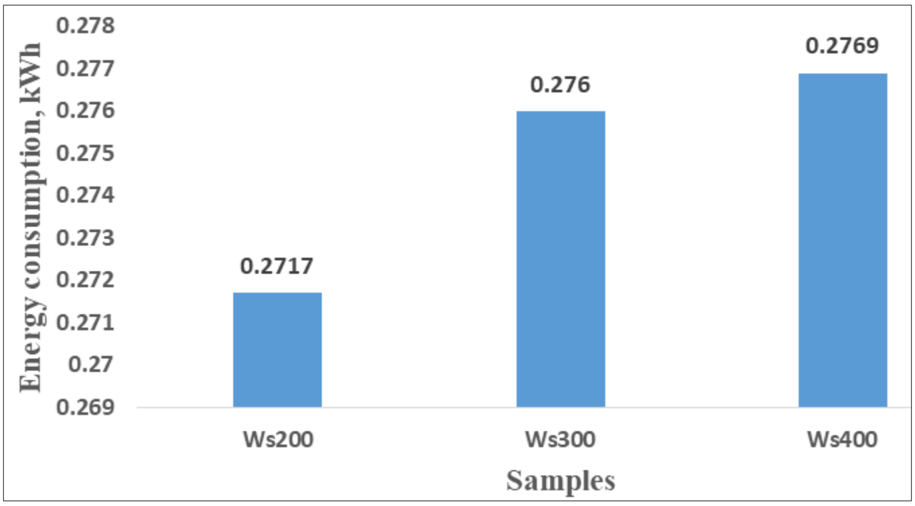

Fig 4: Variation of energy consumption for brackish water samples

4.2.3 Specific energy consumption (SEC) for desalination of brackish water.

Specific energy consumption varies among brackish water samples. Ws200 has the highest specific energy consumption (0.1319 kWh/lit.), while Ws400 has the lowest (0.0979 kWh/lit.) (Table 7, Figure 4). This difference can be attributed to the fact that lower quantities of desalinated water result in higher specific energy consumption.

Table 7: Specific energy consumption during performance evaluation

Sr. No.	Samples	Specific energy consumption, kWh/ lit.
1.	Ws200	0.1319
2.	Ws300	0.1150
3.	Ws400	0.0979

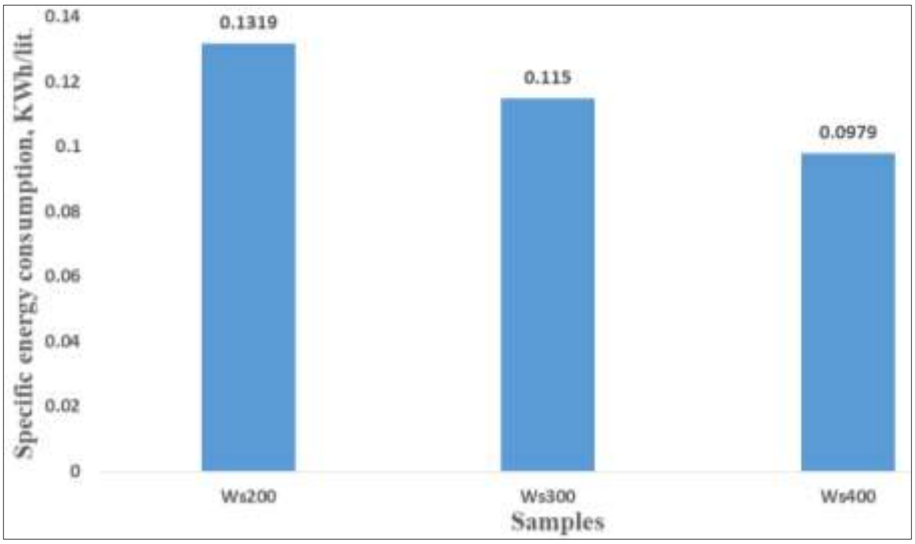

Fig 5: Variation of specific energy consumption values for brackish water samples.

4.2.4 Overall desalination efficiency

The overall desalination efficiency varies among brackish water samples. The range of efficiency, as shown in Table 8, is between 10.33% and 14.33%. Sample Ws400 has the highest overall desalination efficiency (14.33%), while sample Ws200 has the lowest (10.33%). This difference can be attributed to the lower mineral concentration in Ws400, which is collected further from the sea coast compared to Ws200. Figure 5 visually represents the variation in overall desalination efficiency for the different samples.

Table 8: Overall desalination efficiency of solar PV powered desalination unit.

Sr. no.	Samples	Overall desalination efficiency, %
1.	Ws200	10.33
2.	Ws300	12
3.	Ws400	14.13

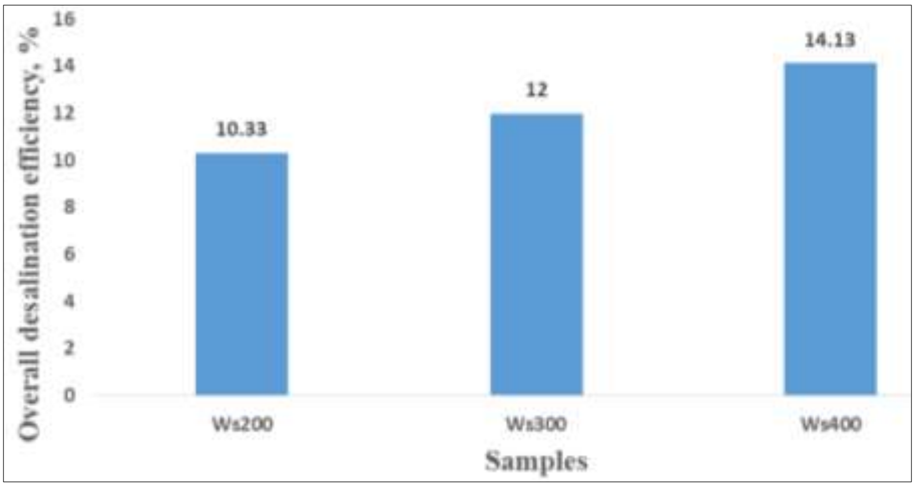

Fig 6: Variation of overall desalination efficiency values for brackish water samples

4.3 Chemical analysis of desalinated water

Chemical analysis of brackish water from desalinated water was carried out for determination of pH, turbidity, TDS, dissolved oxygen, chloride, calcium, magnesium, total hardness concentration. Results obtained are shown in Table 9.

Table 9: Chemical properties of desalinated water obtained from solar PV powered brackish water desalination unit

Sr. No.	Properties	BIS	WHO	Ws200	Ws300	Ws400
1.	pH	6.5-8.5	6.5-8.5	6.89	6.81	6.78
2.	Turbidity(NTU)	1-5	-	Nil	Nil	Nil
3.	TDS (ppm)	500-2000	500-1000	69.33	51	40.66
4.	Dissolved Oxygen (ppm)	6	-	6	6	6
5.	Chloride (ppm)	250-1000	200-300	40.06	34.26	26.53
6.	Calcium (ppm)	75-200	100-300	55.33	37.66	24.33
7.	Magnesium (ppm)	30-100	-	36	26.67	22.33
8.	Total hardness (ppm)	200-600	200-600	82.66	68.33	29.66

(Rawat R and Siddiqui A R, 2019) [17]

Table 10: Comparison of properties of brackish and desalination water

Sr. No.	Properties	Before desalination			After desalination		
		Ws200	Ws300	Ws400	Ws200	Ws300	Ws400
1.	pH	7.42	7..24	7.08	6.89	6.81	6.78
2.	Turbidity (NTU)	Nil	Nil	Nil	Nil	Nil	Nil
3.	TDS (ppm)	15883.33	15617	15463	69.33	51	40.66
4.	Dissolved Oxygen (ppm)	4.36	5.01	5.76	6	6	6
5.	Chloride (ppm)	189.28	144.7	75.36	40.06	34.26	26.53
6.	Calcium (ppm)	148.08	114.96	73.83	55.33	37.66	24.33
7.	Magnesium (ppm)	70.66	53	32	36	26.67	22.33
8.	Total hardness (ppm)	1053.33	849	741	82.66	68.33	29.66

Based on the chemical analysis results presented in Table 10, it is evident that the desalination process led to a reduction in various parameters, making the water suitable for drinking. The following observations can be made:

1. **pH:** Desalination lowered water pH, resulting in a more neutral or slightly acidic level, ideal for drinking.
2. **TDS:** Desalination significantly reduced TDS levels, ensuring safer and more palatable water.
3. **Dissolved Oxygen:** Desalination decreased dissolved oxygen levels, but they remain within acceptable limits for drinking water.
4. **Chloride:** Desalination reduced chloride concentration, improving water taste.
5. **Calcium and Magnesium:** Desalination decreased calcium and magnesium concentrations, reducing hardness and scaling.
6. **Total Hardness:** Desalination lowered total hardness, minimizing mineral-induced scale buildup.

Furthermore, the values obtained from the chemical analysis of the desalinated water, as shown in Table 9, comply with the standards set by the Bureau of Indian Standards (BIS) and the World Health Organization (WHO) for drinking water. This suggests that the desalinated water meets the recommended guidelines for safe consumption.

5. Conclusion

Desalinated water sample Ws400 having properties like pH, turbidity, TDS, dissolved oxygen, chloride, calcium, magnesium, total hardness and their values 6.78, Nil, 40.66 ppm, 6 ppm, 26.53 ppm, 24.33 ppm, 24.33 ppm, 29.66 ppm gives the highest output capacity.

The specific energy consumption values show that Ws400 has the lowest energy consumption per liter of water produced, indicating higher efficiency compared to Ws200 and Ws300. Ws400 gives minimum specific energy consumption of 0.0979 kWh/lit and maximum specific energy consumption is of 0.1319 kWh/lit for Ws200.

Ws400 with properties pH, Turbidity, TDS, dissolved oxygen, chloride, calcium, magnesium, total hardness and their values 6.78, 40.66 ppm, 6 ppm, 26.53 ppm, 24.33 ppm, 24.33 ppm, 29.66 ppm has the highest desalination performance and efficiency

Ws200 pH, Turbidity, TDS, dissolved oxygen, chloride, calcium, magnesium, total hardness with values 6.89, Nil, 69.33 ppm, 6 ppm, 40.06 ppm, 55.33 ppm, 36 ppm, 82.66 ppm has higher mineral content and hardness in the desalinated water as compared to Ws300 and Ws400.

Desalination process effectively improved the quality of the water by reducing various parameters, making it potable and meeting the standards for drinking water quality.

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