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Experimental studies on quality of desalinated water derived from single slope passive solar still

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ABSTRACT

The influences of climatic, operational, and design parameters on the performance of different solar stills configurations have been examined by many experimental and numerical studies to grasp the best design. The prime factors studied were solar radiation, glass cover tilt angle, latitude angle, depth of water level, and addition of dyes with the saline water. In this paper, an attempt has been made to study the correlations of physical and chemical properties of saline water used and desalinated water obtained from the single slope passive solar still. Water samples were tested in water testing laboratory available at Tamilnadu Water Supply and Drainage (TWAD) board, Chepauk, Chennai, India. The data obtained from the water samples analysis were correlated and the relationship between the various physical and chemical properties with Total Dissolved Solids was obtained. The correlation obtained could be used to predict the unknown water sample physical and chemical properties under the specified conditions. The study also finds that there is an improvement in the water quality obtained from the solar still.

Keywords: Physical and chemical examination; Correlations; Sea water; Desalinated water

1. Introduction

Potable water is an imperative for sustainability of mankind. Lack of hygienic water is the cause of serious illness. Tuberculosis, cholera, diarrhea, typhoid, and malaria are the main waterborne diseases, which kill over two million people every year, the immeasurable majority being children mostly in developing countries [1]. The straight use of sea water is not possible because it contains different types of salts. Distillation is a popular thermal process for purification of water and the most notable of them is water desalination. Most of the common water distillation processes has a ferocious thirst for fossil fuels and electric power. The solar energy can be utilized to turn out fresh water directly in a solar still (passive solar still). The thermal energy from a solar thermal system can be indirectly used in solar stills (active solar still). The methodologies used to improve the performance of the active and passive solar stills were retrospected by many researchers [2,3]. Through a theoretical investigation [4–6], a descriptive solar still model was built to assess the effect of an unpredictable event on the performance of the system. The exergy efficiency and

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exergy destruction calculations [7] are also useful for improving the efficiency of solar still by quantifying the types, locations, and magnitudes of losses in the system.

Even though several correlations were derived for solar still desalination system, such correlations only show the effect of parameters on the performance of the solar still (distillate output). The effect of solar radiation, dyes with saline water, glass cover tilt angle, and different saline water depths on the yield of the basin type solar still was studied and four performance correlations were derived by Khalifa and Hamood [8]. These correlations illustrate that the still productivity to be affected by the saline water depth and glass cover tilt angle by 33–63%, respectively. The study also found that still productivity will improve up to 20% by the addition of dark soluble dye to the saline water. In addition to a relation between the optimum cover tilt angle and the latitude angle, the trend of the relation between the cover tilt angle and productivity of simple solar still on different seasons was established by Abdul Jabbar N. Khalifa [9]. The study found that the optimum tilt angle at the latitude of 15˚N is around 19˚, and at 35˚N is about 32˚. Radwan et al. [10] investigated the relationship between the normalized temperature values of the different still components with local time, also the incident solar radiation and heat loss for different days in single slope solar still inclined at an angle of 20˚ to one direction (I-20˚) at Egypt. The R^2 value was found by constructing linear fitting lines and it varies from 0.38 to 0.89 for still components temperature difference with local time for dissimilar days. In the same way, the R^2 values vary between 0.46 and 0.68 for the incident solar radiation with heat loss for various days of experiment.

A performance study on solar still was carried out with different samples such as tap water, sea water, and dairy industry effluent using an optimized condensation technique by Vinoth Kumar and Kasturi Bai [11] at Madurai Kamaraj University campus (9˚54´´N, 78˚06´´E). The parameters such as pH, electrical conductivity, chloride, total hardness, and total dissolved solids (TDS) of desalinated water was identified and compared with water quality standards. The study revealed that the desalinated water quality is comparable with rainwater, mineral water, and Environmental Protection Agency (EPA) standards for potable water. Javad Abolfazli Esfahani et al. [12] experimentally studied the effect of thermoelectric cooling on the performance of potable active solar still at Semnan (35˚33´´N, 53˚23´´E), Iran. The pH and TDS of the inlet and distilled water were measured every day and the result confirmed that the obtained water to be used for drinking purpose. The pH values of 8, 7.8, and 8.15 in the saline water were reduced to 7.35, 7.2, and 7.25, respectively, in the distilled water. The TDS values of 635, 568, and 592 ppm in the saline water were reduced to 110, 131, and 128 ppm, respectively, in the distilled water.

An attempt was made by Velmurugan et al. [13] to generate potable water from industrial effluents at Madurai (9˚54´´N, 78˚06´´E). The impurities and bacteria present in the effluents were removed in the settling tank, which is fabricated with chambers that consists of different materials like pebbles, black rubber, and sand. The TDS level of 6,069 mg/L in the raw effluent is reduced to 110 mg/L in the distilled water. The biological oxygen demand (BOD) and chemical oxygen demand (COD) values were reported as zero mg/L in the distillated water, while these values were 258–554 mg/L in raw effluent, respectively. The sewage and industrial effluents treatment in the solar still was carried out by Rada Zarasvand Asadi et al. [14]. The experiment was performed by feeding low-strength sewage wastewater, high-strength sewage waste water, and palm oil mill effluent in to a solar still. The study revealed that the COD of the low-strength sanitary wastewater is reduced to 1.5 mg/L from 69.8 mg/L, whereas the COD of the high-strength sanitary wastewater is reduced to 44.6 mg/L from 342.9 mg/L. Ahsan et al. [15] developed low-cost triangular solar still for converting saline water into potable water using solar energy in rural and coastal areas of Malaysia. The effects of some design and operational parameters (e.g. solar radiation intensity, ambient air temperature, and the initial water depth) on the performance of the triangular solar still were investigated. Additionally, some important parameters (e.g. pH, redox, electrical conductivity, TDS, and salinity) were tested in the laboratory and compared with the World Health Organization (WHO) standards for drinking water to evaluate the water quality. The pH values were reduced to 7.7 and 7.29 (after experiment) from 8.7 to 8.18 (before experiment), respectively. The Electrical Conductivity (EC) values prior to the experiment were 43.4 and 39.1 μS/cm, which were reduced to 11.6 and 5.1 μS/cm, respectively, after experiment. The TDS and salinity values of desalinated water are less than the WHO limits (250 mg/L for both). The study found that only limited number of literatures is available with respect to the quality of saline water used and desalinated water obtained from the solar still. In this regard, the present study aims to find out the improvement in the quality of water obtained from the solar still as compared to saline water used and correlation between the different properties within saline water used and desalinated water obtained from the single slope passive solar still.

2. Materials and methods

A single slope passive solar still with basin area 1 × 0.5 m was constructed using stainless steel. Fig. 1 shows the photographic view of the solar still used in the present study. The basin surface was coated with black paint to absorb the maximum possible quantity of solar radiation incident on it. The condenser surface of the still was constructed with 5 mm thick glass cover and placed 13˚ inclination with horizontal (latitude of Chennai). Solar still was placed in east–west direction to receive maximum possible solar radiation. The entire basin still was mounted inside the wooden frame and an insulating material thermocol was placed between the still and wooden frame. A collecting trough made upon by stainless steel was provided in the inner surface of the glass cover to collect the condensate water. The whole system was made vapor tight, by sealing it with putty.

Experiments were conducted at Chennai (13˚5′2′′ N, 80˚16′12′′E), Tamil Nadu, India, from April 2015 to June 2015 during 9 am–5 pm (daylight hours). The experiments were conducted with different types of water samples. The water level was maintained at 1 cm for all the experiments. The saline water was poured inside the still one hour before the start of the experiment and the desalinated water was collected between 9 am and 5 pm with a one hour time interval. The solar radiation, ambient temperature, and wind velocity were measured in every one hour and these values for a typical day are given in Table 1.

Fig. 1. Pictorial view of the experimental setup.

Saline water and desalinated water were collected and stored in a clean two liter polythene container. Before collection and storage of samples, the containers were washed two times with the water to be stored. The water samples were filled completely in the container without leaving any air space. The outer cap was screwed after placing a ploythene sheet between the inner and outer caps. The containers were labeled with all required details. The different water samples used in the solar still were submitted to Tamilnadu Water Supply and Drainage (TWAD) board within 24 h from its collection for testing. The methods and instruments used for water quality analysis are listed in Table 2. The physical and chemical test report obtained for different water samples are listed in Table 3.

3. Data analysis

The R language has been used to predict the correlation between different physical and chemical properties of water sample. R is a programming language and software environment used in statistical computing and graphics. It is widely used among statisticians and data miners for developing statistical software and data analysis.

4. Results and discussion

4.1. Turbidity

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of

Table 1
Hourly variation of solar radiation, ambient temperature, and wind velocity data for one typical day of experiment

Sl. no.	Local time (h)	Solar radiation (W/m^2)	Ambient temperature (˚C)	Wind velocity (m/s)
1	9	337	31	0.3
2	10	735	32	0.5
3	11	965	33	0.9
4	12	1,090	35	1.5
5	13	1,045	37	1.1
6	14	903	36	1.5
7	15	636	35	2.1
8	16	365	33	2.3
9	17	185	33	1.9

Table 2
Methods and instruments used to find the physical and chemical properties of water samples

Sl. no.	Property	Methods and instruments used to find physical and chemical examination of water
1	Appearance	Visual method
2	Color	Visual comparison method
3	Odor	Qualitatively measurement
4	Turbidity NT units	Turbidity meter tube
5	Electrical conductivity micro Mho/Cm	Electrical conductivity meter
6	pH	pH meter
7	Total alkalinity as $CaCO_3$ mg/L	Two step titration
8	Total hardness as $CaCO_3$ mg/L	Titration with an EDTA solution
9	Calcium as Ca mg/L	Titration with an EDTA solution
10	Magnesium as Mg mg/L	By difference of total hardness as $CaCO_3$ and calcium hardness as $CaCO_3$
11	Sodium as Na mg/L	Dual channel flame photometer
12	Potassium as K mg/L	Dual channel flame photometer
13	Iron as Fe mg/L	Ammonium thiocyanate method
14	Free ammonia as NH_3 mg/L	Titration with $ZnSO_4$ solution, rochelle salt solution, nessler reagent
15	Nitrite as NO_2 mg/L	Titration with color reagent
16	Nitrate as NO_3 mg/L	UV–visible method
17	Chloride as Cl mg/L	Argentometric method
18	Fluoride as F mg/L	Alizarin method
19	Sulfate as SO_4 mg/L	SPADNS method
20	Phosphate as PO_4 mg/L	Titration with conc. H_2SO_4, conc. HNO_3, stannous chloride and molybdate reagent
21	Tidy's test–mg/L	4 h Permanganate test

suspended particulates. Turbidity decreases the passage of light passing through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, microbes, and other substances. A wide difference in the turbidity value of saline water and desalinated water are observed during sample testing. The minimum and maximum observed turbidity values of saline water are 1.2–4.6 NTU and for desalinated water the values are 0.1–0.5 NTU, respectively. The turbidity of desalinated water increases steeply whereas the turbidity of saline water takes a logarithmic curve with respect to increase in TDS. The turbidity of saline water follows the equation $y = 1.15 \ln(x) - 7.316$ and $R^2 = 0.974$, whereas that of desalinated water is $y = -0.003x + 0.832$ and $R^2 = 0.924$.

4.2. Electrical conductivity

Electrical conductivity is defined as the capacity of water to conduct electrical current, and is directly related to the concentration of different salts dissolved in the water. Salts present in the water are available in the form of cations and anions. Electrical conductivity of water is affected by the presence of inorganic dissolved solids in the form of anions (ions that carry negative charge) and in the form of cations (ions that carry positive charge). Anions are in the form of chloride, nitrate, sulfate, and phosphate. The sodium, magnesium, calcium, iron, and aluminum are available in the form of cations. The results obtained from the test samples shows that the variation of electrical conductivity in both the saline water and desalinated water are following the same trend with the variation of TDS. Both have a linear increase with mild variation in the path they follow as the TDS increases. In saline water samples, electrical conductivity value lies between 3,300 and 44,300 Micro mho/cm and for the desalinated water samples the value lies between 126 and 332 Micro mho/cm. The obtained equation for saline water is $y = 1.428x$ and $R^2 = 1$ and for desalinated water $y = 1.434x - 0.722$ and $R^2 = 1$. Fig. 2 shows the variation of turbidity and electrical conductivity of saline and desalinated water.

The variation of chemical properties of saline and desalinated water for some of the properties is shown in Fig. 3.

4.3. pH

Though pH indicates the water sample's acidity, it is actually a measurement of the potential activity of

Table 3
The physical and chemical properties of saline water and desalinated water samples

	BIS 10500:2012			Saline water					Desalinated water				
Sl. no.	I. Physical examination	Acceptable limit	Permissible limit in the absence of alternate source	Sample 1 (Bore well water)	Sample 2	Sample 3	Sample 4	Sample 5 (Sea water)	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
1	Appearance	–	–	Clear					Clear				
2	Color	5	15	Colorless					Colorless				
3	Odor	Agreeable		None					None				
4	Turbidity NT units	1	5	1.4	2.5	3.5	1.2	4.6	0.5	0.5	0.3	0.5	0.1
5	Total dissolved solids mg/L	500	2,000	2,310	4,655	9,492	26,880	31,010	116	88	176	131	232
6	Electrical conductivity micro mho/cm	–	–	3,300	6,650	13,560	38,400	44,300	165	126	252	187	332
	II. Chemical examination												
7	pH	6.5–8.5		7.11	7.32	7.42	7.6	7.82	6.86	7.15	8.03	6.87	6.63
8	Total alkalinity as $CaCO_3$ mg/L	200	600	284	240	272	220	220	34	38	42	44	54
9	Total hardness as $CaCO_3$ mg/L	200	600	1,200	1,440	2,700	7,800	8,600	47	45	60	53	77
10	Calcium as Ca mg/L	75	200	408	432	840	2,640	2,800	14	13	19	15	22
11	Magnesium as Mg mg/L	30	100	43	86	144	288	336	3	3	3	4	6
12	Sodium as Na mg/L	–	–	226	770	1,620	4,840	5,440	14	7	26	16	34
13	Potassium as K mg/L	–	–	16	40	60	110	130	1	0	2	2	4
14	Iron as Fe mg/L	0.3	0.3	0.3	0.3	0.33	0.31	0.66	0.09	0.11	0.12	0.07	0.1
15	Free ammonia as NH_3 mg/L	0.5	0.5	0.5	0.49	0.92	0.87	1.08	0.92	1.14	1.6	0.35	0.15
16	Nitrite as NO_2 mg/L	–	–	0.77	0.6	0.84	0.35	0.1	0.11	0.12	0.07	0	0.45
17	Nitrate as NO_3 mg/L	45	45	10	7	7	9	6	4	4	4	5	9
18	Chloride as Cl mg/L	250	1,000	810	2,050	4,350	12,200	13,800	28	12	50	28	63
19	Fluoride as F mg/L	1	1.5	0.82	0.84	0.92	0.44	0.38	0.14	0.11	0.16	0.14	0.14
20	Sulfate as SO_4 mg/L	200	400	74	98	87	416	462	3	2	4	3	4
21	Phosphate as PO_4 mg/L	–	–	0.04	0.02	0.04	0.05	0.16	0.04	0.03	0.03	0.03	0.06
22	Tidy's test–mg/L	–	–	1.1	1.2	1.3	1.8	3.8	0.6	0.5	0.7	0.4	0.8

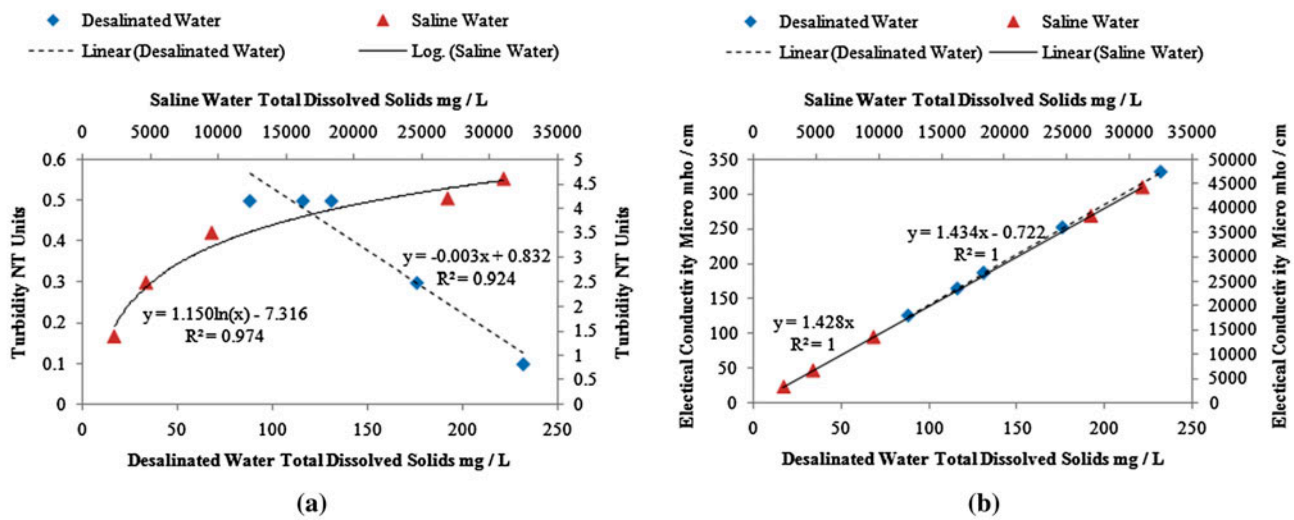

Fig. 2. Variation of physical properties of saline water and Desalinated water: (a) turbidity NT units and (b) electrical conductivity micro mho/cm.

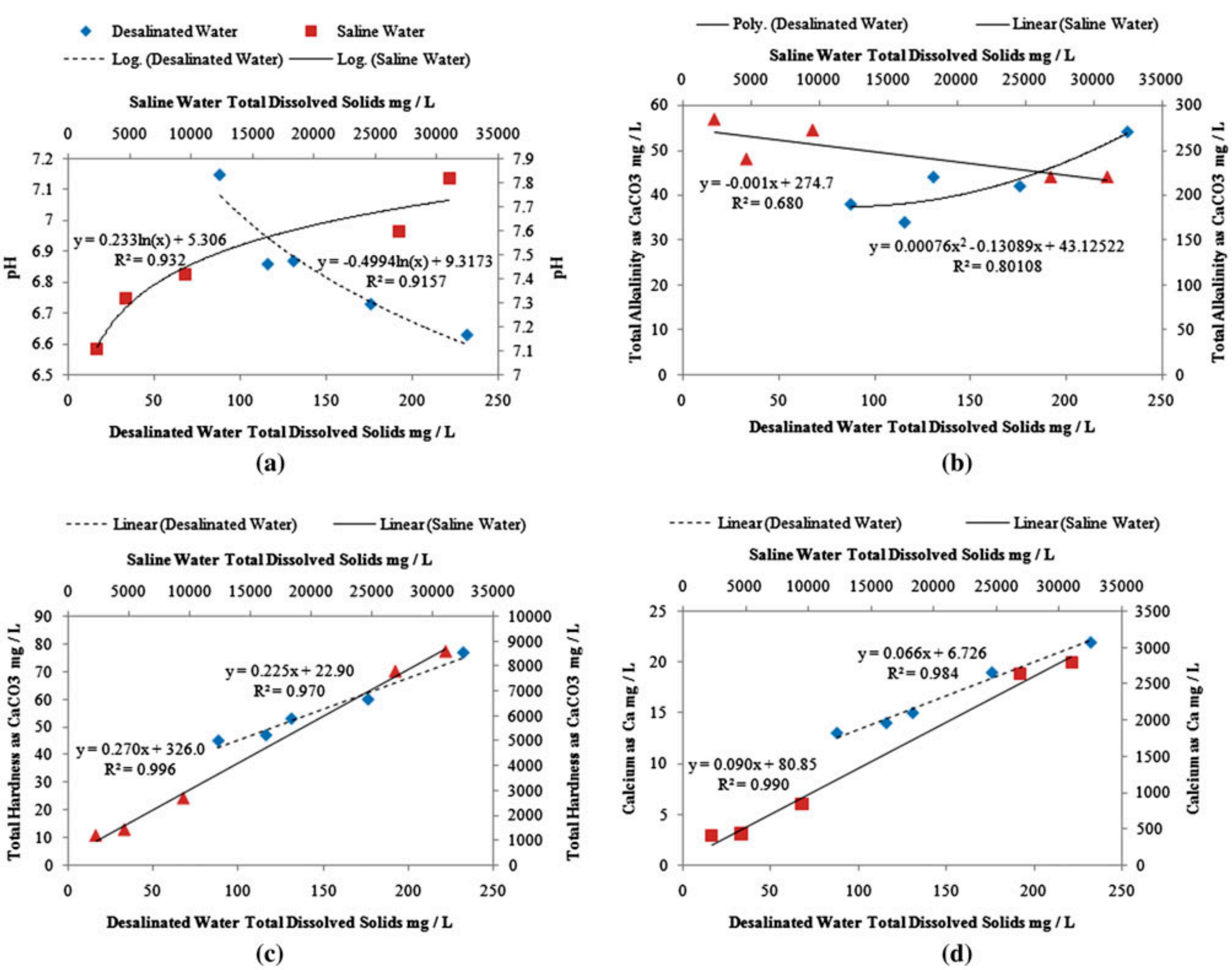

Fig. 3. Variation of chemical properties of saline water and Desalinated water: (a) pH, (b) total alkalinity as $CaCO_3$, (c) total hardness as $CaCO_3$ mg/L, and (d) Calcium as Ca mg/L.

hydrogen ions (H^+) in the sample. The pH values vary between 0 and 14. A sample with pH value of 7.0 indicates that the sample is neutral and pH value below 7.0 indicates it is acid. Sample with a pH value above 7.0 and less than 14.0 are considered bases. The pH value in the saline water samples varied between 7.11 and 7.82. In desalinated water sample pH values observed between 6.63 and 7.15. The pH of saline water and desalinated water increases logarithmically with an increase of TDS value. The study found that the variation of pH values with respect to TDS follows the equation of $y = 0.233 \ln(x) + 5.306$ for saline water and $y = -0.4994 \ln(x) + 9.317$ for desalinated water. The R^2 values of saline water and desalinated water are 0.932 and 0.9157, respectively.

4.4. Alkalinity

Alkalinity is a measure of the capacity of water to neutralize acids. Alkaline compounds in the water such as bicarbonates, carbonates, and hydroxides remove H^+ ions present in the water and lower the acidity nature of the water. The minimum and maximum alkalinity values in the saline water are observed as 220–284 mg/L and for desalinated water the values are 34–54 mg/L. The variation of alkalinity with respect to TDS follows different trends for saline water and desalinated water. The study found that the saline water follows linear variation and desalinated water varies quadratically. The linear and quadratic equation obtained from saline water and desalinated water are $y = -0.001x + 274.7$ and $R^2 = 0.68$, $y = 0.0008x^2 - 0.1309x + 43.13$ and $R^2 = 0.801$, respectively.

4.5. Total hardness

Total hardness is defined as the sum of calcium and magnesium hardness. It is normally represented as $CaCO_3$ and measured in mg of $CaCO_3$ in one liter of water. Total hardness in freshwater is usually in the range of 15–375 mg/L. The study found that in saline water samples, total hardness value lies between 1,200 and 8,600 mg/L and for the desalinated water samples total hardness value lies between 44 and 77 mg/L. The obtained equation for saline water $y = 0.27x + 326$ and $R^2 = 0.996$, for desalinated water $y = 0.225x + 22.90$ and $R^2 = 0.970$.

4.6. Calcium hardness

Calcium hardness in freshwater is in the range of 10–250 mg/L. Calcium hardness values in the saline water samples vary between 408 and 2,800 and for the desalinated water sample the values vary between 13 and 22. The study found that the variation of calcium hardness values with respect to TDS follows the equation of $y = 0.09x + 80.85$ for saline water and $y = 0.066x + 6.726$ for desalinated water. The R^2 values of saline water and desalinated water are 0.990 and 0.9884, respectively.

4.7. Magnesium hardness

Magnesium hardness in freshwater is in the range of 5–125 mg/L. The minimum and maximum magnesium hardness values observed in the saline water is between 43 and 336 mg/L and for desalinated water it varies between 3 and 6 mg/L. The result shows that the saline water follows logarithmic variation and desalinated water varies quadratically. The logarithmic and quadratic equation obtained from saline water and desalinated water are $y = 111.8 \ln(x) + 846.8$ and $R^2 = 0.961$, $y = 0.0002x^2 - 0.0375x + 4.8595$ and $R^2 = 0.9979$, respectively.

4.8. Sodium

Sodium and Potassium in the water maintain the normal osmotic pressure in cells. The recommended sodium levels in the drinking water are typically less than 20 mg/L. The presence of higher quantity of sodium (above about 200 mg/L) spoils the taste of drinking water. In saline water samples, change in sodium value was observed between 226 and 5,440 mg/L and for the desalinated water samples the change was observed between 7 and 34 mg/L. The sodium content of saline water increases exponentially whereas that of desalinated water increases gradually with respect to increase in TDS. The equations area as follows, for saline water $y = 0.181x - 124.7$ and $R^2 = 0.999$, desalinated water $y = 28.22 \ln x - 120.1$, $R^2 = 0.993$.

4.9. Potassium

The presence of low Potassium in the drinking water leads to health hazards like individuals with kidney dysfunction or other diseases such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia. The adequate intake for adults (19–70 years of age) is 4.7 g/d. The results obtained from the test samples shows that the variation of potassium in both the saline water and desalinated water are following the same linear trend with the variation of TDS. The obtained equation for saline water $y = 0.003x + 18.04$

and $R^2 = 0.976$, for desalinated water $y = 0.025x - 1.936$ and $R^2 = 0.916$. Potassium values in the saline water samples vary between 40 and 130 and for the desalinated water sample potassium values between 0 and 4.

4.10. Iron

Iron is a vital element for human nutrition. Minimum daily requirement depends on the age, sex, physiological status, and iron bio availability. The recommended level of iron in the drinking water is between 10 and 50 mg/d. The study found that both the saline water and desalinated water iron content varies exponentially with the increase of TDS. The obtained equation for saline water is $y = 0.27524 \times e^{0.00002x}$ and $R^2 = 0.49256$, for desalinated water the equation is $y = 0.0869 \times e^{0.0007x}$ and $R^2 = 0.036$. In saline water samples the presence of iron content varied between 0.3 and 0.33 mg/L and for the desalinated water samples the iron content was between 0.07 and 0.12 mg/L.

4.11. Free ammonia

The level of ammonia (NH_3) in groundwater is usually less than 0.2 mg/L. Surface water may contain up to 12 mg/L. The minimum and maximum ammonia content in saline water are 0.49–1.08 mg/L and for desalinated water the values are 0.15–1.6 mg/L, respectively. The ammonia value in saline water and desalinated water subjected to power fit with an increase of TDS value. The study found that the variation of ammonia values with respect to TDS follows the equation of $y = 0.049x^{0.293}$ for saline water and $y = 818.3x^{-1.45}$ for desalinated water. The R^2 values of saline water and desalinated water are 0.796 and 0.316, respectively.

4.12. Nitrite

Nitrite levels in drinking-water are usually below 0.1 mg/L. The result shows that the variation of nitride with TDS in saline water follows linear variation and in desalinated water varies quadratically. The linear and quadratic equation obtained from the study for saline water and desalinated water are $y = -0.00002x + 0.841$ and $R^2 = 0.803$, $y = 0.00005x^2 - 0.013x + 9.48$ and $R^2 = 0.953$, respectively. In saline water samples, nitrite value varied between 0.1 and 0.84 mg/L and for the desalinated water samples the values were between 0 and 0.12 mg/L.

4.13. Nitrate

Nitrate concentration in surface water is normally low (0–18 mg/L). The study found that the nitrate values in the saline water samples varies between 6 and 10 mg/L and for the desalinated water sample varies between 4 and 9 mg/L. Nitrate content of saline water subjected to power fit and desalinated water follows

Table 4
Regression equations obtained for the variation of different properties with TDS value of saline water and desalinated water

Sl. no.	Property	Saline water	Desalinated water
1	Turbidity NT units	$1.15 \ln(x) - 7.316$	$-0.003x + 0.832$
2	Electrical conductivity micro mho/cm	$1.428x$	$1.434x - 0.722$
3	pH	$0.233 \times \ln(x) + 5.306$	$-0.4994 \times \ln(x) + 9.317$
4	Total alkalinity as $CaCO_3$ mg/L	$-0.001x + 274.7$	$0.0008x^2 - 0.1309x + 43.135$
5	Total hardness as $CaCO_3$ mg/L	$0.27x + 326$	$0.225x + 22.9$
6	Calcium as Ca mg/L	$0.09x + 80.85$	$0.066x + 6.726$
7	Magnesium as Mg mg/L	$111.8 \times \ln(x) - 846.8$	$0.0002x^2 - 0.0375x + 4.8595$
8	Sodium as Na mg/L	$0.181x - 124.7$	$28.22 \times \ln(x) - 120.1$
9	Potassium as K mg/L	$0.003x + 18.04$	$0.025x - 1.936$
10	Iron as Fe mg/L	$0.27524 \times e^{0.00002x}$	$0.0869 \times e^{0.0007x}$
11	Free ammonia as NH_3 mg/L	$0.049x^{0.293}$	$818.3x^{-1.45}$
12	Nitrite as NO_2 mg/L	$-0.00002x + 0.841$	$0.00005x^2 - 0.013x + 9.48$
13	Nitrate as NO_3 mg/L	$17.03x^{-0.08}$	$0.0004x^2 - 0.103x + 10.28$
14	Chloride as Cl mg/L	$0.452x - 84.96$	$-0.001x^2 + 0.679x - 39.87$
15	Fluoride as F mg/L	$-0.00002x + 0.945$	$-0.000006x^2 + 0.002x - 0.029$
16	Sulfate as SO_4 mg/L	$0.014x + 12.5$	$-0.0001x^2 - 0.0581x - 2.0361$
17	Phosphate as PO_4 mg/L	$0.024 \times e^{0.00005x}$	$0.000003x^2 - 0.0007x + 0.075$
18	Tidy's test–mg/L	$0.977 \times e^{0.00003x}$	$0.00001x^2 - 0.001x + 0.545$

Table 5
The difference of water properties obtained from experiment and R language

Sl. no.	I. Physical examination	Acceptable limit	Permissible limit in the absence of alternate source	Sample 2 (Saline water) experimental values	Sample 2 (Saline water) *R* language	Difference in percentage	Sample 5 (Sea water) experimental values	Sample 5 (Sea water) R language	Difference in percentage	Sample 7 (Desalinated water) experimental values	Sample 7 (Desalinated water) R language	Difference in percentage
1	Turbidity NT Units	1	5	2.5	2.4	4	4.6	4.58	0.43	0.5	0.57	14
2	Electrical conductivity micro mho/cm	–	–	6,650	6,647.3	0.04	44,300	44,282	0.04	126	125.5	0.4
	II. Chemical examination											
3	pH	6.5–8.5	7.32	7.27	0.68	7.82	7.72	1.28	7.15	7.08	0.98	
4	Total alkalinity as $CaCO_3$ mg/L	200	600	240	270	12.5	220	243.7	10.8	38	37.8	0.53
5	Total hardness as $CaCO_3$ mg/L	200	600	1,440	1,582.8	9.9	8,600	8,698.7	1.14	45	42.7	5.11
6	Calcium as Ca mg/L	75	200	432	499.8	15.7	2,800	2,871.8	2.56	13	12.5	3.8
7	Magnesium as Mg mg/L	30	100	86	97.42	13.3	336	309.4	8.60	3	3.11	3.67
8	Sodium as Na mg/L	–	–	770	717.86	6.77	5,440	5,488.1	0.88	7	6.25	10.7
9	Potassium as K mg/L	–	–	40	32	20	130	111.1	14.5	0	0.26	26
10	Iron as Fe mg/L	0.3	0.3	0.3	0.302	0.7	0.66	0.51	22.7	0.11	0.09	18.2
11	Free ammonia as NH_3 mg/L	0.5	0.5	0.49	0.582	18.8	1.08	1.01	6.48	1.14	1.24	8.77
12	Nitrite as NO_2 mg/L	–	–	0.6	0.748	24.7	0.1	0.12	20	0.12	0.19	58.3
13	Nitrate as NO_3 mg/L	45	45	7	8.67	23.9	6	7.44	24	4	4.31	7.7
14	Chloride as Cl mg/L	250	1,000	2,050	2,019.1	1.5	13,800	13,931	0.95	12	12.14	1.17
15	Fluoride as F mg/L	1	1.5	0.84	0.85	1.2	0.38	0.32	15.8	0.11	0.1	9.1
16	Sulfate as SO_4 mg/L	200	400	98	77.67	20.7	462	446.64	3.4	2	2.3	15
17	Phosphate as PO_4 mg/L	–	–	0.02	0.03	50	0.16	0.11	31.3	0.03	0.04	33.3
18	Tidy's test–mg/L	–	–	1.2	1.12	6.67	3.8	2.47	35	0.5	0.53	6

quadratically with increase in TDS. The equations area as follows, for saline water $y = 17.03x^{-0.08}$ and $R^2 = 0.218$, desalinated water $y = 0.0004x^2 - 0.103x + 10.28$, $R^2 = 0.8684$.

4.14. Chloride

Chloride concentration raises the electrical conductivity of water and therefore increases its corrosiveness. The minimum and maximum chloride values observed in saline water are 810–13,800 mg/L and for desalinated water are 12–63 mg/L. The result shows that the variation of chloride values with respect to TDS follows the equation of $y = 0.452x - 84.96$ for saline water and $y = -0.001x^2 + 0.679x - 39.87$ for desalinated water. The R^2 values of saline water and desalinated water are 0.999 and 0.985, respectively.

4.15. Fluoride

Trace amounts of fluorides are present in many waters; higher concentrations are often associated with underground sources. In seawater, the total fluoride concentration of 1.3 mg/L has been reported. In saline water samples, fluoride value varied between 0.44 and 0.92 mg/L and for the desalinated water samples the values varied between 0.11 and 0.16 mg/L. The study found that the saline water follows linear variation and desalinated water follows quadratically with the increase of TDS. The linear and quadratic equation obtained from saline water and desalinated water are $y = -0.00002x + 0.945$ and $R^2 = 0.883$, $y = -0.000006x^2 + 0.002x - 0.029$ and $R^2 = 0.960$, respectively.

4.16. Sulfate

The Sulfate values in the saline water samples varied between 74 and 462 mg/L and for the desalinated water sample the values were between 2 and 4 mg/L. The result shows that the variation of sulfate values with respect to TDS follows the equation of $y = 0.014x + 12.5$ for saline water and $y = -0.0001x^2 - 0.0581x - 2.0361$ for desalinated water. The R^2 values of saline water and desalinated water are 0.964–0.9736, respectively.

4.17. Phosphate

The maximum level of phosphorus in reservoirs used for drinking water is no higher than 0.025 mg/L. Phosphates are not toxic to living beings unless at very high levels. High levels of phosphate can cause digestive problems. The minimum and maximum phosphate values of saline water are 0.02–0.16 mg/L and for desalinated water 0.03–0.06 mg/L were observed in the water samples test. Phosphate content of desalinated water increases exponentially whereas the phosphate of saline water takes a quadratic curve with respect to increase in TDS. Phosphate content of saline water follows the equation $y = 0.024 \times e^{0.00005x}$ and $R^2 = 0.649$, whereas that of desalinated water is $y = 0.000003x^2 - 0.0007x + 0.075$ and $R^2 = 0.781$.

4.18. Tidy's Test

Tidy's test is used to find out the amount of oxygen required to oxidize the organic matter present in the water samples. When water is mixed with potassium permanganate in acid solution, a certain amount of oxygen is taken from the potassium permanganate by oxidizable matter in the sample. Very pure water absorbs little oxygen whereas water polluted with animal and vegetable organic matter absorbs considerable quantities of oxygen. The Tidy's value varies between 1.1 and 3.8 mg/L for saline water samples and for the desalinated water samples the value varies between 0.4 and 0.8 mg/L. The study found that the variation of Tidy's value with respect to TDS follows the equation of $y = 0.977 \times e^{0.00003x}$ for saline water and $y = 0.00001x^2 - 0.001x + 0.545$ for desalinated water. The R^2 values of saline water and desalinated water are 0.816 and 0.692, respectively.

The correlations between different properties obtained from the study are listed in Table 4. The percentage variation between the experimental readings and value predicted by the R language for few water samples are listed out in Table 5.

5. Conclusions

The solar desalination process was carried out in a single slope passive solar still to find out the improvement of the physical and chemical properties of the desalinated water obtained from the solar still. The relationship between the various properties with TDS value in the saline water and desalinated water are also predicted using R language. The findings from the sample studies in the present study are:

(1) There is an appreciable improvement in all physical and chemical properties of the desalinated water samples obtained from the solar still compared to saline water used in the present study.

(2) Most of the physical and chemical properties of the desalinated water samples obtained in the present study are within the standard limits even though the values are higher than the standard values in the saline water.
(3) The relationship between different properties with TDS value of the water samples follows logarithmic, linear, exponential, quadratic, and power fit equations.
(4) The minimum and maximum R^2 values (0.036–0.9979) are found from the desalinated water properties such as Fe and Mg.
(5) The correlations obtained to be used to predict the unknown water samples properties under the specified TDS.

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