https://doi.org/10.22581/muet1982.2203.03

2022, 41(3) 23-31

Development of cost-effective solar water desalination unit for the arid regions of rural areas of Sindh

Riaz Ahmed Soomro *, Maryam Arain, Azizullah Channa, Kundan Kumar, Abdul Aziz Chana

Institute of Environmental Engineering and Management, Mehran University of Engineering and Technology, Jamshoro Sindh Pakistan

* Corresponding author: Riaz Ahmed Soomro, Email: riazahmedsoomro90@gmail.com

Received: 01 March 2019, Accepted: 25 February 2022, Published: 01 July 2022

KEYWORDS

Cost Effective

Electrical Conductivity

Solar Desalination

Total Dissolved Solids

Sindh

ABSTRACT

In this study we have designed and fabricated a household solar water desalination unit for the arid regions of rural areas of Sindh like Tharparkar district. Drought conditions, shortage of drinking water and relying on saline water in arid regions of Sindh is a serious problem. In areas under these tracts, it is difficult to obtain drinkable water. This study focuses on the development of a cost effective and affordable desalination unit having simple construction, easy to use, repair, maintain and can be operated by an unskilled man. The solar desalination unit comprises of a solar oven, condenser, and collector pot. In this research various water samples were collected from three arid regions of Tharparkar district i.e., Islamkot, Diplo and Mithi. The performance of solar water desalination unit was assessed by analysing the Total Dissolve Solids (TDS), pH and Electrical Conductivity (EC) of all samples. The sample collected, before treatment had maximum TDS, conductivity, and pH values as 10421 mg/L, 20842 μS/cm and 8 respectively. Those sample after treatment reduced to TDS of 230 mg/L, conductivity of 460 μS/cm and pH of 7.4. This portable solar desalination unit showed remarkable results and found as effective in the removal of TDS from all water samples. The efficiency of unit was calculated as 35.2% with maximum daily output of 5 litres. This unit was constructed at very low cost of PAKPKR 4500/- and its complete rely on solar energy which makes it quite affordable for those which cannot afford expensive treatment techniques. This unit has very minimal maintenance cost and does not require electricity. The values for pH, TDS, and EC achieved from this unit are satisfying the World Health Organization (WHO) guidelines for drinking water quality.

1. Introduction

Huge population of our planet suffering from the shortage of water, 40% population of arid and semi-arid countries have periodic droughts [1]. In arid countries some of the highest growth rate are found, a lot of the population facing the sever water scarcity. Pakistan is facing water shortages and drought conditions in most areas increases day by day [2]. In Pakistan data on groundwater show increase in salinity from north to south. Sindh region has been suffering from water

© Mehran University of Engineering and Technology 2022

scarcity since long time. In Pakistan among the provinces the unequal distribution of water has always been cause of conflict. From the water scarcity point of view Sindh has the largest desert of the world (Tharparkar) [3]. Tharparkar desert is a place where the water shortage is naturally occurring. The significance of water in the lives and identities of people of Tharparkar is strongly associated with their cultural and regional practices and environment [4]. In Tharparkar the cultural and religious practices are directly reflect the importance of local ecosystem [5]. Instead of importance of water the cultural and religious life get more affected in the Tharparkar desert which is largely unexplored problem in the Tharparkar people. Culture and human society have strong relationship with water, it is important to find out the best way to deal with the situation and water scarcity effect on the social lives of people [6]. Health issues present in the Tharparkar includes early deliveries, diarrhoea, and weight loss during birth and pneumonia. The people have travel long to avail the facilities because of mobility issues is one of the major challenges faced by the communities [7]. In different societies lifestyle components relation with the water insecurity was conducted by the many researchers [8-9]. Large part of the Punjab and most of the Sindh of Pakistan have the brackish to saline ground water. Indus basin is rift valley which is converted into a flat plain. In most part of the Indus plain has led to brackish groundwater frequent instruction by alleviation and sea [10]. From North to south the data showed a gradual increase in salinity in ground water of Pakistan. Sindh province has large areas which is affected by the salinity 85% mainly the rural areas than the Khyber-Pakhtunkhwa province which is 0.1% [11]. Baluchistan province suffering from the shortage of water but free from the salinity. Now a day's various difficult problems are faced by arid lands than ever before. Mostly the arid areas facing the falling water table and increasing issue of the salinity [12].

Until and unless arid region has great intensity of solar radiations. The intensity of solar radiation can generate the concept of the solar water treatment techniques and can be adopted in the arid regions with fresh water [13-14]. In Pakistan on horizontal surface the mean solar insolation falling is about 200-250 watt per sq. meters with 1500-3000 sunshine hours in a year [15]. Solar water desalination has high installation cost and required large area to install and have low operating and maintenance cost. Most of the plant are installed which has the different methods, materials, and variations in the geometry as well as operation and construction method [16-17]. Advance technologies such as Solar-assisted desalination which treat the water from medium to large scale. It has wide application from the past few years and increase in the future as per demands [18]. Solar desalination technologies require a low capital cost, easy to operate and easy to manage and can be operate by the unskilled and local people and easy to maintain also construct locally such as in Pakistan [19].

In Islamkot, Mithi and Diplo cities of Tharparkar district EC values ranges from 2000-5000 µS/cm particularly in the aquifer [20]. According to Sindh Water Commission 778 Reverse Osmosis (RO) plants has been installed by Sindh Government to provide drinkable water for the citizen of Tharparkar and other cities of Sindh. Out of 778 RO Plants 156 are non-functional, 412 RO plants are functional, 92 under construction. Sindh Government got notification for the issues related to the RO plants installed in the Tharparkar and other cities which were facing the scarcity of water. They have installed the RO plants and considered the cost of operation and maintenance. According to commission report RO plants in Tharparkar, Umerkot, Thatta district found many challenges. Commission highlighted that RO plants did not treat the water which were fit for the drinking purpose and there is no facility of laboratory of water testing through which the water quality analysis has been conducted to assess the quality of water [21].

Fig. 1. Solar Water Desalination Equipment

The rural community of arid regions faces so many problems related to the saline water. To overcome those problem, we have designed a portable, cost effective and solar water desalination unit. The aim of this study was to design and assess the performance of portable low-cost solar water desalination unit. And to evaluate its efficiency for the removal of TDS, pH and EC from the water samples taken from various regions of Tharparkar district containing high ranges of these contaminants.

2. Materials and Methodology

2.1 Designing of Solar Water Desalination Unit

The fabricated portable solar water desalination unit (PSWD) comprises of four main parts include solar oven, condenser, lower basin pot, and stand as shown in Fig. 1. The constructed PSWD is a simple solar oven that converts 5 litres of salt water into fresh water every day. It is made of clay and locally available materials and needs no electricity or filtration devices to work.

The top of the equipment has black boiler with a water-tight cap. The saline water is filled through water inlet and the cap is sealed so that no steam can escape. Both the temperature and pressure increase within the boiler throughout the day and the condenser is connected through which steam is condense and steam converted into the liquid is collected into the clay pot. The Table 1 shows description of all the parts of the PSWD.

Table 1

Description of portable solar water desalination parts

S. No.	Parts	Pictorial View	Description
1.	Black Solar Oven		This is main component which is situated on the top with the help of Stand having inner stainless-steel part with black color and the glass cap. Intel of copper pipe with rubber cork and have the channel of steel surrounding of the wall of the stainless-steel pot.
2.	Supporting Pot		It is made up of clay, which is used for supporting the solar oven, with circular trapezoidal shape and having diameter of 13 inch.
3.	Clay Stand		It is a stand on which the solar water oven is placed at some height. This is made of clay; the height of the stand is 11 inches. This is circular drum in shape of diameter 9.5 inch.
4.	Copper Condenser		The copper condenser through which we connect the solar oven with the lower basin. It is used to condense the steam and transfer the steam from the solar oven to the lower basin. At the end of the pipe the nozzle is fitted to condense the remaining steam and convert it into the pure water.
5.	Lower Basin Cap		This lower basin cap is made up of steel, which is fitted in the pot so that no steam can escapes out.
6.	Lower Basin Pot		This is the basin in which the treated water or purified water is collected. It is the basin which acts as a condenser of the steam in which the steam is condensed. This is made up of the one clay pot with the metallic cape.

2.2 Cost Estimation

In designing of a SWD Equipment basically for the rural communities, the prime object was to keep the equipment cost effectively. The oven utilized in this equipment cost was PKR 1500 and the supporting pot for oven cost only PKR 300 The stand to support the equipment was built from clay and cost PKR 500 only. The condenser used for the transfer of steam from the solar oven to the lower basin costs PKR 600 only. And the lower basin cap and lower basin pot utilized in the equipment costs PKR 250 and PKR 350, respectively.

Furthermore, the Cost estimation of various components is provided in Table 2. The cost for the fabrication was about PKR 1000. The total cost of unit is PKR 4500 (approximately USD 33). In other parts of world solar desalination units are designed such as single basin solar still have cost PKR 6040 having efficiency of 30.65% [4].

Table 2

Cost estimation for the components

S. No.	Parts	Cost in Pakistan (PKR)
1.	Black Solar Oven	1500/-
2.	Supporting Pot	300/-
3.	Clay Stand	500/-
4.	Copper Condenser	600/-
5.	Lower Basin Cap	250/-
6.	Lower Basin Pot	350/-

2.3 Study Area

The study focuses on the district Tharparkar which is a desert region in the Southern part of Sindh Pakistan [18]. Study area comprises of three main cities of Tharparkar district i.e., Mithi, Islamkot and Diplo, located in south-east edge of the Sindh, Pakistan as shown in Fig. 2. The study areas are positioned between 69136.2270 – 70145.1920 longitude and Latitude respectively [22]. These areas have major water crisis because of limited groundwater as an only source of water for the people. The unreliable other source of the water for the people of Mithi, Islamkot and Diplo is the unexpected rainfall. The groundwater that people consume in this area is mostly saline or brackish and has a high concentration of various salts and minerals, which are dangerous for human health, as well as livestock. Ground water quality of Islamkot and Diplo is not good for drinking purpose, contains high concentration of TDS in it.

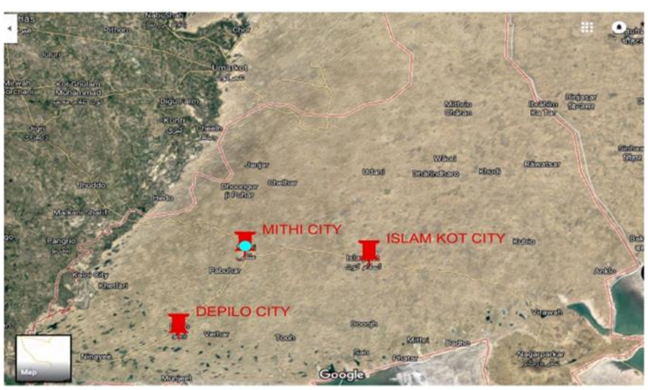

Fig. 2. GIS Map of Mithi, Diplo And Islamkot Cities of Tharparkar

2.4 Samples Collection and Preservation

All precautionary measures were followed while collecting the water samples from selected sites. Totally 10 samples from each city were collected from thickly populated areas. The samples were collected from the dug wells and groundwater. All the samples were collected in the clean water plastic bottles and preserve according to the WHO guideline [23]. Samples were store in the dry, clean, and clear environment. From each location 6 liters water sample is collected and preserve at 4°C for the analysis of pH, TDS, and EC.

2.5 Samples Analysis

The pH, TDS and EC were analyzed for all samples in the Water and Soil Laboratory, Institute of Environmental Engineering and Management, Mehran University of Engineering and Technology, Jamshoro, Pakistan. The pH is measured through the digital pH meter (WSTL007, WTW Germany). The TDS and EC were measured using HACH (PCRWR) conductivity meter.

3. Experimental Procedure

3.1 Treatment Procedure

The PSWD was tested in open space and is working on the principle of the humidification and dehumidification. The procedure is very simple as the sun rays fall on the glass cover of unit the oven temperature increases and the saline water is converted in to steam. The steam hits on the glass cover some of it condensed that is collected into the inner channel fitted to the wall of the black solar oven and the remaining passes through the copper condenser pipe and condensed into the pure water and collected into the lower basin pot.

3.2 Cleaning/Removal of Salts from the Unit

After purification the salts of the raw water are settled down into the lower portion of solar oven, it is then back washed to remove those settle able solids. For washing and cleaning of the settle able solids the water is injected through the inlet pipe and then unit was backwashed manually. The unit becomes ready within 10 minutes for the next time purification of the saline water. The PV model used in this paper is a Soltech PV model and it is a fixed model; the Soltech PV model (and parameters) is available in the Simulink. Therefore, the system is coupled with Maximum Power Point Tracking system known as MPPT, with a Perturb and Observe (PandO) algorithm to extract the maximum possible power from PV. Table 1 shows the parameters of the photovoltaic module used in this system; they are adapted from.

4. Results and Discussion

Different samples were collected form Mithi, Islamkot and Diplo city. Ten samples were collected from each

© Mehran University of Engineering and Technology 2022

city and were analysed for TDS, EC and pH before and after treatment. All the samples were treated with the help of PSWD unit.

Samples collected from Mithi, Islamkot and Diplo were tagged as M1-M10, I1-I10 and D1-D10 respectively. From the analysis it was observed that the samples before treatment had high TDS value exceeding WHO standards in all cities. Moreover, the most of EC and pH value were approximately within the limits of WHO guidelines for drinking water. As per WHO guidelines for Drinking-water Quality [10], the satisfactoriness of water with a TDS dimension of under 600 mg/L is commonly viewed as great; drinking water turns out to be altogether and progressively unpalatable at TDS levels greater than around 1000 mg/L. The nearness of elevated amounts of TDS may likewise be questionable to consumers, inferable from intemperate scaling in water pipes, radiators, boilers, and household appliances. However, WHO does not propose any wellbeing-based rule an incentive for TDS. No wellbeing-based rule esteem has been proposed by WHO for pH either. Although pH normally has no immediate effect on purchasers, it is a standout amongst the most imperative operational water quality parameters. The ideal pH required changes in various supplies as per the requirement of the water and the idea of the development materials utilized in the circulation framework, yet it is for the most part in the range 6.5 – 8.5 [23].

4.1 Results of Samples from Mithi City

The sample collection process was carried for the Mithi city. Ten samples were collected from different areas of Mithi, and all the samples were tagged as M1-M10 as shown in Table 3. The samples collected has maximum TDS of 10421 mg/L and minimum of 735 mg/L and maximum EC of 20842 µS/cm and minimum of 1470 µS/cm before treatment. From treated samples maximum TDS value obtained was 375 mg/L and minimum TDS obtained was 185 mg/L as shown in Fig. 3. Similarly, for EC maximum value after treatment was 750 µS/cm and minimum 370 µS/cm as shown in Fig. 4. After treatment, the water obtained was suitable for drinking as the TDS and EC value were very much low and within the limits of WHO standards. In previous study the water quality parameters of simple single basin solar still unit had TDS, pH and EC values before and after desalination were in order of TDS 370-30 mg/L, EC 1.291-0.041 mS/cm and pH 6.72 – 6.5 respectively [4].

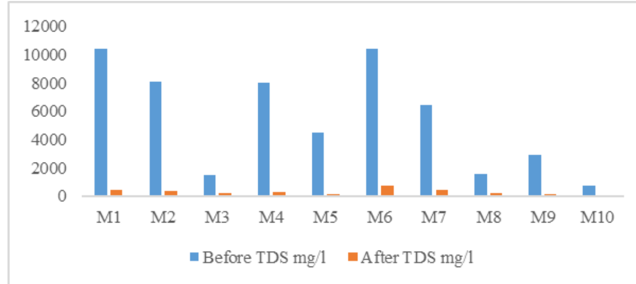

Fig. 3. TDS of Samples before and after Treatment, Mithi City

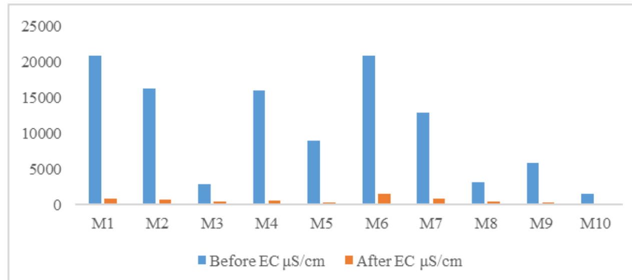

Fig. 4. EC of Samples before and after Treatment, Mithi City

4.2 Results of Samples from Islamkot City

Similarly, 10 samples were collected from the Islamkot city. All the samples were tagged as I1, I2, I3, I4, I5, I6, I7, I8, I9, and I10 as shown in Table 4. The maximum value of TDS reported as 7516 mg/l and minimum 334 mg/L. After the treatment with PSWD unit the maximum TDS value obtained was 314 mg/L and minimum 150 mg/L as shown in Fig. 5. Similarly, the EC values after the treatment ranged from 628 and 300 µS/cm as shown in Fig. 6.

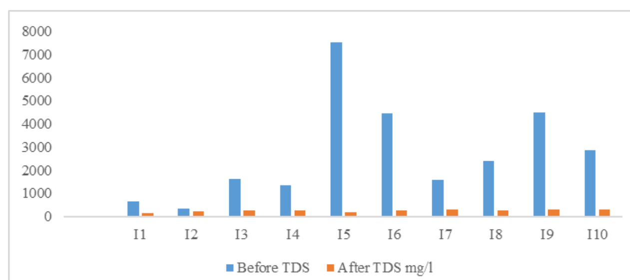

Fig. 5. TDS of Samples before and after Treatment, Islamkot City

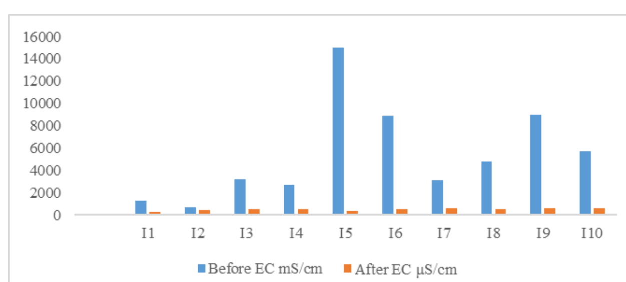

Fig. 6. EC of Samples before and after Treatment, Islamkot City

4.3 Results of Samples from Diplo City

In diplo city 10 samples were collected from different areas. The sample ID is given according to first letter of the cities such as for Diplo "D" as shown in Table 5. The results of TDS values of Diplo city showed maximum in D10 sample as 10196 mg/L and minimum in D1 as 886 mg/L. After treatment from PSWD the remarkable results achieved such as for TDS maximum 365 mg/L and minimum 245 m/L as shown in Fig. 7. Similarly, the EC value is also gotten good reduction such as maximum 730 µS/cm and minimum 490 µS/cm as shown in Fig. 8.

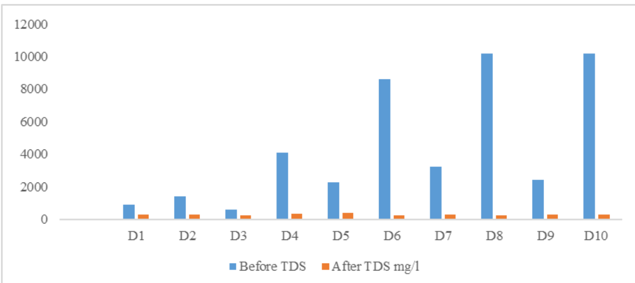

Fig. 7. TDS of Samples before and after Treatment, Diplo City

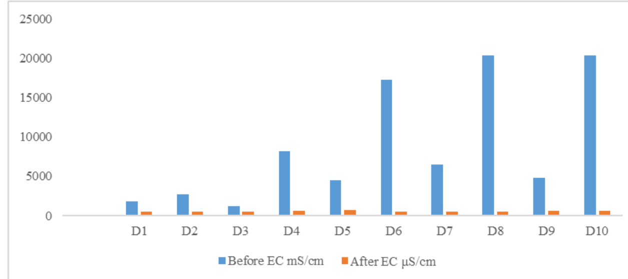

Fig. 8. EC of Samples before and after Treatment, Diplo City

Typically, efficiency of simple single basin stills has been observed as 25% [25]. While through modification of unit, by providing insulation to reduce losses efficiency of unit can be increased to 30 – 40% [4]. The design of PSWD unit utilized in this research was modified by providing Mud pot at bottom of unit to collect water, rubber seals at top of unit to reduce steam losses and insulation to reduce heat losses to increase efficiency of system. After modification of PSWD efficiency observed was 35.2%.

Table 3

Results of Mithi water samples before and after treatment

Samples ID	Location Ambient Temperature (ºC)	PSWD Inner Temperature (ºC)	pH	Before TDS (mg/L)	After TDS (mg/L)	Before EC (µS/cm)	After EC (µS/cm)
M1	48.02	93.5	7.4	10421	230	20842	460
M2	46.45	91.4	7.8	8120	243	16240	486
M3	40.09	85.6	8	1455	375	2910	750
M4	49.15	95.2	7.9	8025	223	16050	446
M5	49.26	95.6	7.2	4485	185	8970	370
M6	44.32	87.2	7.3	10402	265	20804	530
M7	45.04	88.5	7.1	6420	237	12840	474
M8	39.02	78.4	7.6	1553	342	3106	684
M9	46.32	91.2	7.6	2945	214	5890	428
M10	48.03	93.6	7.7	735	234	1470	468

Table 4

Results of Islamkot water samples before and after treatment

Samples ID	Location Ambient Temperature (ºC)	PSWD Inner Temperature (ºC)	pH	Before TDS (mg/L)	After TDS (mg/L)	Before EC (µS/cm)	After EC (µS/cm)
I1	44.04	87.2	7.4	643	150	1286	300
I2	41.12	82.3	7.8	334	239	668	478
I3	42.67	84.3	7.2	1612	260	3224	520
I4	45.22	88.7	7.5	1346	278	2692	556
I5	46.16	91.1	7.4	7516	167	15032	334
I6	43.37	85.3	7.6	4450	265	8900	530
I7	41.27	82.5	7.2	1565	286	3130	572
I8	43.21	85.3	7.3	2405	257	4810	514
I9	40.76	85.7	7.6	4482	314	8964	628
I10	43.02	86.3	7.7	2863	289	5726	578

© Mehran University of Engineering and Technology 2022

Table 5

Results of Diplo water samples before and after treatment

Samples ID	Location Ambient Temperature (ºC)	PSWD Inner Temperature (ºC)	pH	Before TDS (mg/L)	After TDS (mg/L)	Before EC (µS/cm)	After EC (µS/cm)
D1	42.42	84.0°C	7.8	887	276	1774	552
D2	42.02	83.7°C	7.3	1381	279	2762	558
D3	46.02	91.0°C	7.5	605	245	1210	490
D4	40.27	85.5°C	7.6	4086	325	8172	650
D5	38.52	76.5°C	7.8	2239	365	4478	730
D6	44.02	87.1°C	7.2	8622	248	17244	496
D7	42.02	84.2°C	7.9	3240	279	6480	558
D8	43.22	86.4°C	7.7	10194	254	20388	508
D9	42.72	84.3°C	7.1	2420	284	4840	568
D10	44.35	87.7°C	7.6	10196	290	20392	580

Table 6

Correlation of parameters

Parameters	pH	TDS Before	TDS After	EC Before	EC After
pH	1				
TDS Before	-0.0877	1			
TDS After	-0.03307	0.81279	1		
EC Before	-0.0877	1	0.81279	1	
EC After	-0.03307	0.81279	1	0.81279	1

4.4 Correlation Table

The correlation Table 6 shows the positive and negative correlation between pH TDS and EC before and after treatment. The correlation is negative between the pH with before and after treatment result of TDS and EC while the positive correlation is found in pH to pH, TDS before to TDS before, TDS after to TDS after, EC before to EC before and EC after to EC after with other parameters.

4.5 Hierarchical Cluster Analysis

In this analysis the similar results are encounter in same class and the results having variation in analyzed values are placed in another class. In this hieratical cluster analysis is shown in dendrogram, which divide the results of all samples in groups and subgroups. The dendrogram for TDS concentration in drinking water samples of three cities of Tharparkar district are shown in Fig. 9, and this divided in to two groups namely A and B and both are also divided into two subgroups. Group-A is larger than Group-B which show the high TDS concentration then Group-B.

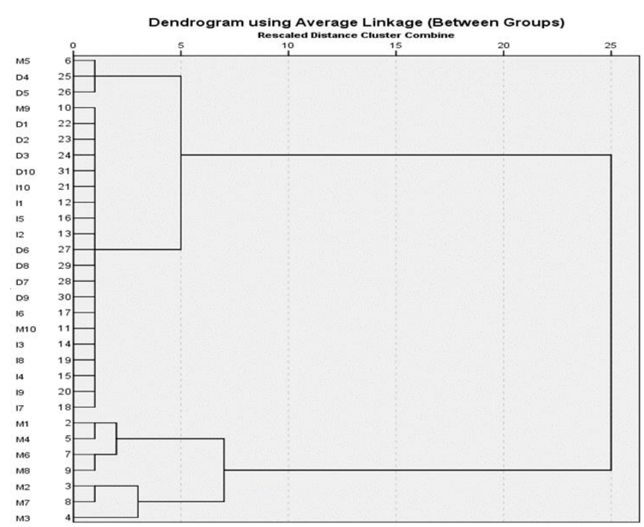

Fig. 9. Dendrogram Represents the Similarity in TDS Concentration Between Sampling Location

5. Conclusion

The present study shows that the TDS concentration from drinking water samples collected from three cities of district Tharparkar were crossed the maximum permissible limit for TDS recommended by WHO. In this study the designed solar water desalination unit was found as an efficient and cost-effective desalination unit consuming minimal cost of around PAKPKR 4500/-. The efficiency of the unit is 35.2% through this household solar water desalination unit. The study concluded that this low cost and highly efficient treatment unit should be recommended for the arid regions of rural areas of Sindh like Tharparkar which facing shortage of drinking water and relying on saline water for their drinking purpose.

6. Acknowledgement

Authors would like to acknowledge the Director, Institute of Environmental Engineering and Management, Mehran University of Engineering and Technology, Jamshoro Sindh Pakistan, for openhanded research support required in this study.

7. References

[1] G. T. Miller, "Environmental Science", Wadsworth Publishing Co., Belmont, CA, 2nd edition, 1989.

[2] S. Postel, "The Last Oasis: Facing Water Scarcity", World Watch Environmental Alert Series, EarthScan, 1992.

[3] J. H. Ensink, M. R. Konradsen, F. Jensen, and P.K. van, D. W Hoek, "Linkages between irrigation and drinking water in Pakistan", Working Paper 46, International Water Management Institution, vol. 14, 2002.

[4] M. A. Samee, U. K. Mirza, T. Majeed, and N. Ahmad, "Design and performance of a simple single basin solar still", Renewable and Sustainable Energy Reviews, vol. 11, no.3, pp. 543-549, 2007.

[5] K. Gagne, "Gone with the trees: deciphering the Thar Desert's recurring droughts", Current Anthropology, vol. 54, no. 4, pp. 497-509, 2013.

[6] T. Chaudhry, "Understanding water scarcity in the socio-cultural context in Thar Desert of Pakistan", Journal of International Development and Cooperation, vol. 23, no. 1, pp. 15-25, 2017.

[7] S. Siyal, X. Peng, and A. W. Siyal, "Socioeconomic analysis: A case of Tharparkar", Journal of Public Affairs, vol. 18, no. 4, pp. 1–3, 2018.

[8] S. Alkire, and A. Alkire, "Teaching Literature in the Muslim World: A Bicultural Approach", TESLEJ, vol. 10, no. 4, pp. 4, 2007.

[9] R. Walker, M. Gurven, K. Hill, A. Migliano, N. Chagnon, R. Desouza, G. Djurovic, R. Hames, A. M. Hurtado, H. Kaplan, K. Kramer, W. J. Oliver, C. Valeggia, and T. Yamauchi, "Growth rates and life histories in twenty-two small-scale societies", American Journal of Human Biology, vol. 18, no. 3, pp. 295-311, 2006.

[10] M. T. Chaibi, "An overview of solar desalination for domestic and agriculture water needs in remote arid areas", Desalination, vol. 127, no. 2, pp. 119-133, 2000.

[11] A. S. Qureshi, P. G. McCornick, M. Qadir, and Z. Aslam, "Managing salinity and waterlogging in the Indus Basin of Pakistan", Agricultural Water Management, vol. 95, no. 1, pp. 1-10, 2008.

[12] S. Galal, and A. A. Husseiny, "Status of desalination research and technology in the Middle East", Desalination, vol. 20, no. 3, pp. 217-225, 1977.

[13] U. K. Mirza, M. M. Maroto-Valer, and N. Ahmad, "Status and outlook of solar energy use in Pakistan", Renewable and Sustainable Energy Reviews, vol. 7, no. 6, pp. 501-514, 2003.

[14] K. Kumar, M. Arain, A. Chana, "Comparative Study of Solar Inactivation of Total Coliforms through Transparent Plastic Bottles and Fabricated Disinfection Setup", Mehran University Research Journal of Engineering and Technology, vol. 38, no. 2, pp. 379-388, 2019.

[15] J. A. Duffie, and W. A. Beckman, "Solar Engineering of Thermal Processes", Wiley-lnter Science New York, Edition 2, pp. 657-664, 1991.

[16] G. M. Zaki, A.M. Radhwan, and A.O Balbeid, "Analysis of assisted coupled solar stills", Solar Energy, vol. 51, no. 4, pp. 277-288, 1993.

[17] E. Delyannis, and V. Belessiotis, "Solar Desalination: Is It Effective? Part II: Solar Assisted Distillation", International Desalination and Water Reuse Quarterly, vol. 5, no. 1, pp. 28-33, 1995.

[18] M. Herani, and M. Gobind, "A Comparative Study of an Agro-based Industry of Tharparkar with Canal Barrage Area, Sindh (1988-2000) and Suggested Techniques Leading to an Industrial Economy", Ph.D. Thesis, University of Sindh, 2002.

[19] N. A. Zaigham, "Strategic sustainable development of groundwater in Thar Desert of Pakistan", Water Resources in the South, Present Scenario and Future Prospects, vol. 56, pp. 56, 2003.

[20] M. I. Kalhoro, "Report of Commission of Inquiry", Pakistan: Judicial Commission Supreme Court, Supreme Court of Pakistan, 2017.

© Mehran University of Engineering and Technology 2022

[21] T. Rafique, S. Naseem, T. H. Usmani, E. Bashir, F. A. Khan, and M. I. Bhanger, "Geochemical factors controlling the occurrence of high fluoride groundwater in the Nagar Parkar area, Sindh, Pakistan", Journal of Hazardous Materials, vol. 171, no. 1-3, pp. 424–430, 2009.

[22] L. Jenny, "Solar thermal technologies for seawater desalination: state of the art", https://www.diva-portal.org/smash/get/diva2:995032/FULLTEXT01.pdf (accessed 26 Jan 2019).

[23] "Guidelines for drinking-water quality, recommendations. Switzerland, Geneva", World Health Organization, 2004.

[24] G. Mink, L. Horvath, E. G. Evseev, A. I. Kudish, "Design parameters, performance testing and analysis of a double-glazed, air-blown solar still with thermal energy recycle", Solar Energy, vol. 64, no. 4, pp. 265-277, 1998.

[25] G. A. Al-Hassan, S. A. Algarni, S. A., "Exploring of Water Distillation by Single Solar Still Basins", American Journal of Climate Change, vol. 2, no. 1 pp. 57-61, 2013.

© Mehran University of Engineering and Technology 2022