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Performance analysis of solar evaporation for treating coconut husk retting water

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ABSTRACT

Water is the foundation of all forms of life. It is the most abundant physical substance on earth. The study area – Kallipatti village is located 14 km away from Pollachi, Coimbatore district, with a total geographical area of 492.05 hectares and is mostly covered with coconut farms, coir pith industries, etc., Residents from that village pointed out that since the year 2018, water has become their biggest concern. They have been seeing an increasing incidence of skin diseases, eye allergies, throat and lung infections. The present study focused particularly on the treatment of coconut husk retting water. During retting, fibers are degraded and loosened. Environmental pollution and water contamination are associated with conventional retting. The high values of 5-day biochemical oxygen demand associated with the extending flora and fauna were the remarkable feature of the retting zones. In this study, pollution sources were identified, retting water samples were collected, the physico-chemical parameters of the coconut husk retting water samples were tested and compared to Indian standards, and appropriate treatment techniques were obtained based on various literatures. A solar evaporation system is adopted to treat retting water. The main aim of this study is to observe the daily rate of evaporation under various conditions such as daily rate of evaporation and meteorological parameters, rate of evaporation vs. the type of evaporation (single and rack), rate of evaporation vs. plain evaporation, and pan evaporation with algal growth. The evaporated water is condensed and tested for the physico-chemical parameters and compared with the results obtained before treatment. The sludge formed after the evaporation of the coconut husk retting water is collected, dewatered, and made into briquettes that can be used as biomass. The recommendations are given to the small-scale industries to treat the coconut husk retting water based on the cost analysis and rate of evaporation.

Keywords: Algal growth; Biomass; 5-day biochemical oxygen demand; Briquettes; Coconut husk retting water; Environmental pollution; Kallipatti village; Meteorological parameters; Physico-chemical parameters; Rate of evaporation; Solar evaporation system; Water contamination

1. Introduction

Water is the most abundant physical substance and transparent liquid on earth. Water is the foundation of all forms of life. Coir pith is a waste product obtained during the extraction of coir fibre. When the husks of 10,000 coconuts are utilized for coir extraction, one ton of coir pith is obtained as a by-product [1]. Coir pith has constituents like lignin (30%) and cellulose (26%), which will not degrade quickly. Coir pith can absorb eight times its own weight in water. Coir pith pollutes the environment and poses a fire hazard. Coir pith was thrown away in the environment around the extraction units in the form of huge heaps, which occupied large land spaces and caused pollution problems.

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A few regions in Tamil Nadu haven't had access to safe drinking water due to waste from coir pith industries. The traditional method of coir fibre extraction before obtaining coir pith is by retting, a time-consuming process that ends in environmental pollution. The process of decomposing the coconut husk's pulp through natural and chemical processes to separate the coir fibre is called retting. Husk retting is done by soaking coconut husk s in lakes, rivers, ponds, and surface water bodies for around six months to one year (conventional method of practice). But nowadays, coconut husk is kept in a heap and water is sprayed from its top to enhance the retting process. During retting, fibres are degraded and loosened. Some of the water sprayed from the top is absorbed by the husk, and the remainder penetrates into the ground. Environmental pollution and water contamination are associated with the retting process. High values of 5-day biochemical oxygen demand (BOD_5) associated with anoxic conditions and the extent of flora and fauna, fish, and fouling organisms were the remarkable features of retting zones [2]. 1 kg of coconut husk requires 36 L of water to be processed into coir pith. 1 tonne of coconut husk requires 36,000 L of water (40,000 L approx.) The use coefficient of Photosynthetic Active Radiation (PAR) can be improved using agro-technical cultivation methods, notably by increasing plant mineral nutrition. Mineral fertilizers were found to contribute to 1.8–2.0 times increased solar energy accumulation in biomass when used in intensive farming practices [3].

Extraction of fibre from coconut husk after retting leads to extensive pollution of water bodies along with severe destruction of the flora and fauna in the locality [4]. It is a major concern that the retting areas mostly affect aquatic life to a large extent. The retting process also leads to the destruction of fisheries in those areas [5].

With reference to the newspaper articles published in Hindu Tamil dated September, 2020 and The News Minute-Civic Issues on November 26, 2019, the study area was identified based on the complaints made by residents of Kallipatti. Some of the inferences made from the complaints is that the village of Kallipatti hasn't had access to safe drinking water since 2018. The harmful chemicals from coir retting sites seep into water sources and contaminate their groundwater. Residents of the village had been seeing an increasing incidence of skin diseases, eye allergies, and throat and lung infections. Retting water samples were tested and confirmed their fears that they were contaminated. Coir pith industries in the area may be functioning without the requisite permission from the Tamil Nadu Pollution Control Board (TNPCB). Even their cattle are not drinking this water. The pollution of water proves to be challenging for the flora and fauna in that locality, and aquatic life finds it difficult to survive in polluted water, which thereby causes death. In this study, the characteristics of the coconut brown husk retting water effluent were determined. The results are compared with the Bureau of Indian Standards (IS 10500-2012). Then the assessment of water quality through the water quality index (WQI) is done using Brown's equation. Different types of solar evaporation systems (plain evaporation and rack evaporation systems) are carried out [6]. The daily rate of evaporation under various conditions like the meteorological parameters and type of evaporation (single and rack) is observed and compared. Recommendations are given to the industries to treat the coconut husk retting water.

The main objective of the present study is to perform quality assessment tests on coconut husk retting water based on the available physico-chemical data from collected retting water samples from the Kallipatti region.

- To analyse the characteristics of the coconut brown husk retting water effluent.
- Comparison of the results with the Bureau of Indian Standards (IS 10500-2012).
- Assessment of water quality through the water quality index (WQI).
- To fabricate different types of solar evaporation systems (plain evaporation and rack evaporation systems).
- To observe the daily rate of evaporation under various conditions.
  - (i) Daily evaporation rate and meteorological parameters.
  - (ii) Evaporation rate vs. evaporation type (single and rack).
  - (iii) Evaporation rate vs. plain evaporation, as well as evaporation in the pan with water hyacinth growth.

Although this type of solar evaporation system exists, such as "evaporation using a plain pan with a vertically installed pipeline line arrangement", the behaviour of meteorological parameters with respect to the daily rate

Table 1
Methods used for analysis of physico-chemical parameters

Parameters	Methods
pH	Electrometric method by pH meter
Electrical conductivity (µs/cm)	Instrumental method by conductivity meter
Salinity	HI98192 water testing probe
Resistivity (ohms)	HI98192 water testing probe
Total dissolved solids (mg/L)	Gravimetric method
Total hardness (mg/L)	EDTA titrimetric method
Sulfates (mg/L)	Gravimetric method
Chlorides (mg/L)	Argentometric method
Dissolved oxygen (mg/L)	Winkler method
BOD (mg/L)	Winkler method
COD (mg/L)	Instrumental method by Spectroquant TR 420

Table 2
Classification of water quality based on WQI

Water quality index	Water quality
Less than 50	Excellent
50–100	Good
100–200	Poor
200–300	Very poor
Greater than 300	Unsuitable for drinking

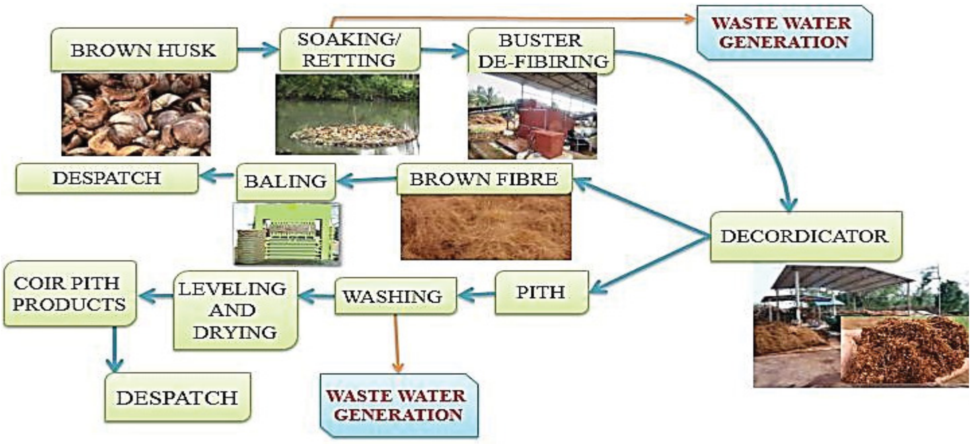

Fig. 1. Pollution sources – process of fiber extraction from brown husk.

Fig. 2. Coconut husk retting process by conventional method.

Fig. 3. Coconut husk retting process by modern method.

of evaporation using various types of evaporation systems has not been extensively studied. Moreover, solar evaporation has not been carried out for the treatment of coconut husk retting water. In this study, the relationship between various meteorological parameters and the rate of evaporation was obtained using multidimensional regression in order to design a similar system on a large scale.

2. Materials and methods

Coimbatore is an important district in the western part of Tamil Nadu. The study area selected is Kallipatti, near Pollachi, in the Coimbatore district. Kallipatti is located around 14 km from Pollachi between 10.7194 N latitude and 77.0826 E longitude. The study area covers a total geographical area of about 492.05 ha. The coconut husk retting water sample is analysed for determination of the degree of pollution with respect to the following physico-chemical parameters.

- pH
- color
- odor
- temperature
- electrical conductivity
- total dissolved solids
- chloride
- sulfates
- total hardness
- dissolved oxygen
- BOD
- chemical oxygen demand

The water quality index can be obtained by Brown's equation and it was also calculated by the weighted index method to determine the suitability of water for drinking purposes. pH, total hardness, chloride, sulfate, total dissolved solids, dissolved oxygen, and conductivity are all taken into account when calculating the water quality index.

2.1. Solar evaporation

Solar evaporation is the most cost-effective technique for the treatment and disposal of high dissolved solids in water [7]. Moreover, solar evaporation is considered to be cost-effective compared to low-cost evaporators and multiple-effect evaporators.

2.1.1. Laboratory setup - plastic crate 64225 CL

Outer dimension – 0.6 m (L) × 0.4 m (B) × 0.225 m (H)
Inner dimension – 0.57 m (L) × 0.365 m (B) × 0.21 m (H)
Dimension of pan used for solar evaporation – 0.57 m (L) × 0.365 m (B) × 0.096 m (H)
Capacity 20 L and surface area – 0.21 m^2

2.2. Experimental setup

i. A lab scale set up of an evaporation pan with the following accessories was done to observe the daily evaporation rate;
ii. Pan (six of 0.6 m × 0.4 m × 0.225 m);
iii. Measuring jar (2 nos., 1,000 mL capacity);

Fig. 4. (a) Solar evaporation, (b) low-cost evaporator and (c) multiple effect evaporator.

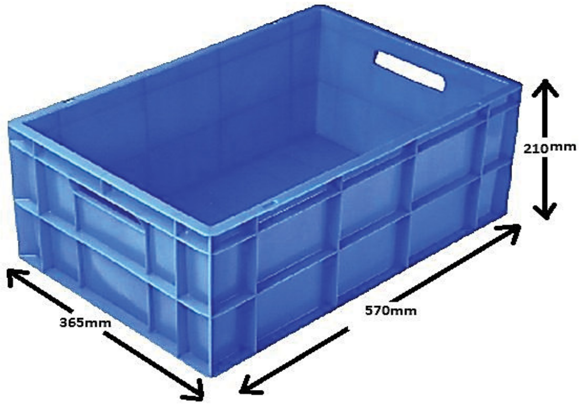

Fig. 5. Solar evaporation pan.

Fig. 6. Coconut husk retting water before and after evaporation.

iv. Metal rack with 3 horizontal partitions (total height of 1 m; height between pans – 0.5 m);
v. Water testing probe HI9819.

2.3. Experimental procedure

2.3.1. Plain solar evaporation pan

In the evaporation pan, 20 L of coconut husk retting water are filled and left in sunlight in an open area (terrace). The initial height of retted water is 96 mm. The following data, such as daily rate of evaporation, temperature, humidity, total dissolved solids, electrical conductivity, and resistivity, were observed.

2.3.2. Rack evaporation system

The top pan is filled with twenty litres of coconut husk retting water, and the rack is kept in sunlight in an open area (terrace) [8]. A vertical metal rack was used. Three pans were placed inside the rack at a vertical interval of 0.50 m between each pan, excluding the top pan. An experiment was carried out for around 15 d and the following data, such as daily rate of evaporation, temperature, humidity, total dissolved solids, electrical conductivity, and resistivity, were observed. The top pan and middle pan consist of 1 mm diameter holes at 50 mm c/c. Woolen threads are inserted into the holes in order to regulate flow uniformly in the form of droplets. The bottom pan acts as the collecting chamber.

2.3.3. Evaporation with water hyacinth

The initial weight of water hyacinth plants taken is 0.5 kg. The initial height of the retted water in the pan along with the water hyacinth is 99 mm [9].

3. Results and discussion

The coconut husk retting water sample is tested for physical and chemical parameters in the laboratory. The suitability of the retting water for irrigation and drinking will depend upon the water quality standards. The quality of the retting water will vary from season to season and from stratum to stratum [10]. The quality standards for drinking water in India are described by Bureau of Indian Standards (BIS) standards IS 10500–2012. This standard specifies the acceptable limits and the permissible limits that can be adopted in the absence of other sources. The results have been compared with Bureau of Indian standards and WQI was calculated. From the results obtained, the treatment methodology to be adopted is decided, and treatment of the retting water is carried out. The treated water is further analysed for physico-chemical treatment and the results are compared with the results obtained before the treatment.

Table 3 shows that the coconut husk retting water sample is found to be acidic. From the water quality analysis, it is observed that coconut husk retting water cannot be used for drinking purposes. Coconut husk retting water samples in the study area exceeds the permissible limits as prescribed by the BIS. It is observed that chlorides are within the permissible limits. On testing the coconut husk retting water sample, TDS, hardness, sulphates, dissolved oxygen, and

Table 3
Physico-chemical testing results for retting water

Name of experiment	Permissible limit	Acceptable limit	Test readings
pH	6.5–8.5	6.5–8.5	7.8
Electrical conductivity (µs/cm)	750–2,250	750	4,773
Total suspended solids (mg/L)	100	–	950
Total dissolved solids (mg/L)	500–2,000	500	2,450
Chlorides (mg/L)	250–1,000	250	190
Sulfates (mg/L)	200–400	200	477
Total hardness (mg/L)	200–600	200	960
Temporary hardness (mg/L)	–	–	460
Permanent hardness (mg/L)	–	–	500
Dissolved oxygen (mg/L)	4	4	2.0
COD (mg/L)	750	750	31,600

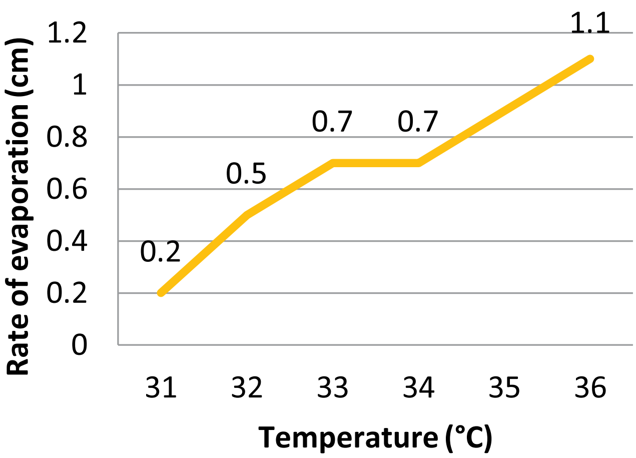

Fig. 7. Temperature vs. rate of evaporation.

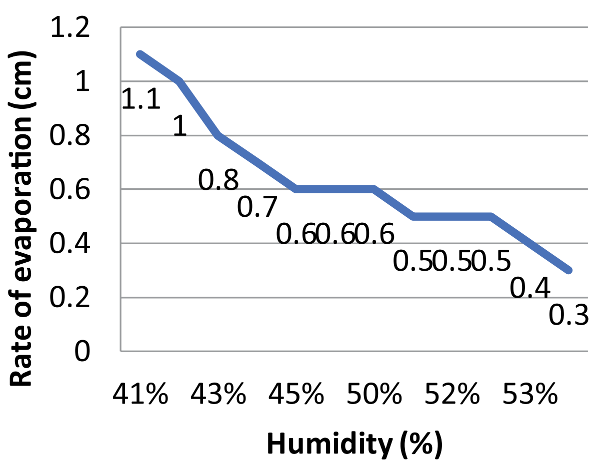

Fig. 8. Humidity vs. rate of evaporation.

chemical oxygen demand (COD) are found to be beyond the permissible limit on comparison with BIS 10200-2012.

pH, total hardness, chloride, sulfate, total dissolved solids, dissolved oxygen, and conductivity results are

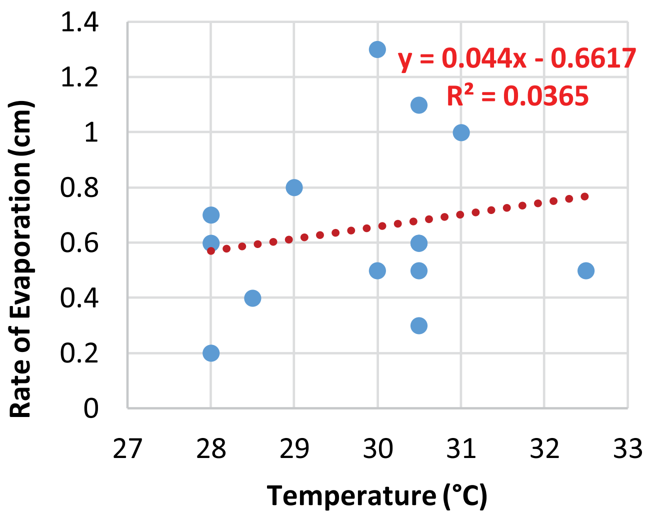

Fig. 9. Multivariate linear regression on the rate of evaporation vs. temperature.

used to calculate the water quality index. From the results obtained, the retting water is categorized as very poor quality water by the water quality index.

According to Figs. 7 and 8, the rate of evaporation increases with increasing temperature and decreases with increasing humidity.

The correlation between the predicted and observed values is analysed using multivariate linear regression. When simple evaporation, rack evaporation, and evaporation with water hyacinth were examined, the difference in anticipated evaporation rate values with respect to temperature and humidity is shown in Figs. 9–14.

4. Conclusion

The study has revealed the impact of the retting water contamination on drinking and agricultural activities. The physico-chemical parameters of the retting water sample from the study area exceed the permissible limit. The WQI assessment confirmed that the retting water is very poor

Table 4
Performance analysis of solar evaporation pan – plain evaporation

Performance analysis of solar evaporation pan for treating coconut husk retting water																						
Time of observation: initial reading – 10 am; final reading – 4 pm																						
A-solar evaporation																						
S. No.	Date	Temperature (°C)		Humidity (%)		Total dissolved solids (ppm)			Electrical conductivity (mS)			Resistivity (ohm)			Salt (PSU)			Rate of evaporation (cm)				
		Initial	Final	Initial	Final	Initial	Final	Diff.	Initial	Final	Diff.	Initial	Final	Diff.	Initial	Final	Diff.	Initial	Final	Diff.		
1	22/2/2021	25	31	64%	57%	2,641	2,716	75	5.240	5.422	0.182	188	184	4	2.78	2.9	0.12	9.6	9.4	0.2		
2	23/2/2021	26	32	63%	52%	2,716	2,938	222	5.422	5.865	0.443	184	170	14	2.9	3.15	0.25	9.4	8.6	0.8		
3	24/2/2021	25	36	51%	45%	2,938	3,146	208	5.865	6.299	0.434	170	159	11	3.15	3.41	0.26	8.6	7.5	1.1		
4	25/2/2021	28	33	52%	43%	3,146	3,552	406	6.299	7.152	0.853	159	140	19	3.41	3.84	0.43	7.5	7.2	0.3		
5	26/2/2021	27	34	52%	44%	3,552	3,759	207	7.152	7.585	0.433	140	133	7	3.84	4.07	0.23	7.2	6.6	0.6		
6	27/2/2021	29	32	46%	52%	3,759	3,879	120	7.585	7.795	0.210	133	126	7	4.07	4.28	0.21	6.6	6.1	0.5		
7	1/3/2021	31	34	44%	21%	3,959	4,369	410	7.895	9.053	1.158	126	118	8	4.32	4.87	0.55	5.6	5.1	0.5		
8	2/3/2021	25	36	64%	60%	4,369	4,889	520	9.053	10.12	1.069	118	109	9	4.87	5.12	0.25	5.1	4.5	0.6		
9	3/3/2021	24	32	63%	59%	4,889	5,276	387	10.12	10.58	0.457	109	98	11	5.12	5.58	0.46	4.5	3.8	0.7		
10	4/3/2021	23	33	59%	43%	5,276	5,494	218	10.58	11.2	0.617	98	95	3	5.58	5.9	0.32	3.8	3.2	0.6		
11	5/3/2021	25	32	60%	50%	5,494	6,235	741	11.2	11.35	0.156	95	90	5	5.9	6.39	0.49	3.2	2.8	0.4		
12	6/3/2021	28	34	45%	52%	6,235	7,194	959	11.35	22.12	10.77	90	78	12	6.39	10	3.61	2.8	1.8	1		
13	8/3/2021	28	32	23%	46%	7,994	9,535	1,541	22.12	35.04	12.92	78	54	24	10	18	8	1.8	0.5	1.3		
14	9/3/2021	26	34	42%	53%	9,535	12,587	3,052	35.04	22	57.04	54	23	31	18	30	12	0.5	0	0.5		

Table 5
Performance analysis of solar evaporation pan – rack evaporation

S. No.	Date	Temperature (°C)		Humidity (%)		Total dissolved solids (ppm)			Electrical conductivity (mS)			Resistivity (ohm)			Salt (PSU)			Rate of evaporation (cm)				
		Initial	Final	Initial	Final	Initial	Final	Diff.	Initial	Final	Diff.	Initial	Final	Diff.	Initial	Final	Diff.	Initial		Final		Diff.
1	22/2/2021	25	31	64%	57%	2,644	2,731	87	5.296	5.432	0.136	189	184	5	2.81	2.9	0.09		9.6		8.8	0.8
2	23/2/2021	26	32	63%	52%	2,731	2,903	172	5.432	5.81	0.378	184	172	12	2.9	3.12	0.22		8.8		8.4	0.4
3	24/2/2021	25	36	51%	45%	2,903	3,347	444	5.810	6.706	0.896	172	149	23	3.12	3.67	0.55		8.1		6.4	1.7
4	25/2/2021	28	33	52%	43%	3,347	3,571	224	6.706	7.149	0.443	149	140	9	3.67	3.88	0.21	6.4	0.9	5.8	0.8	0.6
5	26/2/2021	27	34	52%	44%	3,571	3,820	249	7.149	7.657	0.508	140	131	9	3.88	4.17	0.29	5.8	0.8	5.3	0.8	0.5
6	27/2/2021	29	32	46%	52%	3,820	4,316	496	7.657	8.594	0.937	131	119	12	4.17	4.55	0.38	5.2	0.4	4.8	0	0.4
7	1/3/2021	31	34	44%	21%	4,416	4,826	410	8.794	9.952	1.158	113	105	8	4.85	5.4	0.55	3.8	0	3.4	0	0.4
8	2/3/2021	25	36	64%	60%	4,826	5,346	520	9.952	11.02	1.068	105	98	7	5.4	5.65	0.25	3	0	2.3	0	0.7
9	3/3/2021	24	32	63%	59%	5,346	5,730	384	11.02	11.48	0.458	98	88	10	5.65	6.11	0.46	1.9	0	1.5	0	0.4
10	4/3/2021	23	33	59%	43%	5,730	5,956	226	11.48	12.1	0.617	88	82	6	6.11	6.34	0.23	1.5	0	1	0	0.5
11	5/3/2021	25	32	60%	50%	5,956	6,124	168	12.1	12.26	0.160	82	76	6	6.34	6.56	0.22	1	0	0	0	1

Table 6
Performance analysis of solar evaporation pan – evaporation with water hyacinth

S. No.	Date	Temperature (°C)		Humidity (%)		Total dissolved solids (ppm)			Electrical conductivity (mS)			Resistivity (ohm)			Salt (PSU)			Rate of evaporation (cm)			Initial DO	Final DO	BOD
		Initial	Final	Initial	Final	Initial	Final	Diff.	Initial	Final	Diff.	Initial	Final	Diff.	Initial	Final	Diff.	Initial	Final	Diff.	mg/L	mg/L	mg/L
1	22/2/21	25	31	64%	57%	2,599	2,646	47	5.175	5.286	0.111	193	189	4	2.74	2.82	0.08	10.1	9.9	0.2	2.4		
2	23/2/21	26	32	63%	52%	2,646	2,886	240	5.286	5.753	0.467	189	174	15	2.82	3.1	0.28	9.7	9.2	0.5			
3	24/2/21	25	36	51%	45%	2,886	3,076	190	5.753	6.145	0.392	174	163	11	3.1	3.31	0.21	8.9	8.6	0.3			
4	25/2/21	28	33	52%	43%	3,076	3,450	374	6.145	6.895	0.750	163	145	18	3.31	3.73	0.42	8.5	8.4	0.1			
5	26/2/21	27	34	52%	44%	3,450	3,635	185	6.895	7.285	0.390	145	137	8	3.73	3.94	0.21	8.4	7.3	1.1	2	1.8	18
6	27/2/21	29	32	46%	52%	3,635	3,996	361	7.285	8.353	1.068	137	127	10	3.94	4.12	0.18	7.3	6.5	0.8			
7	1/3/21	31	34	44%	21%	4,296	4,402	106	8.353	8.414	0.061	127	118	9	4.12	4.36	0.24	5.9	5.8	0.1			
8	2/3/21	25	36	64%	60%	4,402	4,506	104	8.414	8.583	0.169	118	111	7	4.36	4.53	0.17	5.6	5.3	0.3	1.6	1.8	6
9	3/3/21	24	32	63%	59%	4,506	4,606	100	8.583	8.836	0.253	111	103	8	4.53	4.71	0.18	5.1	4.4	0.7			
10	4/3/21	23	33	59%	43%	4,606	4,812	206	8.836	9.436	0.600	103	95	8	4.71	5.22	0.51	4.3	3.8	0.5			
11	5/3/21	25	32	60%	50%	4,812	5,119	307	9.436	10.25	0.814	95	90	5	5.22	5.72	0.50	3.6	3.1	0.5			
12	6/3/21	28	34	45%	52%	5,119	7,689	2,570	10.25	15.5	5.25	90	76	14	5.72	9.24	3.52	3	1.6	1.4	1.8	1.5	3
13	8/3/21	28	32	23%	46%	7,689	10,780	3,091	15.5	20.5	5	76	52	24	9.24	14.52	5.28	1.6	0.2	1.4			
14	9/3/21	26	34	42%	53%	10,780	14,490	3,710	20.5	29.7	9.2	52	34	18	14.52	18.24	3.72	0.2	0	0.2			

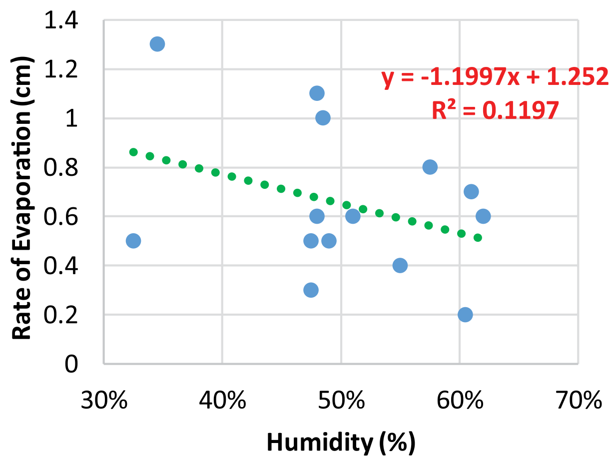

Fig. 10. Multivariate linear regression on the rate of evaporation vs. humidity.

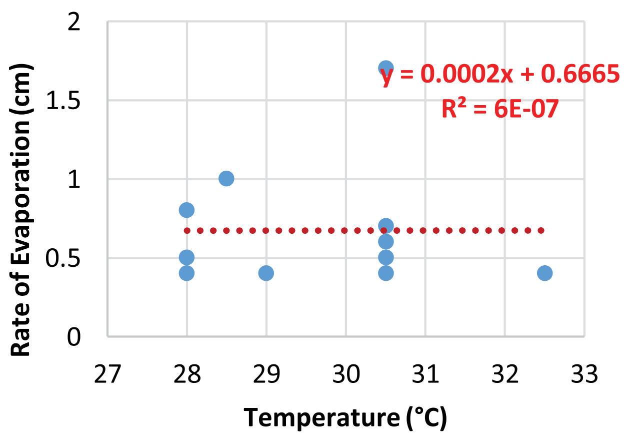

Fig. 11. Multivariate linear regression on the rate of evaporation vs. temperature.

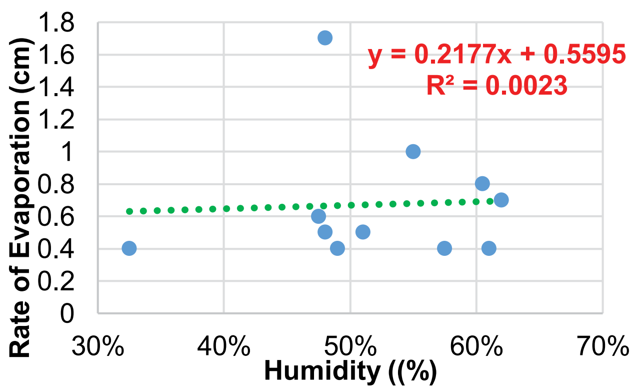

Fig. 12. Multivariate linear regression on the rate of evaporation vs. humidity.

quality and can't be used for drinking purposes. From the analysis of retting water sample testing results, it is revealed that the fibre water used for the retting process is unfit for any domestic use and needs proper treatment before consumption in the study area.

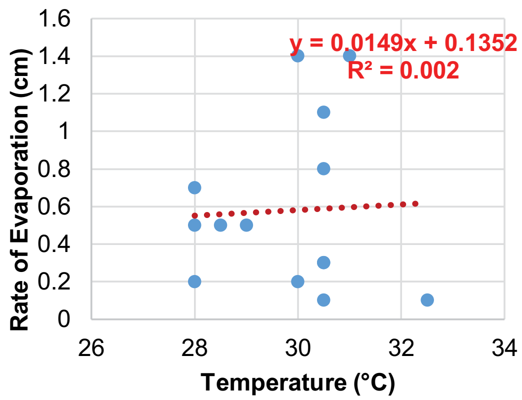

Fig. 13. Multivariate linear regression on evaporation rate with water hyacinth vs. temperature.

Table 7
Test results before and after evaporation

Name of experiment	Permissible limit	Before evaporation	After evaporation
pH	6.5–8.5	7.8	6.97
Electrical conductivity (µs/cm)	750–2,250	4,773	6.7
Total suspended solids (mg/L)	–	950	11
Total dissolved solids (mg/L)	500–2,000	2,450	30
Chlorides (mg/L)	250–1,000	190	25
Sulfates (mg/L)	200–400	477	218
Total hardness (mg/L)	200–600	960	175
Temporary hardness (mg/L)	–	460	78
Permanent hardness (mg/L)	–	500	97
Dissolved oxygen (mg/L)	4	2	4
COD (mg/L)	750	31,600	64

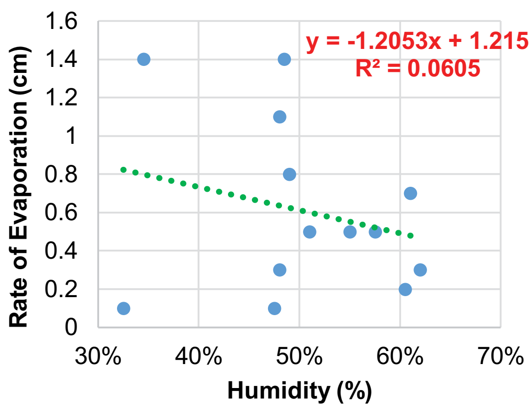

Fig. 14. Multivariate linear regression on the evaporation rate with water hyacinth vs. humidity.

Solar evaporation is adopted to treat the retting water as it is the only cost-effective technique for the treatment and removal of high TDS in water. In low-cost evaporation, 1,000 L of wastewater influent evaporates 500 L/d as treated water, but in solar evaporation, 1,000 L of wastewater influent evaporates 50 L/d. The rate of evaporation in a rack evaporation system is 1.5 times more efficient compared to plain solar evaporation. The rate of evaporation was found to increase if the meteorological parameters were suitable. The rate of evaporation in low-cost evaporation is 10 times more efficient than solar evaporation. The initial cost of a low-cost evaporator is 15 times higher than plain solar evaporation. Rack evaporation systems can be preferred compared to plain solar evaporation and low-cost evaporation systems. Small-scale industries can adopt the rack evaporation method as it performs high evaporation at a low cost.

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