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ACTIVATED BIO CHAR: A HIGHLY EFFECTIVE ADSORBENT FOR THE REMOVAL OF CONTAMINANTS FROM DAIRY WASTEWATER

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ABSTRACT

This study evaluated the efficiency of activated biochar, made from cotton stalk biomass, in removing contaminants from dairy processing plant wastewater. The biochar adsorber targeted pollutants like pH, EC, TDS, TSS, Turbidity, BOD, and COD. Different doses (2g, 6g, 10g) of adsorbent were tested in 1 liter of wastewater over 1, 2, and 3-hour contact times. Maximum biosorption of contaminants was observed with a 10g/L dosage of activated biochar and 3-hour contact time, showing high removal efficiency. Initial pH of the dairy wastewater was 6.83, which adjusted to about 7.5 after treatment with both chemically and physically activated biochar. The initial EC was 1.655 dS/m, reduced by up to 26.64% with physically activated biochar and 24.47% with chemically activated biochar. TDS concentration, initially at 1060.75 mg/L, was reduced by 26.73% and 24.56%, respectively. TSS, initially 473.665 mg/L, decreased by 67.85% with physical activation and 65.37% with chemical activation. Turbidity, initially at 133 NTU, reduced by 75.99% and 75.65%, respectively. COD and BOD levels, initially 1110.5 and 406.5 mg/L, were reduced by 71.80% and 73.43% with physically activated biochar, and 67.92% and 72.82% with chemically activated biochar. Nitrogen removal efficiency was 73.37% with physical activation and 69.92% with chemical. Phosphorus removal was 70.44% and 65.44%, respectively. Lead, initially 2.04 mg/L, was reduced by 77.45% with physical activation and 74.50% with chemical activation, while Zinc, initially 1.01 mg/L, was reduced by 79.20% and 77.22%, respectively. Results indicate that activated biochar from cotton stalk is effective for removing contaminants from dairy wastewater. The highest removal efficiency was achieved with a 10g/L dosage and 3-hour contact time. Comparatively, physically activated biochar showed slightly better removal efficiency than chemically activated biochar.

Key words: Activated Biochar, Adsorption, Contaminants, Removal efficiency, Wastewater.

Introduction

Biochar's application in wastewater treatment is broadly categorized into organic and inorganic remediation. Biochar, derived from carbon-rich biomass through pyrogenic black carbon, is gaining attention for its multifunctionality, including carbon sequestration, soil fertility enhancement, bio-energy production, and environmental remediation (Mohan *et al.*, 2014). Biochar's porosity and functional groups are crucial for diverse applications, but unmodified biochar faces limitations with its small surface area and poor pore properties (Tan *et al.*, 2016). Raw biochar exhibits limited adsorption capacity for contaminants in concentrated wastewater (Nair and Vinu, 2016; Yao *et al.*, 2013). Activating biochar has garnered scientific attention for better environmental applications, particularly through physical and chemical activation techniques (Lee *et al.*, 2018). Activated biochar finds applications in soil remediation, particularly for removing organic pollutants and heavy metals through absorption (Ahmad *et al.*, 2014).

Dairy processing plants can be characterized by intensive water consumption and high pollution potential (Duarte *et al.*, 2016). The amount and composition of the wastewater generated from dairy plants are closely related processed products, the production schedule, operating methods, plant design, and degree of water management being applied and subsequently the amount of water being recycled (Dvarioniene *et al.*, 2012). In general, wastes from the dairy processing industry contain high concentration of organic material as biological oxygen demand (BOD) and chemical oxygen demand (COD), suspended solids (SS), nutrients, suspended oil or grease and large variations in pH (Demirel *et al.*, 2005; Luo *et al.*, 2011).

In adsorption, the adsorb ate is associated with the adsorbent's surface until equilibrium is achieved. The steps involved in the adsorption process include:

(a) Physical adsorption in which the adsorbate settles on the adsorbent's surface;

(b) Precipitation and complexation in which the adsorbate deposits on the adsorbent's surface;

(c) Pore filling in which the adsorbate is condensed into the pore of the adsorbent (Fagbohungbe *et al.,* 2017).

Activated bio char is highly effective for dairy plant wastewater treatment due to its high surface area and adsorption capabilities, removing contaminants like organic compounds, heavy metals, phosphorus, and nitrogen. It stabilizes pH, mitigates odors, and requires minimal energy, repurposing agricultural waste for sustainable, cost-effective treatment. Its long-lasting performance and ability to target specific contaminants make it a valuable addition to wastewater treatment systems. (Logan *et al.*, 2022).

Materials and Methods

Water Sample Collection

The effluent was collected in plastic cans from the Dairy processing plant near Junagadh city, Junagadh, Gujarat. The samples were preserved below 4°C temperature.

Physio-Chemical Analysis of Wastewater

pH

Glass electrode digital pH meter was used to measure the pH of the wastewater sample before which It was calibrated using the electrometric method.

Electrical conductivity (EC)

Digital Electrical conductivity meter was used to measure the EC of the wastewater before which it was calibrated with different standards (Richard, 1954).

Total dissolved solids

Digital TDS meter was used to measure the TDS of the wastewater before which it was calibrated with different standards (Howard, 1933**)** Gravimetric method.

Turbidity (NTU)

It is a measure of cloudiness of water. Turbidity meter is an instrument for measuring and comparing the turbidity of liquids by passing light through them and determine how much light is reflected by the particles in the liquid. The normal measuring range is 0 to 100 is expressed as Nephelometric Turbidity Units (Mhaske *et al.,* 2014).

Total suspended solids (TSS)

The total suspended solids were measured using the Gravimetric method. The principle involved is evaporation of the liquid at 103-105°C (APHA, 1998).

TSS mg/l = (A-B) × 1000/ Sample volume (ml)

Chemical oxygen demand (COD)

Indian Standard methods of sampling and test (physical and chemical) for water (APHA, 2005) method was used to analyze the COD in the samples.

$$\text{COD (mg/l)} = \frac{(\text{B-A})\times\text{Normality of Fe(NH}_4)(\text{SO}_4)_2\,6\text{H}_2\text{O}\times 8\times 1000}{\text{ml of sample taken for estimation}} \quad (1)$$

Where,

A = ml of titrant required for titration against blank, in ml

B = ml of titrant required for titration of sample, in ml

Biochemical Oxygen Demand (BOD)

Azide Modification of Iodometric method as explained in APHA (2000) was used to measure BOD content present in the samples.

$$\text{BOD (mg/L)} = D_1 - D_2 \times D_f \quad (2)$$

Where,

D_1 = DO of diluted sample immediately after preparation (mg/l).

D_2 = DO of diluted sample after 5 days' incubation at 20°C (mg/l).

D_f = Dilution factor

Total Kjeldahl Nitrogen

Total nitrogen was estimated by Kjeldahl method as explained in Physio-Chemical Examination of Water Sewage and Industrial Effluents. However, Salicylic acid thiosulphate modification of Kjeldahl method was used to convert all forms of nitrogen to ammonia.

$$TKN \text{ as } N\ (mg/l) = \frac{(\text{A - B})\times 0.28\times 1000}{\text{V}} \quad (3)$$

Where, A = ml 0.02 N H_2SO_4 for sample

B = ml 0.02 N H_2SO_4 for blank

V = Volume of sample in ml

Total Phosphorus

For phosphates estimation, reagent "A" (added 1 g of ammonium molybdate, 0.02 g of potassium antimony tartrate in 1000.0 ml measuring flask. Then 16 ml of concentrated sulphuric acid will be added to the contents and then distilled water will be added slowly. Finally, the contents will be allowed to dissolve by shaking) and reagent "B" (dissolved 0.88 g of ascorbic acid in 1000.0 ml of reagent "A") will be prepared. Reagent "B" will be prepared freshly (should be prepared freshly) and 4 ml of this reagent "B" will be added to water sample. Made up the volume up to 25 ml with distilled water and absorbance of the color will be measured at 630 nm wavelength in spectrophotometer.

Heavy metals

Nitric acid-hydrochloric acid method was used for digestion of water sample for heavy metal analysis as suggested by APHA (2000). The filtered solution was directly aspirated and concentration of the trace metals was analysed through Atomic Absorption Spectrophotometer (AAS). Specific hollow cathode lamps were used for analysis of different metals. The elements chosen for analysis was zinc (Zn), cadmium (Cd), iron, copper, nickel and lead (Pb) because these are ubiquitous pollutants present in the wastewater.

Process modification at various adsorbent dose and residence time

In this wastewater treatment experiment, a known quantity of prepared biochar (2gm, 6gm and 10gm) was introduced into the wastewater samples (1000 ml) with the aim of mitigating contaminants. Thorough mixing, facilitated by a digital shaker, ensures optimal contact between the biochar and contaminants. The mixture was allowed to interact for a specified contact time (1hour, 2hours and 3hours), during which gentle agitation may be employed to enhance the biochar's adsorption capabilities. Subsequently, the treated water was separated from the biochar using Whatman No. 4 filter paper, and the collected water was subjected to physio-chemical analysis. The concentrations of contaminants in the treated water were measured and compared with initial concentrations to gauge the extent of contaminant removal.

Details of Independent and Dependent Variable

S.	Type of Variable	Levels	Details
Independent Variable			
1.	Biochar Activation Method	2 levels	A_1 = Chemically Activated
			A_2 = Physically Activated
2.	Absorbent dose	3 levels	W_1 = 2gm
			W_2 = 6gm
			W_3 = 10gm
3.	Shaking Time	3 levels	T_1 = 1hour
			T_2 = 2hours
			T_3 = 3hours
Dependent Variable			
4.	Parameters	Ph, TDS, TSS, EC, Turbidity, COD, BOD, Heavy metals, Total Phosphorus, Nitrogen	

Removal Efficiency

$$\textit{Removal efficiency}\ (\%) = \frac{C_i - C_f}{C_i} \times 100 \tag{4}$$

Where,

C_i is initial concentration of Contaminants in solution

C_f is final concentration of Contaminants in solution.

Statistical Analysis

Statistical analysis was carried out by the Factorial Complete Randomized Design (FCRD) method in which the effect of various treatments on various parameters was analyzed (Panse and Sukhatme, 1967).

Results and Discussion

The results of the experiments conducted on "Activated biochar: A highly effective adsorbent for the removal of contaminants from dairy wastewater." have been described.

Initial Physio-Chemical Characteristics of Dairy Processing Plant Wastewater

The Wastewater sample was collected from Dairy Processing Plant near to Junagadh city and the initial characterization of the effluent was done. The initial concentrations of various parameters of the effluent were found to be present above the permissible limits. The

Table 1: Initial characteristics of dairy processing plant wastewater.

S. no.	Parameters	Concent-ration	Permissible limit for irrigation (Source: CPCB)
1.	pH	6.828	6.0 – 8.5
2.	EC (dS/m)	1.655	0.75
3.	TDS (mg/l)	1060.750	< 750
4.	TSS (mg/l)	473.665	-
5.	Turbidity (NTU)	133	< 30
6.	COD (mg/l)	1110.25	150
7.	BOD (mg/l)	406.500	30
8.	Nitrogen (mg/l)	50.698	Max. 20.00
9.	Phosphorus (mg/l)	54.985	Max. 10.00
10.	Lead (mg/l)	2.040	0.79
11.	Zinc (mg/l)	1.008	2.00

Table 2: Properties of Cotton stalk activated biochar (Faldu *et. al.*, 2024).

Biochar Properties	Chemically activated cotton stalk biochar	Physically activated cotton stalk biochar
Ash content (%, d.b)	13.52	15.10
Volatile matter (%, d.b)	37.38	40.40
Fixed carbon (%, d.b)	45.12	44.49
Calorific value (cal/g)	8092.5	8021.7
pH	4.56	8.34
EC (dS/m)	1.9	1.13

analysed results are shown in the Table 1. In general, wastes from the dairy processing industry contain high concentration of organic material as biological oxygen demand (BOD) and chemical oxygen demand (COD), suspended solids (SS), nutrients, suspended oil and/or grease, and large variations in pH (Demirel *et al.*, 2005; Luo *et al.*, 2011).

Evaluation of physically and chemically Activated Bio char for Removal of Contaminants from Dairy Processing Plant Wastewater

Effect of various treatments on pH concentration

The initial concentration of pH in the wastewater sample was found to be about 6.828. after wastewater absorbent treatment results of pH in wastewater shown in the Table 3 and comparative graph of pH value at Initial and after wastewater treatments are shown in the Fig. 1.

Table 3: Activated bio char treatments effect on pH.

Sr. No.	Initial concentration of pH	Treatment	After treatment concentration of pH
1	6.828	$A_1T_1W_1$	7.468
2	6.828	$A_1T_1W_2$	7.483
3	6.828	$A_1T_1W_3$	7.518
4	6.828	$A_1T_2W_1$	7.498
5	6.828	$A_1T_2W_2$	7.515
6	6.828	$A_1T_2W_3$	7.688
7	6.828	$A_1T_3W_1$	7.445
8	6.828	$A_1T_3W_2$	7.498
9	6.828	$A_1T_3W_3$	7.498
10	6.828	$A_2T_1W_1$	7.435
11	6.828	$A_2T_1W_2$	7.468
12	6.828	$A_2T_1W_3$	7.495
13	6.828	$A_2T_2W_1$	7.318
14	6.828	$A_2T_2W_2$	7.385
15	6.828	$A_2T_2W_3$	7.435
16	6.828	$A_2T_3W_1$	7.365
17	6.828	$A_2T_3W_2$	7.373
18	6.828	$A_2T_3W_3$	7.468

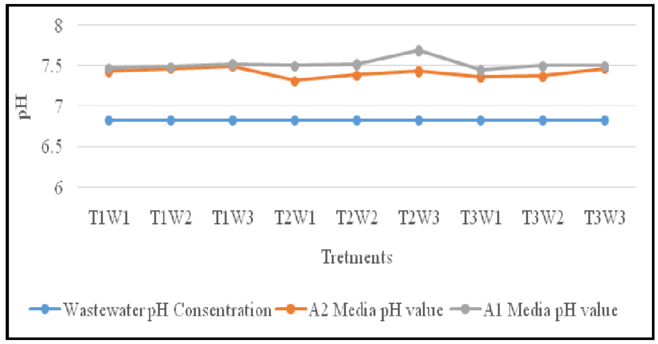

Fig. 1: Comparison of pH value before and after treatments of wastewater.

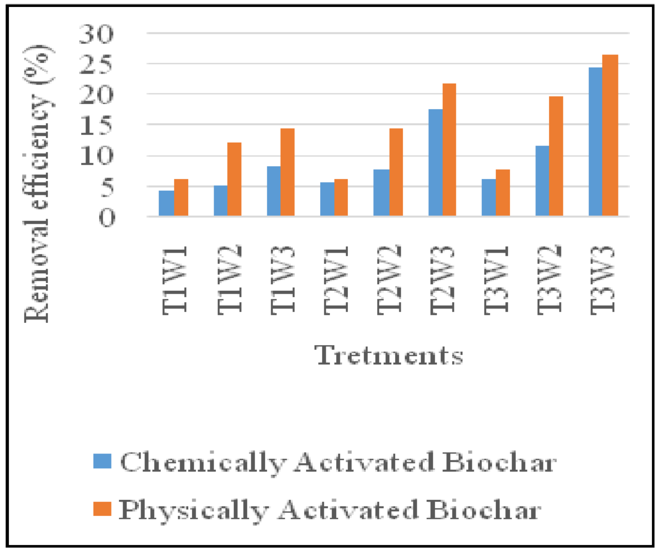

Fig. 2: Comparison of EC removal efficiency.

Table 4: Effect of various treatments on EC concentration.

Sr. No.	Initial concent-ration of EC	Treat-ment	After treatment concentration of EC (dS/m)	Removal efficiency (%)
1	1.655	$A_1T_1W_1$	1.582	4.41
2	1.655	$A_1T_1W_2$	1.570	5.14
3	1.655	$A_1T_1W_3$	1.519	8.22
4	1.655	$A_1T_2W_1$	1.560	5.74
5	1.655	$A_1T_2W_2$	1.526	7.79
6	1.655	$A_1T_2W_3$	1.361	17.76
7	1.655	$A_1T_3W_1$	1.550	6.34
8	1.655	$A_1T_3W_2$	1.459	11.84
9	1.655	$A_1T_3W_3$	1.250	24.47
10	1.655	$A_2T_1W_1$	1.551	6.28
11	1.655	$A_2T_1W_2$	1.453	12.21
12	1.655	$A_2T_1W_3$	1.412	14.68
13	1.655	$A_2T_2W_1$	1.553	6.16
14	1.655	$A_2T_2W_2$	1.414	14.56
15	1.655	$A_2T_2W_3$	1.292	21.93
16	1.655	$A_2T_3W_1$	1.526	7.79
17	1.655	$A_2T_3W_2$	1.326	19.88
18	1.655	$A_2T_3W_3$	1.214	26.65

Table 5: Effect of various treatments on TDS concentration.

Sr. No.	Initial concent-ration of TDS (mg/l)	Treat-ment	After treatment concentration of TDS (mg/l)	Removal efficiency (%)
1	1060.75	$A_1T_1W_1$	1012.41	4.56
2	1060.75	$A_1T_1W_2$	1004.64	5.29
3	1060.75	$A_1T_1W_3$	971.86	8.38
4	1060.75	$A_1T_2W_1$	1014.40	4.37
5	1060.75	$A_1T_2W_2$	976.80	7.91
6	1060.75	$A_1T_2W_3$	870.72	17.91
7	1060.75	$A_1T_3W_1$	981.50	7.47
8	1060.75	$A_1T_3W_2$	933.92	11.96
9	1060.75	$A_1T_3W_3$	800.16	24.57
10	1060.75	$A_2T_1W_1$	992.80	6.41
11	1060.75	$A_2T_1W_2$	929.60	12.36
12	1060.75	$A_2T_1W_3$	903.68	14.80
13	1060.75	$A_2T_2W_1$	993.76	6.31
14	1060.75	$A_2T_2W_2$	905.12	14.67
15	1060.75	$A_2T_2W_3$	827.04	22.03
16	1060.75	$A_2T_3W_1$	976.48	7.94
17	1060.75	$A_2T_3W_2$	848.64	19.98
18	1060.75	$A_2T_3W_3$	777.12	26.74

Table 6: Effect of various treatments on TSS concentration.

Sr. No.	Initial concent-ration of TSS (mg/l)	Treat-ment	After treatment concentration of TSS (mg/l)	Removal efficiency (%)
1	473.665	$A_1T_1W_1$	422.50	10.80
2	473.665	$A_1T_1W_2$	350.50	26.02
3	473.665	$A_1T_1W_3$	261.00	44.89
4	473.665	$A_1T_2W_1$	396.25	16.34
5	473.665	$A_1T_2W_2$	311.25	34.30
6	473.665	$A_1T_2W_3$	248.25	47.59
7	473.665	$A_1T_3W_1$	393.25	16.98
8	473.665	$A_1T_3W_2$	211.00	55.45
9	473.665	$A_1T_3W_3$	164.00	65.38
10	473.665	$A_2T_1W_1$	420.50	11.22
11	473.665	$A_2T_1W_2$	344.25	27.32
12	473.665	$A_2T_1W_3$	260.25	45.05
13	473.665	$A_2T_2W_1$	381.75	19.40
14	473.665	$A_2T_2W_2$	252.50	46.69
15	473.665	$A_2T_2W_3$	237.25	49.91
16	473.665	$A_2T_3W_1$	353.50	25.37
17	473.665	$A_2T_3W_2$	227.00	52.07
18	473.665	$A_2T_3W_3$	152.25	67.86

Effect of various treatments on EC concentration

The initial concentration of EC in the wastewater sample was found to be about 1.655 dS/m. Among the various treatments carried out, it was concluded that physically activated biochar with 10g/l of the wastewater used in the retention time of 3 hours had the highest EC removal efficiency of about 26.65% and similarly, chemically activated biochar had the EC removal efficiency of about 24.47%.

Effect of various treatments on TDS concentration

The initial concentration of TDS in the wastewater sample was found to be about 1060.75 mg/l. The experimental results are shown in the Table 5 and comparative graph of removal efficiencies of Chemically and Physically activated biochar are shown in the Fig. 3. For 2g, 6g and 10g of physically activated and chemically activated biochar in higher retention time of 3 hours, the removal efficiencies were found to be 14.80%, 22.03%, 26.74% and 8.38%, 17.91%, 24.57% respectively.

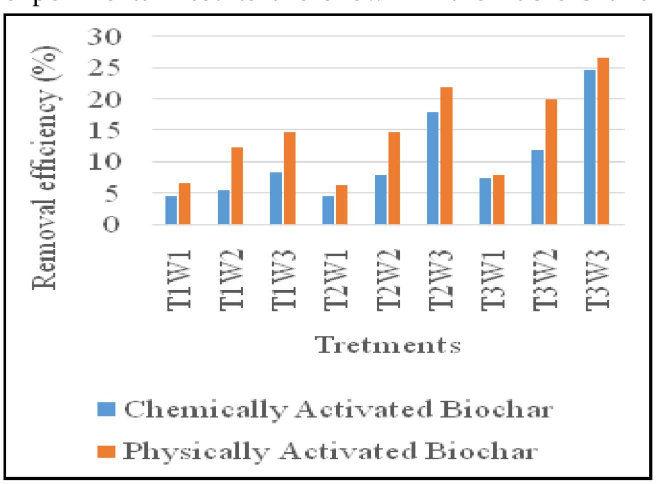

Fig. 3: Comparison of TDS removal efficiency.

Effect of various treatments on TSS concentration

The initial concentration of TSS in the wastewater

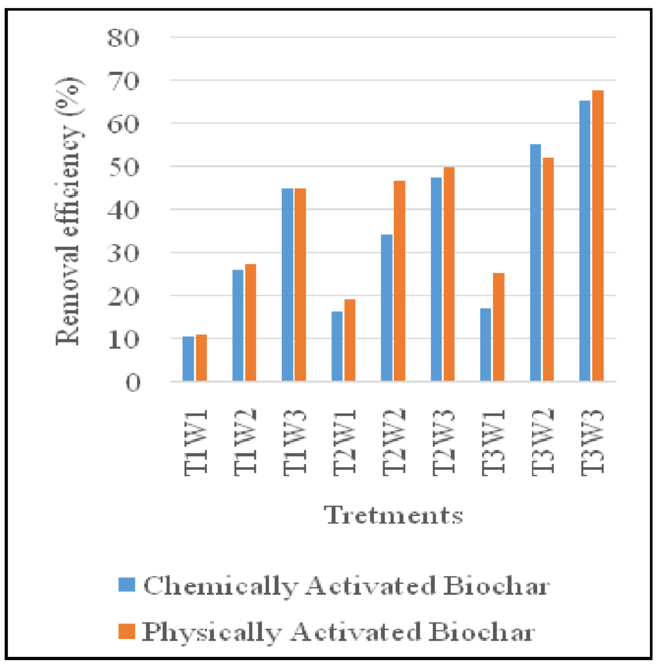

Fig. 4: Comparison of TSS removal efficiency.

Table 7: Effect of various treatments on Turbidity concentration.

Sr. No.	Initial concent-ration of Turbidity	Treat-ment	After treatment concentration of Turbidity	Removal efficiency (%)
1	133	$A_1T_1W_1$	80.900	39.17
2	133	$A_1T_1W_2$	80.025	39.83
3	133	$A_1T_1W_3$	75.650	43.12
4	133	$A_1T_2W_1$	76.500	42.48
5	133	$A_1T_2W_2$	62.325	53.14
6	133	$A_1T_2W_3$	58.000	56.39
7	133	$A_1T_3W_1$	65.825	50.51
8	133	$A_1T_3W_2$	57.750	56.58
9	133	$A_1T_3W_3$	32.375	75.66
10	133	$A_2T_1W_1$	70.125	47.27
11	133	$A_2T_1W_2$	69.350	47.85
12	133	$A_2T_1W_3$	69.475	47.76
13	133	$A_2T_2W_1$	73.050	45.08
14	133	$A_2T_2W_2$	59.950	54.92
15	133	$A_2T_2W_3$	53.075	60.09
16	133	$A_2T_3W_1$	64.600	51.42
17	133	$A_2T_3W_2$	55.475	58.28
18	133	$A_2T_3W_3$	31.925	75.99

sample was found to be about 473.665 mg/l. the highest TSS removal efficiency of about 67.86% and similarly, chemically activated biochar had the TSS removal efficiency of about 65.38%.

Effect of Various Treatments on Turbidity Concentration

The initial concentration of Turbidity in the wastewater sample was found to be about 133. The experimental

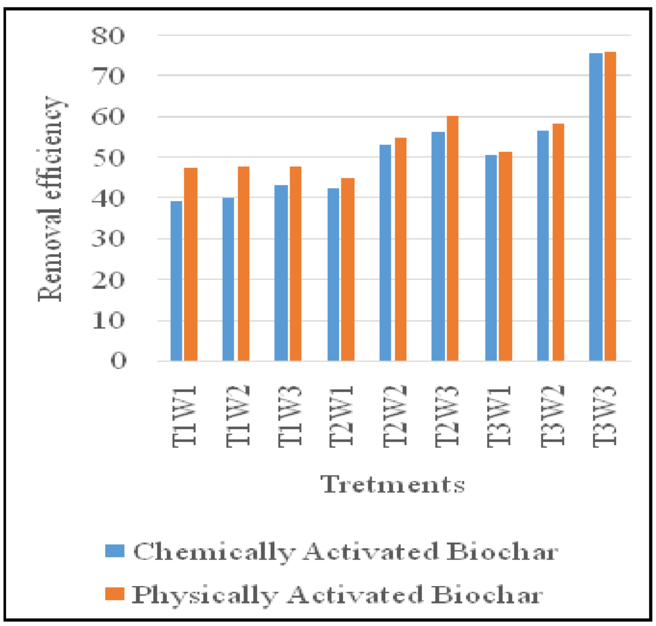

Fig. 5: Comparison of turbidity removal efficiency.

Table 8: Effect of various treatments on COD concentration.

Sr. No.	Initial concent-ration of COD (mg/l)	Treat-ment	After treatment concentration of COD (mg/l)	Removal efficiency (%)
1	1110.25	$A_1T_1W_1$	1065.25	4.053
2	1110.25	$A_1T_1W_2$	881.50	20.60
3	1110.25	$A_1T_1W_3$	555.00	50.01
4	1110.25	$A_1T_2W_1$	1008.50	9.16
5	1110.25	$A_1T_2W_2$	811.00	26.95
6	1110.25	$A_1T_2W_3$	463.75	58.23
7	1110.25	$A_1T_3W_1$	972.50	12.41
8	1110.25	$A_1T_3W_2$	764.50	31.14
9	1110.25	$A_1T_3W_3$	356.25	67.91
10	1110.25	$A_2T_1W_1$	1011.75	8.87
11	1110.25	$A_2T_1W_2$	821.00	26.05
12	1110.25	$A_2T_1W_3$	537.00	51.64
13	1110.25	$A_2T_2W_1$	1010.75	8.96
14	1110.25	$A_2T_2W_2$	724.00	34.79
15	1110.25	$A_2T_2W_3$	423.00	61.90
16	1110.25	$A_2T_3W_1$	971.00	12.54
17	1110.25	$A_2T_3W_2$	616.00	44.58
18	1110.25	$A_2T_3W_3$	313.00	71.81

results are shown in the Table 7 and comparative graph of removal efficiencies of Chemically and Physically activated biochar are shown in the Fig. 5. For 2g, 6g and 10g of physically activated and chemically activated biochar in higher retention time of 3 hours, the removal efficiencies were found to be 47.76%, 60.09%, 75.99% and 43.22%, 56.39%, 75.66% respectively.

Effect of various treatments on COD concentration

The initial concentration of COD in the wastewater

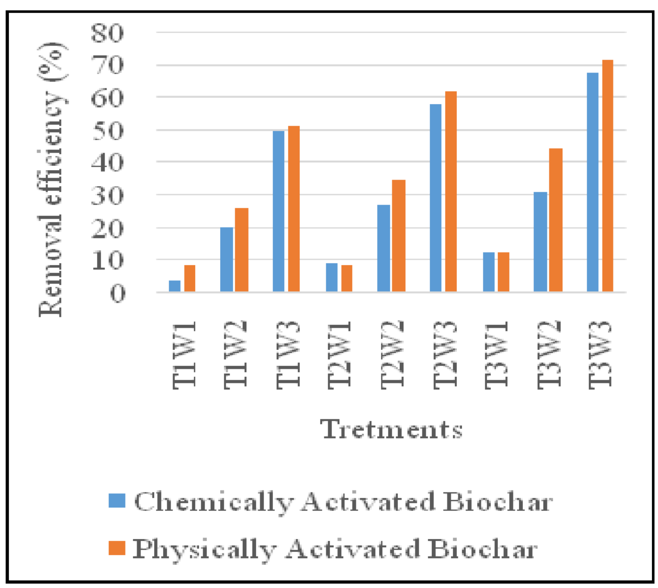

Fig. 6: Comparison of COD removal efficiency.

Table 9: Effect of various treatments on BOD concentration.

Sr. No.	Initial concent-ration of BOD (mg/l)	Treat-ment	After treatment concentration of BOD (mg/l)	Removal efficiency (%)
1	406.50	$A_1T_1W_1$	354.75	12.73
2	406.50	$A_1T_1W_2$	304.25	25.15
3	406.50	$A_1T_1W_3$	183.75	54.79
4	406.50	$A_1T_2W_1$	335.50	17.47
5	406.50	$A_1T_2W_2$	265.25	34.75
6	406.50	$A_1T_2W_3$	169.25	58.36
7	406.50	$A_1T_3W_1$	339.25	16.54
8	406.50	$A_1T_3W_2$	250.00	38.50
9	406.50	$A_1T_3W_3$	110.50	72.82
10	406.50	$A_2T_1W_1$	336.00	17.34
11	406.50	$A_2T_1W_2$	275.75	32.16
12	406.50	$A_2T_1W_3$	179.00	55.96
13	406.50	$A_2T_2W_1$	348.75	14.21
14	406.50	$A_2T_2W_2$	311.25	23.43
15	406.50	$A_2T_2W_3$	142.25	65.00
16	406.50	$A_2T_3W_1$	331.75	18.39
17	406.50	$A_2T_3W_2$	206.50	49.20
18	406.50	$A_2T_3W_3$	108.00	73.43

sample was found to be about 1110.5 mg/l. Among the various treatments carried out, it was concluded that physically activated biochar with 10g/l of the wastewater used in the retention time of 3 hours had the highest COD removal efficiency of about 71.81% and similarly, chemically activated biochar had the COD removal efficiency of about 67.91%. The experimental results are shown in the Table 8 and comparative graph of removal efficiencies of Chemically and Physically activated biochar are shown in the Fig. 6. For 2g, 6g and 10g of physically activated and chemically activated biochar in higher retention time of 3 hours, the removal efficiencies were found to be 51.64%, 61.90%, 71.81% and 50.01%, 58.23%, 67.91% respectively.

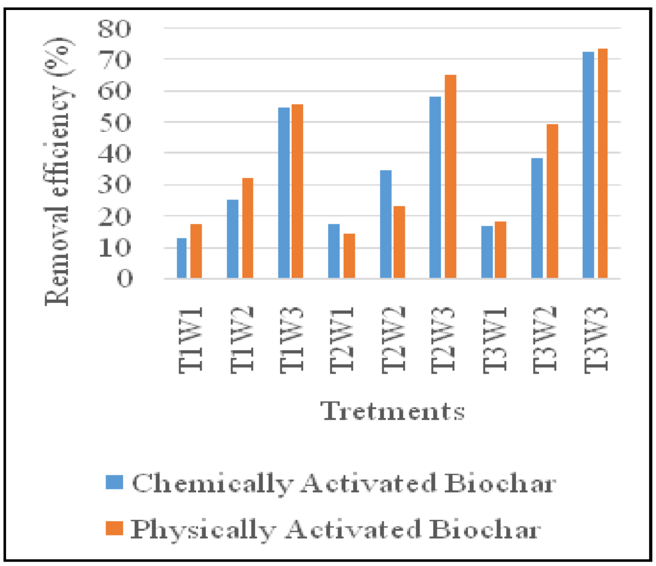

Fig. 7: Comparison of BOD removal efficiency.

Table 10: Effect of various treatments on Nitrogen concentration.

Sr. No.	Initial concent-ration of Nitrogen (mg/l)	Treat-ment	After treatment concentration of Nitrogen (mg/l)	Removal efficiency (%)
1	50.698	$A_1T_1W_1$	38.75	23.57
2	50.698	$A_1T_1W_2$	32.50	35.89
3	50.698	$A_1T_1W_3$	23.25	54.14
4	50.698	$A_1T_2W_1$	35.50	29.98
5	50.698	$A_1T_2W_2$	27.25	46.25
6	50.698	$A_1T_2W_3$	16.50	67.45
7	50.698	$A_1T_3W_1$	39.50	22.09
8	50.698	$A_1T_3W_2$	25.50	49.70
9	50.698	$A_1T_3W_3$	15.25	69.92
10	50.698	$A_2T_1W_1$	35.00	30.96
11	50.698	$A_2T_1W_2$	28.00	44.77
12	50.698	$A_2T_1W_3$	22.00	56.60
13	50.698	$A_2T_2W_1$	35.00	30.96
14	50.698	$A_2T_2W_2$	22.00	56.60
15	50.698	$A_2T_2W_3$	16.50	67.45
16	50.698	$A_2T_3W_1$	34.50	31.95
17	50.698	$A_2T_3W_2$	21.50	57.59
18	50.698	$A_2T_3W_3$	13.50	73.37

Effect of various treatments on BOD concentration

The initial concentration of BOD in the wastewater sample was found to be about 406.5 mg/l.

Effect of various treatments on nitrogen concentration

The initial concentration of Nitrogen in the wastewater sample was found to be about 50.698 mg/l.

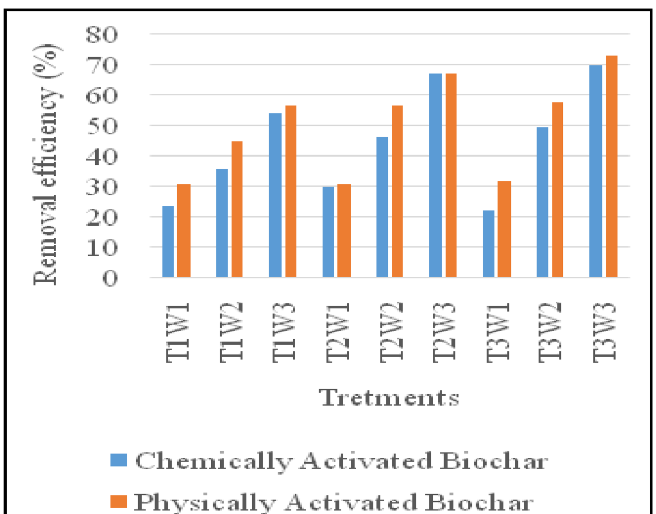

Fig. 8: Comparison of nitrogen removal efficiency.

Table 11: Effect of various treatments on Phosphorus concentration.

Sr. No.	Initial concent-ration of Phosphorus (mg/l)	Treat-ment	After treatment concentration of Phosphorus (mg/l)	Removal efficiency (%)
1	54.985	$A_1T_1W_1$	48.25	12.25
2	54.985	$A_1T_1W_2$	35.75	34.99
3	54.985	$A_1T_1W_3$	28.50	48.17
4	54.985	$A_1T_2W_1$	45.00	18.17
5	54.985	$A_1T_2W_2$	35.25	35.90
6	54.985	$A_1T_2W_3$	22.75	58.63
7	54.985	$A_1T_3W_1$	43.50	20.89
8	54.985	$A_1T_3W_2$	24.75	54.99
9	54.985	$A_1T_3W_3$	19.00	65.45
10	54.985	$A_2T_1W_1$	47.25	14.08
11	54.985	$A_2T_1W_2$	34.00	38.17
12	54.985	$A_2T_1W_3$	25.25	54.08
13	54.985	$A_2T_2W_1$	42.00	23.62
14	54.985	$A_2T_2W_2$	33.50	39.08
15	54.985	$A_2T_2W_3$	20.75	62.26
16	54.985	$A_2T_3W_1$	42.00	23.62
17	54.985	$A_2T_3W_2$	22.00	59.99
18	54.985	$A_2T_3W_3$	16.25	70.45

Among the various treatments carried out, it was concluded that physically activated biochar with 10g/l of the wastewater used in the retention time of 3 hours had the highest nitrogen removal efficiency of about 73.37% and similarly, chemically activated biochar had the nitrogen removal efficiency of about 69.92%. The experimental results are shown in the Table 10 and comparative graph of removal efficiencies of Chemically and Physically

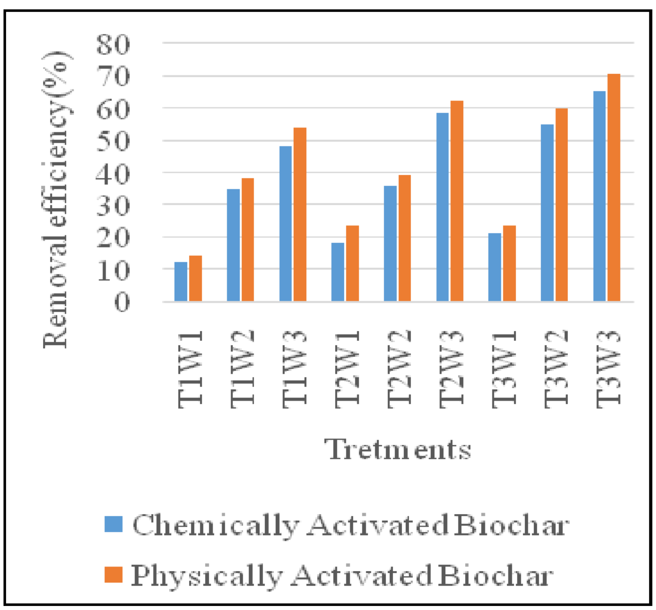

Fig. 9: Comparison of phosphorus removal efficiency.

Table 12: Effect of various treatments on Lead concentration.

Sr. No.	Initial concent-ration of Lead (mg/l)	Treat-ment	After treatment concentration of Lead (mg/l)	Removal efficiency (%)
1	2.04	$A_1T_1W_1$	1.45	28.92
2	2.04	$A_1T_1W_2$	0.97	52.45
3	2.04	$A_1T_1W_3$	0.71	65.20
4	2.04	$A_1T_2W_1$	1.34	34.31
5	2.04	$A_1T_2W_2$	0.77	62.25
6	2.04	$A_1T_2W_3$	0.62	69.61
7	2.04	$A_1T_3W_1$	1.33	34.80
8	2.04	$A_1T_3W_2$	0.67	67.16
9	2.04	$A_1T_3W_3$	0.52	74.51
10	2.04	$A_2T_1W_1$	1.22	40.20
11	2.04	$A_2T_1W_2$	0.88	56.86
12	2.04	$A_2T_1W_3$	0.45	77.94
13	2.04	$A_2T_2W_1$	1.11	45.59
14	2.04	$A_2T_2W_2$	0.62	69.61
15	2.04	$A_2T_2W_3$	0.55	73.04
16	2.04	$A_2T_3W_1$	0.92	54.90
17	2.04	$A_2T_3W_2$	0.57	72.06
18	2.04	$A_2T_3W_3$	0.46	77.45

activated biochar are shown in the Fig. 8. For 2g, 6g and 10g of physically activated and chemically activated biochar in higher retention time of 3 hours, the removal efficiencies were found to be 56.60%, 67.45%, 73.37% and 54.14%, 67.45%, 69.92% respectively.

Effect on Phosphorus

The initial concentration of Phosphorus in the wastewater sample was found to be about 54.985 mg/l. Among the various treatments carried out, it was concluded that physically activated biochar with 10g/l of the wastewater used in the retention time of 3 hours had the highest phosphorus removal efficiency of about 70.45% and similarly, chemically activated biochar had the phosphorus removal efficiency of about 65.45%. The experimental results are shown in the Table 11 and comparative graph of removal efficiencies of Chemically and Physically activated biochar are shown in the Fig. 9. For 2g, 6g and 10g of physically activated and chemically activated biochar in higher retention time of 3 hours, the removal efficiencies were found to be 54.08%, 62.26%, 70.45% and 48.17%, 58.63%, 65.45% respectively.

Effect on Lead

The initial concentration of Lead in the wastewater sample was found to be about 2.04 mg/l. Among the various treatments carried out, it was concluded that physically activated biochar with 10g/l of the wastewater

Table 13: Effect of various treatments on Zinc concentration.

Sr. No.	Initial concent-ration of Zinc (mg/l)	Treat-ment	After treatment concentration of Zinc (mg/l)	Removal efficiency (%)
1	1.01	$A_1T_1W_1$	0.44	56.43
2	1.01	$A_1T_1W_2$	0.43	57.42
3	1.01	$A_1T_1W_3$	0.35	65.35
4	1.01	$A_1T_2W_1$	0.46	54.45
5	1.01	$A_1T_2W_2$	0.35	65.35
6	1.01	$A_1T_2W_3$	0.28	72.28
7	1.01	$A_1T_3W_1$	0.45	55.45
8	1.01	$A_1T_3W_2$	0.25	75.25
9	1.01	$A_1T_3W_3$	0.23	77.22
10	1.01	$A_2T_1W_1$	0.42	58.41
11	1.01	$A_2T_1W_2$	0.31	69.31
12	1.01	$A_2T_1W_3$	0.3	70.30
13	1.01	$A_2T_2W_1$	0.38	62.38
14	1.01	$A_2T_2W_2$	0.29	71.29
15	1.01	$A_2T_2W_3$	0.25	75.25
16	1.01	$A_2T_3W_1$	0.35	65.35
17	1.01	$A_2T_3W_2$	0.25	75.28
18	1.01	$A_2T_3W_3$	0.21	79.21

used in the retention time of 3 hours had the highest Lead removal efficiency of about 77.45% and similarly, chemically activated biochar had the Lead removal efficiency of about 74.51%. The experimental results are shown in the Table 12 and comparative graph of removal efficiencies of Chemically and Physically activated biochar are shown in the Fig. 10. For 2g, 6g and 10g of physically activated and chemically activated biochar in

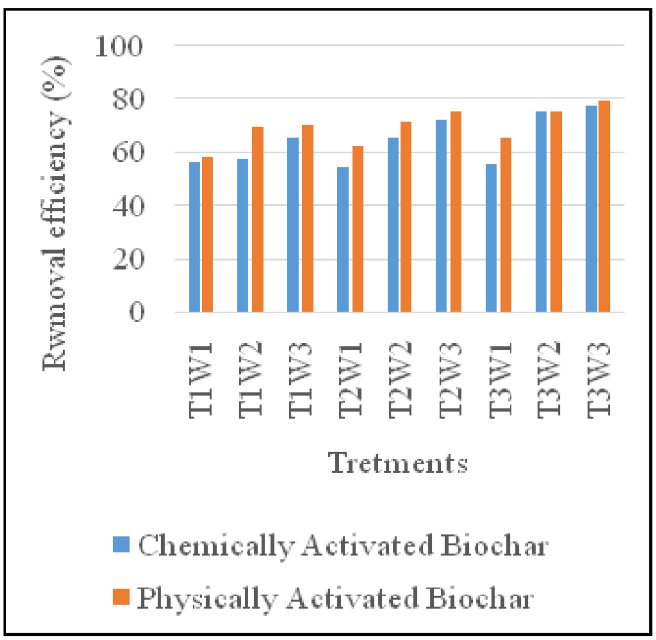

Fig. 10: Comparison of lead removal efficiency.

higher retention time of 3 hours, the removal efficiencies were found to be 70.94%, 73.04%, 77.45% and 65.20%, 69.61%, 74.51% respectively.

Effect on Zinc

The initial concentration of Zinc in the wastewater sample was found to be about 1.01 mg/l. Among the various treatments carried out, it was concluded that physically activated biochar with 10g/l of the wastewater used in the retention time of 3 hours had the highest Zinc removal efficiency of about 79.21% and similarly, chemically activated biochar had the Zinc removal efficiency of about 77.22%. The experimental results are shown in the Table 13 and comparative graph of removal efficiencies of Chemically and Physically activated biochar are shown in the Fig. 11. For 2g, 6g and 10g of physically activated and chemically activated biochar in higher retention time of 3 hours, the removal efficiencies were found to be 70.30%, 75.25%, 79.21% and 65.35%, 72.28%, 77.22% respectively.

Conclusion

The study tested three dosages (2g, 6g, 10g) of two types of activated biochar in 1 litre of wastewater at retention times of 1, 2, and 3 hours, totalling 18 treatments. Results showed higher dosages and longer retention times improved pollutant removal, with physically activated biochar outperforming chemically activated biochar. The optimal treatment was 10g of physically activated biochar per litre at 3 hours, significantly reducing pollutant levels to safe discharge limits. Activated biochar proved to be a cost-effective, eco-friendly solution for wastewater treatment. Further research on its toxicological impact is recommended for sustainable use.

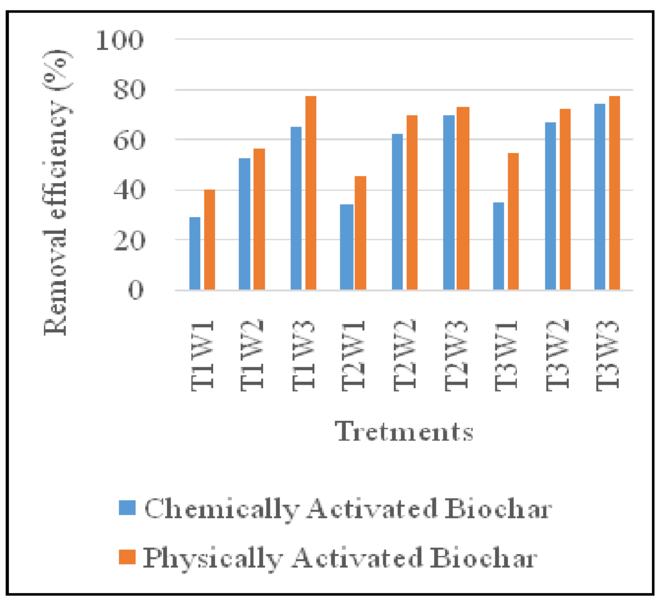

Fig. 11: Comparison of zinc removal efficiency.

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