



Influence of Zeolite Application on Soil Infiltrated with Sewage Effluent

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A laboratory-based soil column study was undertaken to assess the influence of zeolite application on soil treated with sewage effluent. Seven treatments, varying in zeolite proportions ($T_1=0.25\%$, $T_2=0.50\%$, $T_3=0.75\%$, $T_4=1.00\%$, $T_5=1.25\%$, $T_6=1.50\%$, and T_7 =control without zeolite), were replicated three times for the experiment. Analysis of leachate and residual soil after the experiment included parameters such as pH, electrical conductivity (EC), organic carbon (OC), available nitrogen, phosphorus, and potassium. Results indicated a significant increase in soil pH, EC, organic carbon, available nitrogen, phosphorus, and potassium with zeolite application. Leachate from the control column exhibited the highest values for pH (7.74), EC ($190.33 \mu\text{Scm}^{-1}$), BOD (34.33 mg L^{-1}), COD (72.67 mg L^{-1}), nitrate-N (40.23 mg L^{-1}), phosphorus (5.96 mg L^{-1}), and potassium (12.31 mg L^{-1}), differing significantly from leachate collected from treatment columns.

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1. INTRODUCTION

The management of sewage effluent poses significant challenges to environmental sustainability, particularly regarding its impact on soil quality and ecosystem health. With the increasing demand for wastewater treatment and disposal, there is a growing need for effective remediation strategies to mitigate the adverse effects of sewage effluent on soil ecosystems. One such strategy involves the application of zeolites, which have shown promise in various environmental remediation applications due to their unique adsorption and ion exchange properties. Zeolites are microporous, aluminosilicate minerals with a high surface area and cation exchange capacity, making them effective adsorbents for a wide range of contaminants, including heavy metals, organic pollutants, and nutrients. In the context of soil remediation, zeolites have been investigated for their potential to mitigate the negative effects of sewage effluent infiltration by adsorbing pollutants, improving soil structure, and enhancing nutrient retention. Several studies have explored the influence of zeolite application on soil properties and plant growth in sewage-contaminated environments, yielding promising results. However, there is still a need for a comprehensive understanding of the mechanisms underlying the interactions between zeolites, sewage effluent, and soil components. Additionally, the effectiveness of zeolite-based remediation strategies may vary depending on factors such as zeolite type, application rate, soil characteristics, and the composition of the sewage effluent.

This research aims to study the influence of zeolite application on soil infiltrated with sewage effluent, with a focus on its effects on soil physicochemical parameters. By examining the current state of knowledge and identifying key research gaps, this study seeks to provide insights into the potential role of zeolites in mitigating the environmental impact of sewage effluent contamination and informing future remediation efforts.

2. MATERIALS AND METHODS

A laboratory-based soil column study was conducted to examine the impact of zeolite on sewage-treated soil. Soil samples were obtained from the Agricultural Farm at the Institute of

Agricultural Sciences, BHU, Varanasi, while effluent was sourced from the Bhagwanpur sewage treatment plant in Varanasi. The experimental soil was slightly alkaline in nature having a pH of 7.75 and non-saline with EC 0.30 dS m⁻¹. The bulk density, particle density, and porosity of the soil were 1.31 g cm⁻³, 2.46 g cm⁻³, and 47.38 % respectively. The organic carbon content was 4.79 g Kg⁻¹. The available nutrient content was found to be nitrogen 207.87 Kg ha⁻¹, phosphorus 22.43 Kg ha⁻¹, and potassium 197.07 Kg ha⁻¹. The synthetic zeolite of type A was purchased from Sigma Aldrich. The pH of the effluent was 8.01 which represents its slightly alkaline nature. The electrical conductivity of the effluent was 590 µScm⁻¹. The biological oxygen demand of the effluent was found to be 77 mg L⁻¹, while the chemical oxygen demand was 225 mg L⁻¹. Nitrate N present in the effluent sample was 12.85 mg L⁻¹, phosphate content was 6.14 mg L⁻¹ and potassium content was 8.1 mg L⁻¹. Cylindrical polyvinyl chloride pipes of 10 cm diameter and 50 cm in height, were set up on a wooden stand. These pipes were filled with soil up to a depth of 30 cm, with the top 15 cm containing soil mixed with varying proportions of zeolite (T₁=0.25%, T₂=0.50%, T₃=0.75%, T₄=1.00%, T₅=1.25%, T₆=1.50%, and T₇=control without zeolite). Each treatment was replicated three times. A funnel was placed at the base of the columns to collect leachates. Following saturation of the soil columns with sewage effluent, leaching was initiated, and the collected leachates were subjected to analysis for key parameters using standard procedures. Subsequently, the soil was removed from the columns. The soil mixed with zeolite (designated as the D₁ layer) and the soil from the 15-30 cm depth (designated as the D₂ layer) were separated. The soil samples were then allowed to air-dry in the shade, processed, and analyzed for various physical and chemical properties, including pH, electrical conductivity, organic carbon, available N, P, and K. Statistical analysis of the leachate data was conducted using a completely randomized design (CRD), while soil data were analyzed using a factorial CRD design, with the adsorbent treatment as one factor with seven levels and the column layer as the second factor with two levels (D₁ and D₂).

3. RESULTS AND DISCUSSION

Table 1 to Table 6 present data on the impact of zeolite application on soil pH, electrical

conductivity (EC), organic carbon content, available nitrogen (N), available phosphorus (P), and available potassium (K) following infiltration with sewage water. The highest pH recorded was 7.88, observed in treatment T₆, which was statistically comparable to T₅ but significantly higher than all other treatments. Conversely, the lowest pH was recorded in the control column, which was statistically similar to treatments T₁ and T₂. The alkaline nature of zeolite contributed to the increase in soil pH. However, a slight decrease in pH was noted down the column, likely due to the leaching of basic cations present in the sewage effluent. This phenomenon aligns with findings reported by Szatanik-Kloc et al. [1],

indicating a rise in soil pH following the addition of zeolite. Zeolite application had a significant increase in the EC of soil. The EC of the control soil column was reported to be 0.41 dS m⁻¹ which was significantly lower than the EC of the rest treatment column soil except T₁. Soil from the T₆ column had the highest EC ie. 0.53 dS m⁻¹. EC of the soil going down the column also increased significantly. An increase in cation exchange capacity of soil due to the addition of zeolite [2,3] might be the reason behind increasing the EC of the soil. Leaching of the cations present in sewage water down the column resulted in comparatively higher EC at D₂.

Table 1. Effect of zeolite application on soil pH

Treatment	D ₁	D ₂		Mean (T)		
T ₁	7.65	7.70		7.68 ^d		
T ₂	7.69	7.75		7.72 ^{cd}		
T ₃	7.72	7.79		7.75 ^c		
T ₄	7.77	7.77		7.77 ^{bc}		
T ₅	7.82	7.83		7.83 ^{ab}		
T ₆	7.87	7.89		7.88 ^a		
T ₇	7.62	7.71		7.67 ^d		
Mean (D)	7.73 ^b	7.78 ^a		7.76		
SE(m)(T)	CD (T)	SE(m)(D)	CD (D)	SE(m)(TXD)	CD (TXD)	CV(%)
0.026	0.075	0.014	0.040	0.036	0.106	0.814

Table 2. Effect of zeolite application on soil EC (dS m⁻¹)

Treatment	D ₁	D ₂		Mean (T)		
T ₁	0.39	0.44		0.42 ^d		
T ₂	0.42	0.47		0.45 ^{cd}		
T ₃	0.45	0.50		0.48 ^{bc}		
T ₄	0.47	0.48		0.48 ^{bc}		
T ₅	0.48	0.51		0.50 ^{ab}		
T ₆	0.52	0.55		0.53 ^a		
T ₇	0.37	0.45		0.41 ^d		
Mean (D)	0.44 ^b	0.49 ^a		0.46		
SE(m)(T)	CD (T)	SE(m)(D)	CD (D)	SE(m)(TXD)	CD (TXD)	CV(%)
0.016	0.045	0.008	0.024	0.022	0.064	8.177

Table 3. Effect of zeolite application on soil organic carbon (g Kg⁻¹)

Treatment	D ₁	D ₁		Mean (T)		
T ₁	4.82	4.79		4.80 ^{de}		
T ₂	4.83	4.80		4.82 ^{cd}		
T ₃	4.84	4.81		4.83 ^{bc}		
T ₄	4.85	4.80		4.82 ^{bc}		
T ₅	4.86	4.80		4.83 ^b		
T ₆	4.87	4.83		4.85 ^a		
T ₇	4.81	4.79		4.80 ^e		
Mean (D)	4.84 ^a	4.80 ^b		4.82		
SE(m)(T)	CD (T)	SE(m)(D)	CD (D)	SE(m)(TXD)	CD (TXD)	CV(%)
0.004	0.011	0.002	0.006	0.030	0.086	1.016

Table 4. Effect of zeolite application on soil available nitrogen (mg Kg⁻¹)

Treatment	D ₁	D ₂	Mean (T)			
T ₁	95.63 ^{de}	94.31 ^{de}	94.97 ^c			
T ₂	97.74 ^{bcd}	95.65 ^{de}	96.69 ^{bc}			
T ₃	101.18 ^{abc}	96.94 ^{cd}	99.06 ^{ab}			
T ₄	102.94 ^{ab}	96.28 ^{cde}	99.61 ^{ab}			
T ₅	103.84 ^a	96.51 ^{cde}	100.18 ^{ab}			
T ₆	105.16 ^a	96.95 ^{cd}	101.06 ^a			
T ₇	91.19 ^e	95.19 ^{de}	93.19 ^c			
Mean (D)	99.67 ^a	95.98 ^b	97.82			
SE(m)(T)	CD (T)	SE(m)(D)	CD (D)	SE(m)(TXD)	CD (TXD)	CV(%)
1.302	3.772	0.696	2.016	1.841	5.334	3.260

Table 5. Effect of zeolite application on soil available phosphorus (mg Kg⁻¹)

Treatment	D ₁	D ₂	Mean (T)			
T ₁	11.42	10.47	10.95 ^c			
T ₂	11.56	10.59	11.08 ^{bc}			
T ₃	11.72	10.79	11.25 ^{bc}			
T ₄	11.93	10.96	11.44 ^{bc}			
T ₅	12.13	11.20	11.67 ^b			
T ₆	14.16	11.36	12.76 ^a			
T ₇	11.20	10.50	10.85 ^c			
Mean (D)	12.02 ^a	10.84 ^b	11.43			
SE(m)(T)	CD (T)	SE(m)(D)	CD (D)	SE(m)(TXD)	CD (TXD)	CV(%)
0.234	0.678	0.125	0.362	0.331	0.959	5.016

Table 6. Effect of zeolite application on soil available potassium (mg Kg⁻¹)

Treatment	D ₁	D ₂	Mean (T)			
T ₁	88.75	88.51	88.63 ^c			
T ₂	89.10	88.92	89.01 ^c			
T ₃	89.25	89.21	89.23 ^{bc}			
T ₄	89.32	89.33	89.33 ^{bc}			
T ₅	90.20	89.68	89.94 ^b			
T ₆	91.99	89.96	90.98 ^a			
T ₇	88.74	88.34	88.54 ^c			
Mean (D)	89.62 ^a	89.14 ^b	89.38			
SE(m)(T)	CD (T)	SE(m)(D)	CD (D)	SE(m)(TXD)	CD (TXD)	CV(%)
0.303	0.877	0.162	0.469	0.428	1.241	0.830

Table 7. Effect of zeolite application on leachate parameters

Treatment	Parameters						
	pH	EC (µScm ⁻¹)	BOD (mg L ⁻¹)	COD (mg L ⁻¹)	Nitrate N (mg L ⁻¹)	P (mg L ⁻¹)	K (mg L ⁻¹)
T ₁	7.19	113.67	8.00	32.33	25.14	6.30	10.33
T ₂	7.20	117.00	6.33	33.33	23.64	6.04	9.77
T ₃	7.17	115.33	6.67	35.67	22.86	5.97	8.52
T ₄	7.15	116.67	7.33	35.00	19.34	5.68	8.33
T ₅	7.21	113.67	6.00	32.00	16.30	5.52	7.11
T ₆	7.21	115.67	7.00	35.00	14.56	5.12	5.67
T ₇	7.74	190.33	34.33	72.67	40.23	5.96	12.31
SEM	0.03	2.01	1.18	1.56	0.47	0.16	0.25
CD	0.07	4.92	2.89	3.82	1.15	0.40	0.62
CV	0.63	2.76	18.94	6.87	3.52	4.84	4.96
S/NS	S	S	S	S	S	S	S

It was observed that the application of zeolite resulted in a significant increase in the organic carbon of the soil. The available organic carbon of the control soil column was reported to be 4.80 g Kg^{-1} which was significantly lower than the rest of the treatment column soil except T_1 . Soil from the T_6 column had the highest available organic carbon i.e. 4.85 g Kg^{-1} . Available organic carbon of the soil going down the column also decreased significantly and it was 4.84 g Kg^{-1} in the upper 15 cm layer and 4.80 g Kg^{-1} in the lower (15 – 30 cm) region. This difference can be attributed to the zeolite addition in the upper layer. A study by Aminiyan et al. [4] also noted an increase in water-soluble and other fractions of organic carbon in the soil post-zeolite addition. Furthermore, the infiltration of sewage effluent into the soil likely contributed to the rise in available organic carbon content, particularly in the upper soil layers. Similar findings were reported by Mishra et al. [5] and Alghobar et al. [6].

Zeolite application significantly increased the available nitrogen content of the soil. It was observed that mixing 1.5 % of zeolite (T_6) into the soil resulted in the highest available soil N i.e. $101.06 \text{ mg Kg}^{-1}$ which was significantly higher than that of the control column (T_7) which showed 93.10 mg Kg^{-1} N. Zeolite addition likely contributed to this increase by reducing NH_4^+ losses through increased cation exchange capacity and NH_4^+ adsorption onto the zeolite mineral lattice, as well as enhanced soil moisture [7]. Moreover, zeolite inclusion prevented nitrate N leaching by adsorbing NH_4^+ ions [8,9], making it less accessible for microbial oxidation and resulting in elevated nitrogen concentration in the upper soil layer. The interaction effect was also found to be significant and the highest N $105.16 \text{ mg Kg}^{-1}$ was reported in T_6D_1 and the lowest 91.19 mg Kg^{-1} in T_7D_1 .

The application of zeolite resulted in a significant increase in the available phosphorus content of the soil. It was observed that mixing 1.5 % of zeolite (T_6) into the soil resulted in the highest available soil P i.e. 12.76 mg Kg^{-1} which was significantly higher than that of the control column (T_7) which showed 10.85 mg Kg^{-1} P. The available P content in the control column (T_7) was significantly lower than that in T_5 and T_6 . The addition of zeolite likely enhanced phosphorus availability by increasing soil moisture and cation exchange capacity (CEC), allowing for the adsorption of Ca^{2+} ions. This lowers the concentration of Ca^{2+} ions in the soil solution,

resulting in more dissolution of calcium phosphate and making phosphorus more available to plants [9]. Furthermore, zeolite, with its negative charges and alkaline nature, may mitigate soil pH, reduce exchangeable aluminum, and alleviate soil acidity, all of which decrease the fixation of phosphorus by metal oxyhydroxides in the soil [10]. The interaction effect was found to be insignificant.

The application of zeolite significantly increased the available potassium content of the soil. Mixing 1.5 % of zeolite (T_6) into the soil resulted in the highest available soil K i.e. 90.98 mg Kg^{-1} which was significantly higher than that of the control column (T_7) which showed 88.54 mg Kg^{-1} K. The available K content in control column T_7 was significantly lower than that of T_5 and T_6 . A consistent increase in available potassium was observed with increasing zeolite dose, supported by findings from Ravali et al. [11], Mpanga et al. [12], and Abdi et al. [13]. Zeolites, owing to their high porosity and cation exchange capacity (CEC), enhance soil CEC, thus improving the soil's capacity to retain and release nutrients such as ammonium (NH_4^+) and potassium (K^+). The interaction effect was found to be insignificant. The increase in available nitrogen, available phosphorus and available potassium content was attributed to the infiltration of sewage water into the soil, a phenomenon supported by Alghobar et al. [6].

The impact of zeolite application on the physicochemical properties of sewage effluent passed through the soil is outlined in Table 7. The experiment revealed a notable influence of zeolite application on these parameters. The pH of the leachate from the control column (7.74) was significantly higher than that of the leachate from columns treated with zeolites. Additionally, the electrical conductivity (EC) of the control column's leachate ($190.33 \mu\text{Scm}^{-1}$) surpassed that of the other treatment columns. The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of the control column's leachate were notably higher at 34.33 mg L^{-1} and 72.67 mg L^{-1} , respectively, compared to other treatment columns. Nitrate nitrogen levels in the control column's leachate were significantly elevated at 40.23 mg L^{-1} , while treatment T_6 exhibited the most notable reduction, with nitrate content measured at 16.30 mg L^{-1} . Phosphate content was lowest in T_6 at 5.12 mg L^{-1} , significantly lower than the control's 5.96 mg L^{-1} . Moreover, potassium content in the control column's leachate (12.31 mg L^{-1}) was

notably higher than that of leachate from columns treated with zeolites. The reduction in physicochemical properties of sewage effluent after infiltrating it through the zeolite-mixed soil column can be attributed to several mechanisms like adsorption, ion exchange, physical filtration, and chemical reactions.

4. CONCLUSION

Mixing zeolite with soil has a significant effect on the physicochemical properties of residual soil after infiltrating it with sewage water. It was observed that zeolite application to the soil significantly increased the soil pH, EC, organic carbon, available nitrogen, available phosphorus, and available potassium. Leachate collected after infiltrating the zeolite-treated soil column showed significant differences in the parameters. The pH, EC, BOD, COD, nitrate- N, P, and K of the leachate was maximum under the control column which differed significantly from that of the leachate collected from treatment columns.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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