Influence of zeolite application on soil infiltrated with sewage effluent

Abstract

A laboratory-based soil column study was undertaken to assess the influence of zeolite on soil treated with sewage. Soil samples were procured from the Agricultural Farm at the Institute of Agricultural Sciences, BHU, Varanasi, while effluent was sourced from the Bhagwanpur sewage treatment plant in Varanasi. Seven treatments, varying in zeolite proportions (0.25%, 0.50%, 0.75%, 1.00%, 1.25%, 1.50%, and 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 maximum values for pH, EC, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate-N, phosphorus, and potassium, differing significantly from leachate collected from treatment columns.

Keywords: Infiltration, leachate, zeolite**.**

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.

Material and Method

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. 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 (0.25%, 0.50%, 0.75%, 1.00%, 1.25%, 1.50%, and a 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 adsorbent material (designated as D1 layer) and the soil from the 15-30 cm depth (designated as 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 (EC), organic carbon (OC), available nitrogen (N), phosphorus (P), and potassium (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).

Result 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. (2021), 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. Increase in cation exchange capacity of soil due to addition of zeolite (Rehakova et al. 2004, Xiubin and Zhanbin 2001) 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.

The application of zeolite led to a significant increase in the soil's organic carbon content. The control soil column exhibited a lower available organic carbon content of 4.95%, significantly lower than that of the soil columns treated with zeolite. Notably, the T6 column soil displayed the highest available organic carbon content at 5.13%. As observed, the available organic carbon content decreased significantly down the column, measuring 5.11% in the upper 15 cm layer and 5.03% in the lower layer (15–30 cm). This difference can be attributed to the zeolite addition in the upper layer. A study by Aminiyan et al. (2015) 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. (2023) and Alghobar et al. (2014).

Zeolite application significantly increased the available nitrogen content in the soil. Mixing 1.5% zeolite (T6) resulted in the highest available soil nitrogen at 226.37 Kg ha-1, notably higher than the control column (T7) which recorded 208.75 Kg ha-1 of nitrogen. Zeolite addition likely contributed to this increase by reducing NH4+ losses through increased cation exchange capacity and NH4+ adsorption onto the zeolite mineral lattice, as well as enhanced soil moisture (Ippolito et al., 2011). Moreover, zeolite inclusion prevented nitrate N leaching by adsorbing NH4+ ions (Aghaalikhani et al., 2012; Zheng et al., 2019), making it less accessible for microbial oxidation and resulting in elevated nitrogen concentration in the upper soil layer. The interaction effect was also significant, with the highest nitrogen concentration observed in T6D1 (235.56 Kg ha-1) and the lowest in T7D1 (213.23 Kg ha-1).

The application of zeolite resulted in a significant increase in the available phosphorus content of the soil. Mixing 1.5% zeolite (T6) led to the highest available soil phosphorus at 28.58 Kg ha-1, notably higher than the control column (T7) which recorded 24.30 Kg ha-1 of phosphorus. The available phosphorus content in the control column (T7) was significantly lower than in other treatments, except for T1.The addition of zeolite likely enhanced phosphorus availability by increasing soil moisture and cation exchange capacity (CEC), allowing for the adsorption of Ca2+ ions. This lowers the concentration of Ca2+ ions in the soil solution, resulting in more dissolution of calcium phosphate and making phosphorus more available to plants (Zheng et al., 2019). 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 (Aainaa et al., 2018). The interaction effect was found to be insignificant.

The application of zeolite significantly increased the available potassium content of the soil. Mixing 1.5% zeolite (T6) resulted in the highest available soil potassium at 230.42 Kg ha-1, which was notably higher than the control column (T7) with 198.33 Kg ha-1 of potassium. The available potassium content in the control column (T7) was significantly lower than that of other treatment columns. A consistent increase in available potassium was observed with increasing zeolite dose, supported by findings from Ravali et al. (2021), Mpanga et al. (2020), and Abdi et al. (2006). 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 (NH4+) and potassium (K+). The interaction effect was significant, with the highest potassium content observed in treatment T6 at a soil depth of 15-30 cm (T6D2), statistically comparable to T6 at a soil depth of 0-15 cm (T6D1).The increase in available nitrogen, available phosphorusand available potassium content was attributed to the infiltration of sewage water into the soil, a phenomenon supported by Alghobar et al. (2014).

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 μScm-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 T6 exhibited the most notable reduction, with nitrate content measured at 16.30 mg L-1. Phosphate content was lowest in T6 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 ractions.

Conclusion:

Mixing of zeolite with soil renders 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 the significant differences in the parameters. The pH, EC, BOD, COD, nitrate-N, P, and Kof the leachate was maximum under control column which differed significantly with that of the leachate collected from treatment columns.

References :

Szatanik-Kloc A, Szerement J, Adamczuk A, Józefaciuk G. Effect of Low Zeolite Doses on Plants and Soil Physicochemical Properties. Materials. 2021; 14(10):2617. https://doi.org/10.3390/ma14102617

Rehakova, M.; Cuvanova, S.; Dzivak, M.; Rimar, J.; Gavalova, Z. Agricultural and agrochemical uses of natural zeolite of the clinoptilolite type. Curr. Opin. Solid State Mater. Sci. 2004, 8, 397–404. [CrossRef]

Xiubin, H.; Zhanbin, H. Zeolite applications for enhancing water infiltration and retention in loess soil. Resour. Conserv. Recycl. 2001, 34, 45–52. [CrossRef]

Aminiyan MM, Safari Sinegani AA &Sheklabadi M. (2015). The effect of zeolite and some plant residues on soil organic carbon changes in density and soluble fractions: Incubation study. Eurasian Soil Science. 2016, 5 (1) 74 - 83.18393/ejss.2016.1.074-083.

Mishra S, Kumar R and Kumar M. 2023. Use of treated sewage or wastewater as an irrigation water for agricultural purposes- Environmental, health, and economic impacts. Total Environment Research Themes. Volume 6, 2023, 100051. ISSN 2772-8099. https://doi.org/10.1016/j.totert.2023.100051.

Alghobar MA, Ramachandra L, Suresha S. 2014. Effect of Sewage Water Irrigation on Soil Properties and Evaluation of the Accumulation of Elements in Grass Crop in Mysore City, Karnataka, India. American Journal of Environmental Protection. Vol. 3, No. 5, 2014, pp. 283-291. doi: 10.11648/j.ajep.20140305.22

Ippolito JA, Tarkalson DD and Lehrsch GA. (2011). Zeolite Soil Application Method Affects Inorganic Nitrogen, Moisture, and Corn Growth. Soil Science, 176(3), 136–142. doi:10.1097/ss.0b013e31820e4063.

Aghaalikhani, Majid; Gholamhoseini, Majid; Dolatabadian, Aria; Khodaei-Joghan, Aydin; Sadat Asilan, Kamal (2012). Zeolite influences on nitrate leaching, nitrogen-use efficiency, yield and yield components of canola in sandy soil. Archives of Agronomy and Soil Science, 58(10), 1149–1169. doi:10.1080/03650340.2011.572876

Zheng J; Chen T; Chi D ; Xia G ; Wu Q ; Liu G, ; Chen W, ; Meng W, ; Chen Y and Siddique KHM. (2019). Influence of Zeolite and Phosphorus Applications on Water Use, P Uptake and Yield in Rice under Different Irrigation Managements. Agronomy, 9(9), 537–. doi:10.3390/agronomy9090537

Aainaa, H.N.; Ahmed, O.H.; Ab Majid, N.M. 2018. Effects of clinoptilolite zeolite on phosphorus dynamics and yield of Zea Mays L. cultivated on an acid soil. PLoS ONE 2018, 13, e0204401.

Ravali C, Rao KJ, Anjaiah T and Suresh K. 2021. Soil Application of Zeolite Affects Inorganic Nitrogen, Water Soluble and Exchangeable Potassium. International Journal of Environment and Climate Change11(11): 267-273. DOI: 10.9734/IJECC/2021/v11i1130541.

Mpanga IK, Braun H and Walworth J. 2020. Zeolite Application in Crop Production: Importance to Soil Nutrient, Soil Water, Soil Health, and Environmental Pollution Management. The University of Arizona Cooperative Extension.

Abdi, G.; Khosh-Khui, M.; Eshghi, S. Effects of Natural Zeolite on Growth and Flowering of Strawberry Fragariaxananassa Duch. Int. J. Agric. Res. 2006, 1, 384–389. [CrossRef]

Tables:

Table 1: Effect of zeolite application on soil pH

<table>
<tr><th></th><th colspan="2">D1</th><th colspan="2">D2</th><th colspan="2">Mean (T)</th></tr>
<tr><td>T1</td><td colspan="2">7.65</td><td colspan="2">7.70</td><td colspan="2">7.68^{d}</td></tr>
<tr><td>T2</td><td colspan="2">7.69</td><td colspan="2">7.75</td><td colspan="2">7.72^{cd}</td></tr>
<tr><td>T3</td><td colspan="2">7.72</td><td colspan="2">7.79</td><td colspan="2">7.75^{c}</td></tr>
<tr><td>T4</td><td colspan="2">7.77</td><td colspan="2">7.77</td><td colspan="2">7.77^{bc}</td></tr>
<tr><td>T5</td><td colspan="2">7.82</td><td colspan="2">7.83</td><td colspan="2">7.83^{ab}</td></tr>
<tr><td>T6</td><td colspan="2">7.87</td><td colspan="2">7.89</td><td colspan="2">7.88^{a}</td></tr>
<tr><td>T7</td><td colspan="2">7.62</td><td colspan="2">7.71</td><td colspan="2">7.67^{d}</td></tr>
<tr><td>Mean (D)</td><td colspan="2">7.73^{b}</td><td colspan="2">7.78^{a}</td><td colspan="2">7.76</td></tr>
<tr><td>SE(m)(T)</td><td>CD (T)</td><td>SE(m)(D)</td><td>CD (D)</td><td>SE(m)(TXD)</td><td>CD (TXD)</td><td>CV(%)</td></tr>
<tr><td>0.026</td><td>0.075</td><td>0.014</td><td>0.040</td><td>0.036</td><td>0.106</td><td>0.814</td></tr>
</table>

Table 2: Effect of zeolite application on soil EC

	D1	D2	Mean (T)
T1	0.39	0.44	0.42^{d}
T2	0.42	0.47	0.45^{cd}
T3	0.45	0.50	0.48^{bc}
T4	0.47	0.48	0.48^{bc}
T5	0.48	0.51	0.50^{ab}
T6	0.52	0.55	0.53^{a}

T7	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

	D1		**D2**		**Mean (T)**	
T1	5.12		5.03		5.07^{ab}	
T2	5.12		5.01		5.07^{b}	
T3	5.13		5.04		5.08^{ab}	
T4	5.14		5.06		5.10^{ab}	
T5	5.15		5.05		5.10^{ab}	
T6	5.17		5.09		5.13^{a}	
T7	4.96		4.95		4.95^{c}	
Mean (D)	5.11^{a}		5.03^{b}		5.07	
SE(m)(T)	CD (T)	**SE(m)(D)**	CD (D)	**SE(m)(TXD)**	CD (TXD)	CV(%)
0.021	0.061	0.011	0.033	0.030	0.086	1.016

Table 4: Effect of zeolite application on soil available Nitrogen

	D1		**D2**		**Mean (T)**	
T1	214.20^{de}		211.25^{de}		212.73^{c}	
T2	218.93^{bcd}		214.25^{de}		216.59^{bc}	
T3	226.63^{abc}		217.15^{cd}		221.89^{ab}	
T4	230.58^{ab}		215.67^{cde}		223.12^{ab}	
T5	232.61^{a}		216.19^{cde}		224.40^{ab}	
T6	235.56^{a}		217.17^{cd}		226.37^{a}	
T7	204.28^{e}		213.23^{de}		208.75^{c}	
Mean (D)	223.26^{a}		214.99^{b}		219.12	
SE(m)(T)	CD (T)	**SE(m)(D)**	CD (D)	**SE(m)(TXD)**	CD (TXD)	CV(%)
2.917	8.449	1.559	4.516	4.125	11.949	3.260

Table 5: Effect of zeolite application on soil available phosphorus

	D1	**D2**	**Mean (T)**
T1	25.59	23.45	24.52^{c}
T2	25.90	23.72	24.81^{bc}

T3	26.25		24.17		25.21^{bc}	
T4	26.72		24.54		25.63^{bc}	
T5	27.17		25.09		26.13^{b}	
T6	31.73		25.44		28.58^{a}	
T7	25.10		23.51		24.30^{c}	
Mean (D)	26.92^{a}		24.27^{b}		25.60	
SE(m)(T)	CD (T)	**SE(m)(D)**	CD (D)	**SE(m)(TXD)**	CD (TXD)	CV(%)
0.524	1.518	0.280	0.812	0.741	2.147	5.016

Table 6: Effect of zeolite application on soil available potassium

	D1		**D2**		**Mean (T)**	
T1	215.43^{e}		208.63^{g}		212.03^{f}	
T2	217.47^{e}		211.60^{f}		214.53^{e}	
T3	220.82^{d}		217.15^{e}		218.99^{d}	
T4	223.29^{cd}		221.52^{d}		222.41^{c}	
T5	227.48^{b}		224.51^{c}		226.00^{b}	
T6	230.33^{a}		230.52^{a}		230.42^{a}	
T7	198.40^{h}		198.26^{h}		198.33^{g}	
Mean (D)	219.03^{a}		216.03^{b}		217.53	
SE(m)(T)	CD (T)	**SE(m)(D)**	CD (D)	**SE(m)(TXD)**	CD (TXD)	CV(%)
0.633	1.835	0.339	0.981	0.896	2.594	0.713

Table 7: Effect of zeolite application on leachate parameters

Treatment	**Parameters**						
	pH	**EC**	**BOD**	**COD**	**Nitrate N**	**P**	**K**
T1	7.19	113.67	8.00	32.33	25.14	6.30	10.33
T2	7.20	117.00	6.33	33.33	23.64	6.04	9.77
T3	7.17	115.33	6.67	35.67	22.86	5.97	8.52

T4	7.15	116.67	7.33	35.00	19.34	5.68	8.33
T5	7.21	113.67	6.00	32.00	16.30	5.52	7.11
T6	7.21	115.67	7.00	35.00	14.56	5.12	5.67
T7	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