Heavy Metal Stabilization in Sewage Sludge Composting Process

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Authors' contributions

This work was carried out by the corresponding author MRR during MSc in Soil Science and Agricultural Chemistry under the guidance of author BJ. Authors BJ and RG managed the analyses of the study. Author RG managed the literature searches and correction of the manuscript. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

The most important factor limiting the soil application of sewage sludge is the presence of heavy metals.
This study was conducted to evaluate the effect of composting on nutrient content, heavy metal (Cd, Cr, Ni and Pb) concentration and heavy metal fractions in the sewage composts with different bulking agents (sawdust and coirpith), heavy metal adsorbent (zeolite) and liming materials (lime and flyash). Experimental results revealed that sewage sludge composts were rich in organic carbon and plant nutrients. Total nutrients and heavy metal concentration showed an increasing trend towards the maturity of composts. Heavy metal fractionation studies pointed out that mobile fractions of heavy metals such as exchangeable and carbonate fractions decreased at the end of composting whereas the residual fractions increased which indicates that composting of sewage sludge with heavy metal adsorbent and different bulking agents decreased the mobility and bioavailability of heavy metals. The compost C8 (Sewage sludge + sawdust + zeolite (50:30:20) + flyash) was superior with respect to stabilization of heavy metals studied. The concentration of Cd, Cr and Pb were within the permissible limit as per Fertilizer Control Order (FCO). The addition of coal flyash and zeolite enhanced the stabilization of heavy metals due to the higher alkalinity and

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ion exchange capacity of flyash and zeolite respectively. Polyphenolic group and organic compounds present in sawdust also have the ability to bind heavy metal. The study revealed that composting is an effective technology for reducing the heavy metal bioavailability and the heavy metal speciation studies of the matured composts revealed that considerable portion of the heavy metals were associated with immobile fractions indicating less bioavailability and ecotoxicity.

1. INTRODUCTION

The increase in urbanization and industrialization has caused a drastic increase in the volume of waste water and sewage sludge [1]. Sewage sludge is the residue generated during the waste water treatment process. An estimated 38,354 million liters of sewage with an equivalent amount of sludge per day is presently generated in India. Solid waste generation in class-1 cities of India is 1.9 million tonnes year^{-1}, whereas it is 0.21 million tonnes year^{-1} in class - II cities. Thiruvananthapuram Corporation is the largest city corporation in the Kerala state by area and population. This Municipal Corporation comprises an area of 141.74 sq. km. However, only 30 % of it is covered by a piped sewerage system. Quantum of solid waste and liquid waste generated .is 300 Metric tonnes (MT) and 100 Million litre per day (Ml d) respectively. Handling of huge quantities of sludge causes a significant proportion of the overall operating costs of water treatment works. The main disposal routes of sludge are incineration, sanitary landfill, or for land application. Use of sludge principally in agriculture involves lower costs when compared to incineration and sanitary landfill and all these methods have some potential impact on environment. So appropriate reuse strategies that are sustainable from an environmental and economic point of view are needed. The application of municipal solid waste improves the physico-chemical properties of soil and it act as a rich source of organic matter, macro and micronutrients for plants [2]. Presence of harmful pathogens and heavy metals are the major limiting factors restricting the agricultural use of sewage sludge. The main source of heavy metals in sewage sludge are waste water coming from various industries, domestic sewage, storm water runoff from roads etc. Concentration of metals in sewage sludge depends upon the sewage origin, sewage treatment process and sludge treatment process. By properly stabilizing the heavy metals present in the sludge by composting process it can be effectively utilized for crop production.

Composting of municipal solid waste is a method of diverting organic waste materials from landfills and creating a product, which is available at relatively low-cost and suitable for agricultural purposes [3]. Composting of sewage sludge can be done to minimize the availability of heavy metals by adding various additives [4]. Heavy metals are non-biodegradable and occur in different forms in sewage sludge and its compost. In order to assess the environmental impact of heavy metals their mobility and bioavailability have to be studied. This can be achieved through their chemical speciation in sludge and compost [5]. The total concentrations of heavy metals indicate the extent of contamination and provide only little information about the forms in which heavy metals are present, or about their potential for mobility and bioavailability in the environment [6]. Determination of the content of mobile and immobile fractions of metals is important as far as the mobility of metals are concerned. pH is an important factor that determines the mobility and bioavailability of metals [4]. The addition of liming material is very effective for reducing the plant availability of metals [7]. Coal flyash is the byproduct from coal fired power plants and its composition and pH vary depending upon the source. Addition of coal flyash to the sewage sludge during composting process is important due to the higher levels of CaO and MgO, which can precipitate the heavy metals and thereby reducing the toxicity of heavy metals. Addition of lime reduces heavy metal solubility. Sawdust and coirpith were always used in the sludge composting, which could be as bulking agent and conditioner. Wastewater sludge composting with the use of structural materials can enhance the stability of organic matter, inactivate pathogens and parasites. Bulking agents absorb the moisture, and improve the aeration and the final compost quality. Zeolites are crystalline solids structures made of silicon, aluminum and oxygen that form a framework with cavities and channels. Zeolite have the ability to take up metal due to its cation exchange and molecular sieving properties.

By properly stabilizing heavy metals present in the sludge by composting process it can be effectively utilized for crop production. Detailed studies are necessary in this direction. This will open a new frontier for usage of sewage sludge and thereby solid waste management. Hence the present investigation was carried out to prepare sewage sludge composts using sewage sludge from sewage treatment plant Muttathara Thiruvananthapuram, bulking agents, sawdust and coirpith, heavy metal adsorbent zeolite and liming materials flyash and lime and to characterize for nutrient content, total heavy metal concentration and their fractions.

2. MATERIALS AND METHODS

A composting experiment was conducted in College of Agriculture, Vellayani, Kerala Agricultural University during 2018-19. For compost preparation sewage sludge, sawdust, coirpith and zeolite were mixed in different ratios (Table 1) and lime and flyash were added to bring the pH of sewage sludge to 7. The amount of lime and flyash required were standardized by adding different levels of lime and flyash to 10g each of sewage sludge and determining the pH. The quantity of lime and flyash needed to bring the pH to 7 was ascertained by repeated trials and the quantity required for sewage sludge as per the treatments were calculated. The amount of lime and flyash used were 250 g and 2.5 kg respectively per 50 kg of sewage sludge. Composting method adopted was heap method and the period of composting was for 60 days. The heaps were turned at weekly intervals to provide sufficient oxygen for composting process and watered at 2 days interval to provide sufficient moisture. The temperature range provided during composting was about 50-60 °C. All the treatments were replicated thrice in the composting experiment.

Samples were collected from different zones of the compost heap at the start of the experiment (0th day) and at the end of composting process (60th day). Five samples were collected from each treatment and composite samples were prepared by using quartering technique. Samples were air-dried and passed through 1mm sieve. Compost samples were stored in an air tight container for analysis of pH, electrical conductivity, organic carbon, primary and secondary nutrients, heavy metals and their fractions. pH and electrical conductivity were determined using aqueous extract of dried samples in distilled water (1:5 w/v) using Cyber Scan PC510, pH meter and Systronics MK509

Conductivity meter respectively. Total organic carbon of dried samples were analysed by weight loss on ignition by vario EL cube Elemental Analyzer.

The total N was estimated by Kjeldahl method, P by colorimetry, K by flame photometry and the elements Ca and Mg were analysed by atomic absorption spectroscopy, using Perkin Elmer AAnalyst 400AA Spectrophotometer, S by turbidimetry using Systronics, 2201, Double Beam UV-VIS spectrophotometer. Analysis of the elements (Pb, Cd, Ni and Cr) was carried out by inductively coupled plasma-optical emission spectrophotometer (ICP-OES, Optima 8000). The fractionation of heavy metals were done by using sequential extraction procedure [8]. For exchangeable fraction extraction, 1 g of each sample was treated with 1 M CH_3COONa (pH 8.2) for 1 h at room temperature, for carbonate fraction the residue from first fraction was treated with 1 M CH_3COONa (pH 5.0) for 5 h at room temperature, for reducible fraction the residue from the second fraction was treated with 0.04 M NH_2OH. HCl in 25% v/v CH_3COOH for 6 h at 96 °C, for organic fraction the third residue was treated with 0.02 M HNO_3 and 30% w/v H_2O_2 was used for 2 h at 85 °C and pH 2.0, followed by the addition of 3.2 M CH_3COONH_4 in 20% w/v HNO_3 with 30% w/v H_2O_2 for 3 h at 85 °C and for residual fraction the final residue was digested with conc. HF and conc. HNO_3 for 1 h at room temperature to extract the residual fraction. Between successive extraction, the samples were centrifuged (5000 rpm for 30 min) and filtered. The filtrate was used for the determination of concentration of heavy metal fractions. Detectable limits for Pb (0.098 mg kg^{-1}), Cd (0.005 mg kg^{-1}), Ni (0.076 mg kg^{-1}) and Cr (0.032 mg kg^{-1}).

Table 1. Preparation of sewage sludge composts

Compost 1 (C1)	Sewage sludge + coirpith (50:50) + lime
Compost 2 (C2)	Sewage sludge + coirpith + zeolite (50:30:20) + lime
Compost 3 (C3)	Sewage sludge + sawdust + (50:50) + lime
Compost 4 (C4)	Sewage sludge + sawdust + zeolite (50:30:20) + lime
Compost 5 (C5)	Sewage sludge + coirpith (50:50) + fly ash
Compost 6 (C6)	Sewage sludge + coirpith+ zeolite (50:30:20) + flyash
Compost 7 (C7)	Sewage sludge + sawdust (50:50) +flyash
Compost 8 (C8)	Sewage sludge + sawdust + zeolite (50:30:20) + flyash

compounds. The carbon loss may be due the oxidation of C to CO_2 during composting process [13].

The variation in C: N ratio indicates the microbial decomposition of organic matter and stabilization during the process of composting. It is an important parameter as far as the availability of nutrients is concerned. There is a decrease in C:N ratio during composting. C7 (9.20) recorded the highest value and C2 (7.03) recorded the least value in the mature compost. During the composting process the degradable organic matter is converted to volatile CO_2 and was removed from the compost. As compost age increases there is an increase of nitrogen content

due to mineralisation of organic matter. Along with the loss of carbon and the increase of nitrogen content a reduction in C:N ratio occurs with time [14]. Due to the microbial activity reduction in carbon content as well as evolution of nitrogen occurs [15]. The increase in nitrogen content and microbial protein would have caused decrease in C:N ratio.

3.3 pH and Electrical Conductivity

The changes in pH and Electrical conductivity of the composts during composting is depicted in the Figs. 1 and 2. The pH of different composts ranged between 5.84 to 6.65 during the initial stages of composting. The pH of compost

Table 3. Effect of treatments on moisture content, bulk density, organic carbon and C:N ratio during composting

| Composts	Moisture content (%)		Bulk density (g cc^{-1})		Organic carbon (%)		C:N ratio	
	Initial compost	Mature compost	Initial compost	Mature compost	Initial compost	Mature compost	Initial compost	Mature compost
C1	41.72	47.41	0.40	0.44	25.22	14.23	16.93	8.27
C2	40.82	42.83	0.38	0.41	22.90	11.31	20.09	7.03
C3	35.10	37.45	0.66	0.71	24.53	12.70	20.79	7.90
C4	35.03	39.52	0.62	0.70	21.50	11.47	18.06	7.45
C5	51.09	49.78	0.44	0.47	25.65	13.32	23.75	8.01
C6	43.77	43.42	0.36	0.49	24.50	13.51	22.27	8.55
C7	29.19	39.53	0.57	0.69	23.50	14.45	17.40	9.20
C8	38.71	41.14	0.55	0.64	21.10	13.54	13.79	8.48
SE (m±)	0.68	1.76	0.02	0.01	-	0.54	-	0.52
C.D (0.05)	2.08	3.66	0.08	0.04	NS	1.62	NS	1.56
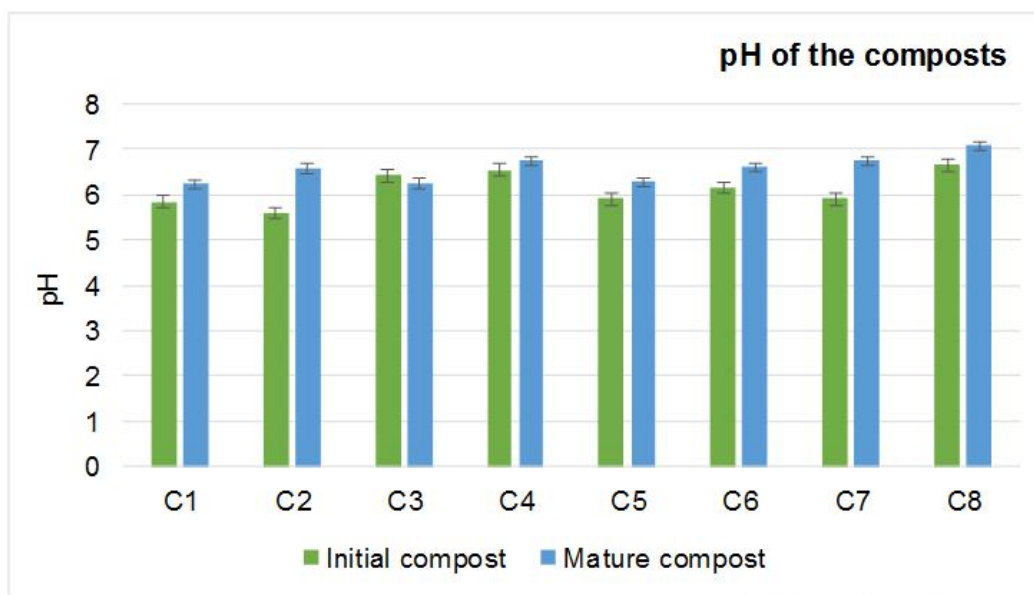
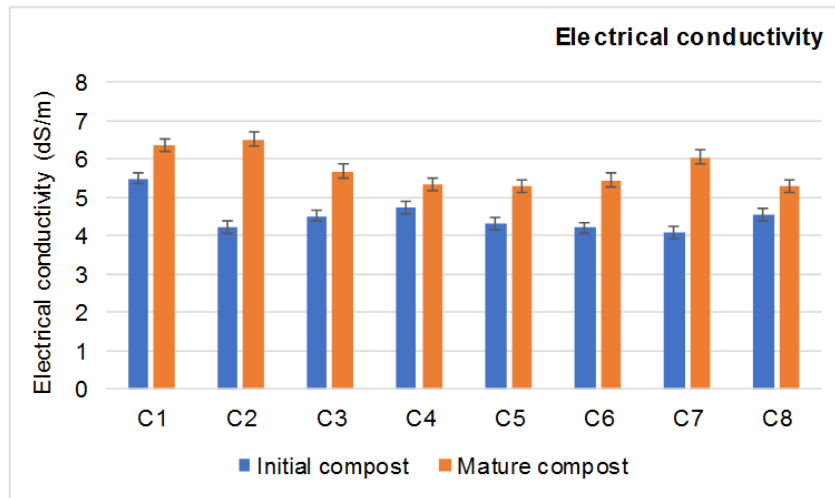**Fig. 1. Effect of treatments on pH of compost during composting**

Fig. 2. Effect of treatments on electrical conductivity of compost during composting

increased at the end of maturity and the values were within the optimum range for development of bacteria (6-7.5) and fungi (5.5 - 8). The compost C8 recorded the highest value of 7.07 which may be due to the activity of proteolytic bacteria and high buffering capacity of bulking agent (sawdust) and activity of flyash which avoids further pH fluctuations [16].

Electrical conductivity of composts increased during the composting period in all composts. The increase in EC value might be due to the release of nutrient elements as a result of the mineralisation process. During composting mineralisation process occurs and this causes the release of cationic and anionic nutrients [17]. The electrical conductivity values of mature composts ranges from 5.03 to 6.52 dS m^{-1}. The least value for electrical conductivity was observed in compost C8 which might be due to the presence of zeolite.

3.4 Primary Nutrients

With ageing of compost there was an increase in the nutrient status of the compost. Total nitrogen content increased during composting mainly due to the concentration effect [18]. The maximum value for nitrogen at the end of composting period was observed in compost 1 (1.72 %). The highest value for this treatment may be due to the bulking agent coirpith. The nitrogen content of coirpith used was higher than that of sawdust. Coirpith also has the ability of cation adsorption which reduces the loss of nitrogen during composting. There was a significant increase of phosphorus and potassium content during

composting but in the final compost there was no significant difference in phosphorus content and the highest value was noticed in C$_8$ (1.24 %). The increase of total phosphorus content during composting may be due to the precipitation of P in solid forms which could not be dissolved and leached quickly. Total potassium content also increased during the composting period. Total potassium content in final compost was the highest in C$_8$ (0.29 %). During composting mineralisation process occurs and this causes the release of cationic and anionic nutrients [17].

3.5 Secondary Nutrients

Secondary nutrients also have an increasing trend towards the end of composting. There was significant influence of treatments on total calcium during composting. The highest value of calcium in the mature compost was observed in C8 (19.06 %), magnesium in C7 (12.72 %) and sulphur in C8 (0.492 %). The increase in these elements may be due to the mineralization process as composting process advanced. Composts C7 and C8 contains flyash which is the residue produced from the coal combustion process containing higher amount of MgO and CaO [19] which would have contributed to higher calcium and magnesium.

3.6 Total Heavy Metal Concentration

The analysis results of total heavy metals Cd, Cr, Ni and Pb in the initial and mature sewage sludge composts shown in Table 5 revealed that total heavy metal concentration in the mature compost were lower than in the original sewage

sludge. This may be due to the dilution effect offered by the bulking agents [5]. Total heavy metal concentration increased as the composts turned to maturity. The increase may be due to the reduction in compost mass at the end of composting. Increase in the heavy metal concentration was due to weight loss of materials during organic matter decomposition and mineralisation process [20]. The least value for all the metals were observed in C8 for Pb (33.06 mg kg^{-1}), Cd (5.41 mg kg^{-1}), Ni (97.62 mg kg^{-1}) and Cr (47.0 mg kg^{-1}). This may be due to the characteristic properties of the components used in the compost. Sawdust is a by- product from wood industry which contain the organic compounds like cellulose, hemicellulose and lignin along with polyphenolic groups. These polyphenolic group have the ability to bind heavy metal [19]. With the addition of zeolite, environmental alkalinity increases, which helps promote the metal adsorption via surface complexation [21]. Natural zeolite has the ability to uptake heavy metals which are in easily available fractions [22]. Flyash which is a residue produced from the coal combustion process

contain higher amount of MgO and CaO. These compounds have the ability to precipitate the heavy metals in sewage sludge compost and thus decrease the toxicity of heavy metals. Also fly ash is a pozzolanic material which reduces the availability of heavy metals.

3.7 Heavy Metal Speciation during Composting

The heavy metal speciation or fractionation give information on the metal bioavailability, their bond strength, remobilization capacity and behavior of metals in the environment. Usually heavy metals are associated with five fractions, namely exchangeable, carbonate, reducible, organic and residual fractions [8]. Metal mobility in the sewage sludge compost might be affected by the chemical composition, content of organic matter, bounded metal and heavy metal speciation [23]. Exchangeable and carbonate fractions of heavy metals are the most mobile fraction. Heavy metal fractions (mg kg^{-1}) in sewage sludge composts are depicted in the Tables 6–9.

Table 4. Total primary and secondary nutrients in sewage sludge composts

Composts	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		S (%)	
	IC	MC	IC	MC	IC	MC	IC	MC	IC	MC	IC	MC
C1	1.49	1.72	0.800	1.150	0.103	0.233	9.37	13.44	5.67	9.53	0.103	0.370
C2	1.14	1.61	0.620	1.070	0.080	0.120	9.40	14.94	5.70	9.67	0.190	0.450
C3	1.18	1.61	0.490	1.170	0.120	0.169	6.67	14.63	5.73	10.59	0.190	0.360
C4	1.19	1.54	0.410	1.040	0.107	0.121	6.67	17.24	5.93	9.90	0.200	0.470
C5	1.08	1.66	0.780	1.200	0.140	0.270	10.63	16.55	6.20	10.44	0.120	0.240
C6	1.10	1.58	0.700	1.080	0.160	0.250	6.60	16.31	7.07	10.42	0.133	0.240
C7	1.35	1.57	0.450	1.120	0.130	0.220	8.00	17.94	7.00	12.72	0.160	0.480
C8	1.53	1.60	0.410	1.240	0.170	0.290	6.80	19.06	6.20	9.90	0.250	0.492
SE (m±)	0.06	0.03	0.017	-	0.009	0.007	0.09	0.336	0.14	0.47	0.011	0.011
CD (0.05)	0.18	0.09	0.057	NS	0.028	0.021	0.33	1.015	0.30	1.42	0.033	0.032

IC: Initial compost MC: Mature compost

Table 5. Total content of heavy metals in sewage sludge composts

Composts	Lead (mg kg^{-1})		Cadmium (mg kg^{-1})		Nickel (mg kg^{-1})		Chromium (mg kg^{-1})	
	Initial compost	Mature compost	Initial compost	Mature compost	Initial compost	Mature compost	Initial compost	Mature compost
C1	37.47	40.32	5.50	5.83	107.34	110.60	48.00	51.00
C2	33.64	39.33	5.25	5.70	98.23	103.49	46.00	50.30
C3	34.66	36.64	5.60	5.90	104.74	106.26	51.17	55.43
C4	32.50	37.01	5.55	5.70	96.24	100.42	49.24	52.04
C5	35.00	38.62	5.40	5.62	103.01	105.41	51.33	53.80
C6	33.26	37.49	5.20	5.90	96.70	99.19	48.57	51.00
C7	35.53	38.00	5.50	5.81	101.03	101.95	45.84	48.40
C8	31.71	33.06	5.00	5.41	96.23	97.62	43.44	47.00
SE (m±)	0.62	0.99	0.08	0.04	1.88	1.02	0.64	0.73
CD (0.05)	1.88	2.98	0.25	0.13	5.67	3.08	1.94	2.21

From the results of heavy metal fractionation studies it was observed that in all composts there was a decrease in mobile fractions namely exchangeable, carbonate and reducible fraction during composting which may be due to the fact that during composting the complexation of heavy metal occurs resulting in a decrease in the bioavailability.

3.7.1 Lead

As composting advances, a decline in the mobile fractions of lead was observed. Least concentration of exchangeable fraction was observed with C2 and C8 (0.360 mg kg^{-1}), while carbonate fraction was the lowest in C2 and C8 (0.310 mg kg^{-1}). Organic and reducible fractions of Pb were not detected. At the end of composting the increase in pH influenced the availability of metal and also due to the presence of zeolite in these composts [21]. The development of slightly alkaline medium decreases the mobility of Pb by forming lead-humus complex. A drop in pH during composting increases the mobility of lead and this metal binds with zeolite and gets transferred to the

most stable fraction. Compost 2 attained the highest value of residual fraction (38.8 %) in the mature compost. This is mainly due to the adsorption and exchange property of zeolite [21]. Liming materials have a significant influence on the immobile fractions of heavy metals. This may be due to the formation of clay – humus complex and the conversion of mobile fractions of heavy metals to the most stable fraction of heavy metal [24].

3.7.2 Cadmium

The mobility of cadmium decreased after composting. The least amount of mobile fractions such as exchangeable (0.053 mg kg^{-1}) and carbonate (0.20 mg kg^{-1}) was observed in the compost C8 during the initial stages of composting. Similar trend was observed in the mature compost also. This may be due to the formation of strong chemical bond between cadmium and degraded organic matter [25]. Organic and reducible fractions were not detected in the initial and mature composts. Highest value of residual fraction was observed in matured compost C1 (5.74 mg kg^{-1}).

Table 6. Fractions of lead

Composts	Pb fractions (Initial compost) mg kg^{-1}					Pb fractions (Mature compost) mg kg^{-1}				
	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5
C1	0.720	0.620	ND	ND	35.13	0.670	0.570	ND	ND	38.00
C2	0.550	0.470	ND	ND	31.00	0.360	0.310	ND	ND	38.80
C3	0.820	0.710	ND	ND	30.13	0.760	0.650	ND	ND	34.25
C4	0.670	0.580	ND	ND	29.01	0.650	0.540	ND	ND	34.90
C5	0.490	0.430	ND	ND	32.02	0.450	0.380	ND	ND	37.02
C6	0.530	0.460	ND	ND	30.03	0.440	0.380	ND	ND	36.00
C7	0.480	0.400	ND	ND	33.62	0.400	0.340	ND	ND	36.90
C8	0.470	0.410	ND	ND	29.00	0.360	0.310	ND	ND	32.00
SE (m±)	0.036	0.017	-	-	-	0.023	0.012	-	-	0.64
CD (0.05)	0.118	0.056	-	-	NS	0.069	0.041	-	-	2.10

F1- Exchangeable, F2- Carbonate, F3- Reducible, F4- Organic, F5- Residual

Table 7. Fractions of cadmium

Composts	Cd fractions (Initial compost) mg kg^{-1}					Cd fractions (Mature compost) mg kg^{-1}				
	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5
C1	0.057	0.208	ND	ND	5.20	0.013	0.017	ND	ND	5.74
C2	0.055	0.206	ND	ND	4.87	0.013	0.017	ND	ND	5.58
C3	0.088	0.376	ND	ND	5.02	0.051	0.031	ND	ND	5.61
C4	0.084	0.303	ND	ND	5.07	0.016	0.025	ND	ND	5.63
C5	0.077	0.286	ND	ND	5.00	0.015	0.026	ND	ND	5.42
C6	0.073	0.258	ND	ND	4.79	0.014	0.021	ND	ND	5.67
C7	0.086	0.300	ND	ND	5.09	0.016	0.023	ND	ND	5.65
C8	0.053	0.200	ND	ND	4.87	0.010	0.015	ND	ND	5.25
SE (m±)	0.002	0.006	-	-	-	0.001	0.002	-	-	0.04
CD (0.05)	0.008	0.020	-	-	NS	0.003	0.006	-	-	0.12

F1- Exchangeable, F2- Carbonate, F3- Reducible, F4- Organic, F5- Residual, ND-Not detectable

Table 8. Fractions of nickel

Composts	Ni fractions (Initial compost) mg kg^{-1}					Ni fractions (Mature compost) mg kg^{-1}				
	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5
C1	1.480	2.400	24.519	28.530	48.82	1.253	1.567	19.433	31.067	55.48
C2	2.076	1.280	23.146	26.900	42.04	1.395	1.040	17.407	29.513	50.26
C3	1.920	1.513	13.502	19.330	65.96	1.647	1.270	10.594	22.030	68.94
C4	2.000	1.592	17.545	23.700	49.15	1.583	1.414	13.383	25.467	58.00
C5	1.470	1.649	18.342	28.333	50.35	1.096	1.543	14.560	31.900	56.03
C6	1.000	2.207	25.313	19.317	45.00	0.094	2.055	20.450	26.740	48.76
C7	1.900	1.500	16.413	25.850	53.78	1.710	1.280	12.553	29.940	56.00
C8	1.423	1.190	13.576	20.277	55.00	1.153	1.039	11.253	28.300	56.79
SE (m±)	0.050	0.057	0.197	0.190	1.11	0.028	0.034	0.296	0.290	1.33
CD (0.05)	0.150	0.172	0.591	0.590	3.68	0.085	0.103	0.889	0.850	4.40

F1- Exchangeable, F2- Carbonate, F3- Reducible, F4- Organic, F5- Residual

Table 9. Fractions of chromium

Composts	Cr fractions (Initial compost) mg kg^{-1}					Cr fractions (Mature compost) mg kg^{-1}				
	F1	F2	F3	F4	F5	F1	F2	F3	F4	F5
C1	0.672	0.384	0.324	0.988	43.97	0.052	0.049	0.364	2.016	48.19
C2	0.977	0.568	0.472	1.412	39.19	0.074	0.073	0.521	2.977	46.03
C3	0.752	0.429	0.359	1.071	47.09	0.056	0.057	0.392	2.282	52.00
C4	0.701	0.403	0.335	0.987	43.96	0.052	0.052	0.364	2.098	48.99
C5	0.717	0.412	0.343	1.025	45.64	0.054	0.053	0.377	2.150	51.02
C6	0.882	0.504	0.422	1.232	42.59	0.065	0.061	0.455	2.642	47.02
C7	0.640	0.365	0.306	0.917	40.44	0.048	0.047	0.336	1.920	45.99
C8	0.702	0.401	0.335	1.007	38.82	0.051	0.051	0.372	2.135	44.90
SE (m±)	0.006	0.001	0.007	0.008	1.21	0.001	0.006	0.005	0.031	1.28
CD (0.05)	0.018	0.003	0.018	0.024	3.99	0.003	0.020	0.017	0.093	4.23

F1- Exchangeable, F2- Carbonate, F3- Reducible, F4- Organic, F5- Residual

3.7.3 Nickel

During the initial stages of composting the least amount of exchangeable fraction of Nickel was in C6 (1.0 mg kg^{-1}) and carbonate fraction in C8 (1.19 mg kg^{-1}). In the mature compost least amount of exchangeable fraction was observed in C6 (0.094 mg kg^{-1}) and the lowest carbonate fraction was associated with C8 (1.039 mg kg^{-1}). This may be due to the nature of zeolite and bulking agents sawdust and coirpith. During the initial stages of composting zeolite binds a significant amount of metal associated with exchangeable and carbonate fractions [26]. Also a significant reduction in the mobile fractions of nickel was observed mainly due to the alkaline stabilization process of flyash. Reduction in mobile fractions may be due to the leaching of Nickel in organic form [27]. Ni has high affinity for dissolved organic matter [28]. The highest value for the residual fraction of Nickel was with C3 (68.94 mg kg^{-1}).

3.7.4 Chromium

There was a significant reduction in concentration of mobile fractions of chromium during composting. Compost C7 registered the lowest exchangeable fraction in initial and final compost with values of 0.640 mg kg^{-1} and 0.048 mg kg^{-1} respectively. In the case of carbonate fraction the least values were observed in compost C1 with 0.384 mg kg^{-1} in initial and 0.052 mg kg^{-1} in final compost. The reduction in the concentration of exchangeable and carbonate fraction may be due to the strong bond formation between the various organic functional groups present in humic substance and the reduction in reducible fraction may be due to the conversion of this fraction to residual fraction [29]. The highest concentration of the residual fraction was obtained in the compost C3 (52 mg kg^{-1}).

4. CONCLUSION

Based on the results generated it can be concluded that composting is an effective technology for decreasing the bioavailability of heavy metals in sewage sludge. The total concentration of heavy metal in the sewage sludge composts were less than in the raw sewage sludge. The compost C8 (Sewage sludge + sawdust + zeolite (50:30:20) + flyash) was superior with respect to stabilization of heavy metals. It had the lowest value for all the

heavy metals studied of which Cd, Cr and Pb were within the permissible limit as per Fertilizer Control Order. Heavy metal fractionation studies pointed out that mobile fractions of heavy metals such as exchangeable and carbonate fractions decreased at the end of composting whereas the residual fractions increased. The lowest values for exchangeable fraction of lead, cadmium and chromium was observed in C8. It also had the least value for carbonate fraction of lead, cadmium and nickel. There is a reduction in mobile fractions of heavy metals and an increment in stable residual fraction. Zeolite used in the study mainly acts as a heavy metal adsorbent which has the ability to take up significant amount of mobile fractions of heavy metals such as exchangeable and carbonate fractions. Coal fly ash used contains higher amount of MgO and CaO compounds which have the ability to precipitate the heavy metals in sewage sludge compost and thus decrease the toxicity of heavy metals to plants. Thus composting of sewage sludge with sawdust, zeolite and flyash decreases the mobility and bioavailability of heavy metals there by reducing possibility of plant uptake and environmental pollution.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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