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A detailed study of the physicochemical parameters of the solid waste dumping grounds adjoining densely populated areas: A case study in India

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Abstract

Background: Industrialization and urbanization in developing countries are the major issues responsible for producing colossal amounts of waste (about 51.35 tons per day). Midnapore municipality as a class-I town (> 100 000 population) puts in a large amount of solid waste without any treatment facility in its districts. Thus, disposal as well as treatment is an area of concern. Waste that comes from different sources could have some beneficial effects along with potentially hazardous side effects. So, finding out the issues is important.

Methods: After selecting the study area, soil samples were collected from five different dumping sites. Different plant micronutrient and heavy metal content of soil samples have been done by spectrophotometric method and atomic absorption spectroscopic analysis. Soil pollution indices geo-accumulation index (I_{geo}), contamination factor (C_f), ecological risk index (E_r), pollution load index (PLI), and modified degree of contamination (MDC) were calculated by standard formulas.

Results: This study shows the presence of a wide variety of elements that have bio-potential. This reveals that it can be used to promote soil fertility due to increases in parameters like soil nitrogen (0.165 ± 0.047%), phosphorus (63.558 ± 15.82 mg/kg), organic carbon (4.22 ± 1.838%), potassium (0.308 ± 0.078%), etc. Assessments of pollution indices showed moderate heavy metal contamination in the study areas.

Conclusion: According to the results of the present study, the soil fertility parameters in the dumping ground are high and can be reused as organic manure; the only issue is a low to moderate level of heavy metal contamination.

Keywords: Trace elements, Soil, Solid waste, Environmental pollution, Micronutrients

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Introduction

The increasing population worldwide is associated with escalating activities related to the survival of human beings, and as a result, a large quantity of municipal, domestic, and industrial waste is generated daily (1). As a developing country, India cannot manage the waste generated daily. Reprehensible waste disposal and management potentially threaten the environment, especially in municipal areas (2).

Toxic leachate is a foremost issue that has been generated from improperly managed dumping sites, and those leachates have been found to have a significant adverse effect on all kinds of life forms. The water body near the dumping site as well as the underground water can be easily contaminated by this leachate. As a result, adverse effects on aquatic organisms and human beings are common. Leachates of different metal(loid)s such as mercury (Hg) and cadmium (Cd) can be potentially too strong to contaminate an adjacent water body (3).

Toxic metal (heavy metal) yields due to indiscriminate disposal, burning, or decay of organic matter and is a major contemporary concern (4). Metals having a specific gravity of more than 5 gcm^{-1} are known as heavy metals and occur mainly in the earth's crust (5). Copper (Cu), lead (Pb), Cd, Hg, nickel (Ni), zinc (Zn), manganese (Mn), and fluoride are such heavy metals. Different anthropogenic activities, including mining, painting, batteries, and municipal waste, cause increasing levels of heavy metal contamination (6). In their recent study, Akhbarizadeh et al, have reported that widely used herbal medicines can be a rich source

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of Mn, Sr, and Cd (especially in dried plant-type herbal medicines) (7). These heavy metals are a potential threat to the ecosystem as they have relative toxicity to a certain level and non-degradability. Crops and vegetables can be a way of introducing heavy metals into the food chain. Thus, exposure to heavy metals is much easier if crop production takes place in the contaminated area (8).

Being only 18.65 km^2 of the total area, Midnapore Municipality has a population of 169 264 according to the 2011 census, but the actual figure has changed drastically day by day. According to the report of the West Bengal government in 2021, a total of 13 708.58 tons of municipal solid waste are generated per day throughout the year from 125 municipalities. As a class-I town (> 100 000 population), Midnapore municipality contributes to a large amount of municipal solid waste with no treatment facility in its district. In case of such high amounts of waste generation daily, an effort should be made to improve the conversion of renewable energy by highlighting the necessity of considering waste and energy at the same time. As the possibility of waste energy generation is growing, it will open investment opportunities in several localities and address issues related to energy scarcity concurrently (9). The heavy metals that could be present in a significant amount in the municipal solid waste can be easily leached into the nearby water bodies, like drains to the river and to the shallow well (the majority of the population in Midnapore municipality uses water from shallow wells for their different daily purposes). Hence, the inhabitants are under a potential threat caused by heavy metal accumulation and leaching. For example, Pb, Cd, and Hg have been found to have the potential to alter the normal functioning of the human kidney.

The evaluation of dump site soil characteristics, especially heavy metals, is an important aspect of risk assessment (10). Heavy metals can be dangerous by accumulating in soil or by entering the food chain upon being taken up by the plant. Leaching of these heavy metals into nearby water bodies can also have adverse effects on the aquatic inhabitants. Heavy metals can also be a potential threat to the soil's normal micronutrients, which are essential for plant growth. So regular monitoring of the status of these heavy metals can be a better imperative to recommend appropriate remediation strategies (11). Therefore, this study was conducted in Midnapore Municipality to specifically determine the levels of heavy metal contamination of soil in waste dumpsites and their effect on soil physicochemical properties. It is expected that the data obtained from the study will be used by environmental regulators, residents, and farmers to expand their knowledge of the hazards of waste dumpsites.

Materials and Methods

Study area

The study was mainly conducted during the monsoon season of 2022 (June 2021–September 2021) in Midnapore municipality, Paschim Medinipur, West Bengal, India. Midnapore is the capital of the undivided Medinipur. Midnapore municipality is at 22.4257° N, 87.3199° E (Figure 1). About 51.35 tons of solid waste are generated in

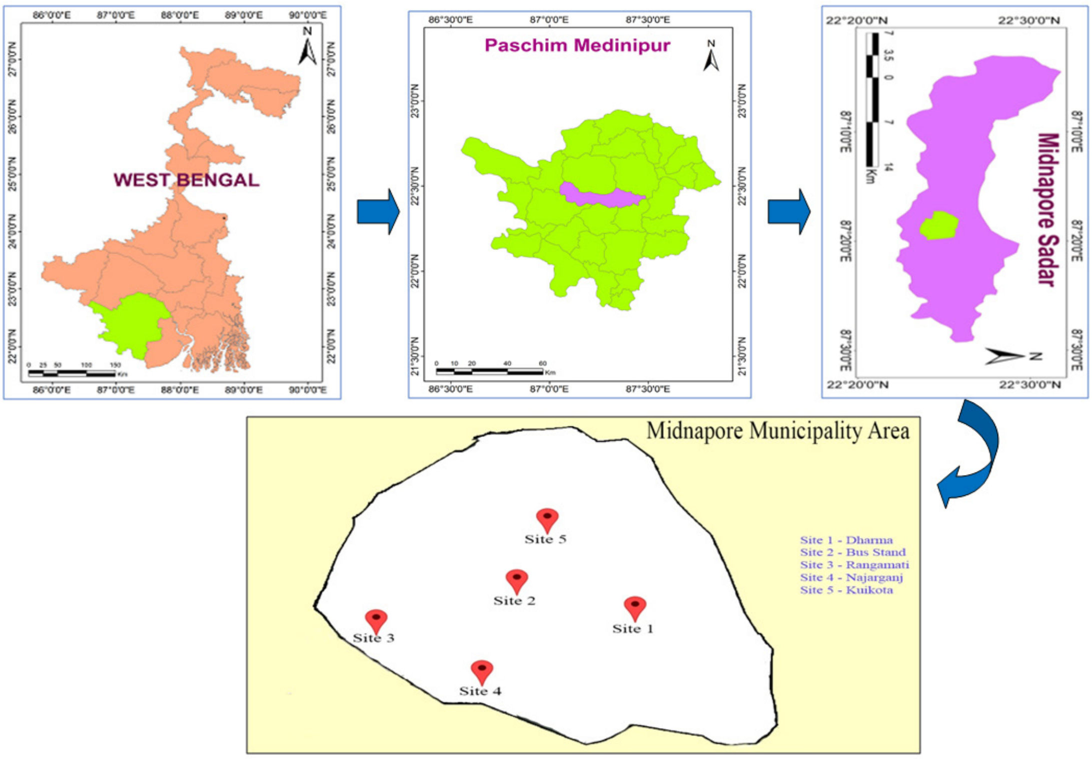

Figure 1. The study area in detail

this municipality every day. Most of the waste substances in Midnapore municipality are generated due to the daily routine activities of people. The presence of various educational institutions, hospitals, and nursing homes leads to an increase in the floating population as well as waste production. As there is no such large-scale industry, the waste that comes from industrial debris is about nil.

Soil sample collection

Five different municipal solid waste (MSW) dumping sites have been selected in Midnapore Municipality and marked as site1 to site 5 [Dharma (site1), Central Bus Stand (site 2), Rangamati (site 3), Najarganj (site 4), and Kuikota (site 5), respectively]. According to the study of Agbeshie and Adjei, from each site, seven different soil samples were collected from a depth of 0–30 cm from each previously demarcated zone of that particular site using a soil auger (12). The collection of seven soil samples from each dump site is obligatory for enhanced data representation. The seven samples collected from each dump site were bulked together to form a composite sample of each dumping site. These composite mixtures from each site were used as the sub-samples for each site and were taken into different plastic containers for laboratory analysis.

As a control, seven different soil samples were collected from non-dumping sites in Midnapore municipality where no dumping activities are taking place, and the samples were analyzed in the laboratory after the similar formation of the composite and sub-sample collection.

Soil sample analysis

All the collected soil samples were first subjected to moisture detection by the hot air-drying method (13). Before being subjected to chemical analysis of the soil samples, all the samples were air-dried, crushed, and sieved through a 2 mm mesh. The pHs of the samples were measured using a pH meter (Laboratory Bench Ph Meter) after making a soil-water suspension in a 1:1 ratio.

The percentage of organic carbon was determined by the Walkley and Black method. The soil samples were oxidized with a recognized amount of chromate ($K_2Cr_2O_7$, Merck, Germany) in the presence of H_2SO_4 (Merck, Germany). The remaining chromates were determined using a spectrophotometer (LabMatrix) at 600 nm (14).

As stated in the study of Subbiah and Asija, the available nitrogen was measured by alkaline permanganate method (15) and according to the study of Deshmukh and Aher available phosphorus (P) was measured by Olsen's method (16). Potassium (K), sodium (Na), calcium (Ca), and magnesium (exchangeable cations) were determined by the standard procedure described by Black (17). The amount of boron present in the soil was determined by spectroscopic analysis (Azomethane H method) (18).

The heavy metal concentration (mg/kg) was determined by the atomic absorption spectrophotometric (Shimadzu AA-7000) method. To determine the fraction of different heavy metals, one-gram soil samples were prepared first with a tri-acid mixture of 15 mL. The tri-acid mixture was prepared by mixing 70% HNO_3 (Merck, Germany), 70% H_2SO_4 (Merck, Germany), and 65% $HClO_4$ (Merck, Germany) in a 5:1:1 ratio. Before being subjected to the atomic absorption spectrophotometer, all the samples were digested at 80 °C until transparency was obtained in the solution, and following cooling, each of the samples was diluted with 50 ml of deionized water (19,20).

Heavy metal contamination assessment

The calculated heavy metal concentrations were used to evaluate different contamination indices. These indices help find out the potential for heavy metal contamination in the soil. In the case of a particular index, there should be some weaknesses and advantages; hence, several indices have been used for better interpretation. The pollution indices employed in this study are geo-accumulation index (I_{geo}), contamination factor (C_f), ecological risk index (E_r), modified degree of contamination (MDC), and pollution load index (PLI).

Background concentration

The choice of background concentration is very important for the calculation of different contamination indices. The background values for Midnapore municipality were unavailable; hence, an alternative approach was taken, according to the study of Sakan et al (21).

Geo-accumulation index

To determine heavy metal contamination in soil, I_{geo} is a very important tool. The formula for the calculation of I_{geo} was developed by Muller (22). The I_{geo} is calculated by the following formula:

$$I_{geo} = \log 2\left[\frac{C_n}{1.5B_n}\right]$$

Where C_n represents the concentration of heavy metals in the soil sample, and B_n represents the background value of heavy metal concentration. According to the study by Muller (22), the I_{geo} value represents the soil contamination status in seven different forms, ranging from uncontaminated soil to heavily contaminated soil. The seven different classes are:

Class 0 ($Igeo < 0$: Practically uncontaminated);
Class I ($0 < I_{geo} < 1$: Uncontaminated to moderately contaminated);
Class II ($1 < I_{geo} < 2$: Moderately contaminated);
Class III ($2 < I_{geo} < 3$: Moderately to heavily contaminated);
Class IV ($3 < I_{geo} < 4$: Heavily contaminated);
Class V ($4 < I_{geo} < 5$: Heavily to extremely contaminated);
Class VI ($I_{geo} > 5$: Extremely contaminated).

Contamination factor

Contamination factor ($C_{f)}$ is another index that is employed to evaluate the soil heavy metal contamination status. It can be calculated using the following formula (23):

$$C_f = \frac{C_h}{C_b}$$

Where, C_h and $C_{b,}$ represent the value of the heavy metal concentration in the present scenario and the background heavy metal concentration, respectively. The C_f value can be characterized in the following way for interpreting the soil contamination status:
$C_f < 1$: Low contamination factor.
$1 \leq C_f < 3$: Moderate contamination factor.
$3 \leq C_f < 6$: Considerable contamination factor.
$6 \geq C_f$: Very high contamination factor (23).

Ecological risk index

According to Hokanson, ecological risk index factor (ERIF) is used to evaluate the possible ecological threats due to the presence of heavy metals in soil (23). It can be obtained by the following formula:

$$ű_{ű} = \quad \times$$

Where C_f can also be calculated, and T_r represents the toxic response factor. T_r for Cu, Ni, Zn, Pb, and Mn are 5, 5, 1, 5, and 1, respectively (24,25).

Hakanson stated that the E_r values can be classified into five different degrees of ecological risk (23).
$E_r < 40$: Low ecological risk.
$40 \leq E_r < 80$: Moderate ecological risk.
$80 \leq E_r < 160$: Considerable ecological risk.
$160 \leq E_r < 320$: High ecological risk.
$E_r \geq 320$: Very high ecological risk.

Modified degree of contamination

To understand the degree of contamination of soil, a modified version of the degree of contamination calculative formula is used, which was created by Abrahim and Parker, in 2008 (26).

$$ű \quad = \sum \frac{C_f}{n}$$

Where C_f can be calculated and n is the number of analyzed heavy metals. According to Abrahim and Parker (26):
MDC < 1.5: Nil to a very low degree of contamination;
1.5 ≤ MDC < 2: Low degree of contamination;
2 ≤ MDC < 4: Moderate degree of contamination;
4 ≤ MDC < 8: High degree of contamination;
8 ≤ MDC < 16: Very high degree of contamination;
16 ≤ MDC < 32: Extremely high degree of contamination;
MDC ≥ 32: Ultra-high degree of contamination.

Pollution load index

It is mainly used to detect contamination of multiple elements. PLI also allows a comparison of the pollution levels at different sites at different times. PLI is obtained as the n^{th} root of the product of the n measured C_f of the detected metals in the soil.

$$PLI = \sqrt[n]{C_{f1} \times C_{f2} \times C_{f3} \times \ldots\ldots\ldots \times C_{fn}}$$

Chon et al, interpreted the calculated PLI according to the following reference (27).
PLI < 1, the soil is unpolluted;
If 1 ≤ PLI < 2, the soil is moderately polluted;
If 2 ≤ PLI < 10, the soil is strongly polluted;
If PLI ≥ 10, the soil is extremely polluted.

However, according to Zarei et al, PLI can be classified as:
No pollution, if PLI < 1;
Moderate pollution, if 1 ≤ PLI < 2;
Heavy pollution, if 2 ≤ PLI < 3;
And extremely heavy pollution, if PLI ≥ 3 (28).

Statistical analysis

Mainly two different statistical analyses are employed in this study. To establish the relationship between various metals and other physical properties using descriptive statistical analysis, Pearson's correlation coefficient matrix (using MS Excel) has been applied. The concentrations of various heavy metals in the soil were compared using one-way analysis of variance (ANOVA).

Results

The waste dumped in different places needs to be treated before it can create diverse hazards. As MSW is full of a large amount of organic and inorganic stuff, it could be beneficial for enriching soil fertility parameters while neglecting pollution issues (16). Parameters regarding soil fertility in the five studied areas are presented in Table 1. The mean organic carbon percentage is 4.22 ± 1.83%, recording the highest amount (7.24%) in site 4, and the mean available nitrogen is 0.165 ± 0.047%, which is also the maximum (0.024%) in site 4. The amount of phosphorus also showed a peak amount (82.15 mg/kg) in site 4 averaging 63.55 ± 15.82 mg/kg. Potassium was found to be highest in site 3 (0.44%), with a mean value of 0.308 ± 0.078%.

The concentration of heavy metals in different study areas is given in Table 2, whereas the variation of heavy metal concentration in different dumping sites along with their background concentration is given in Figure 2.

All heavy metals, except fluoride, Cd, and Zn, accumulate abundantly at site 4. Fluoride and Cd were highest at site 1 (0.48 and 2.12 mg/kg, respectively), and Zn was highest at site 3 (322.3 mg/kg). In site 1, site 2, and site 4 the concentration of heavy metals followed in a decreasing manner like Mg > Zn > Cu > Pb > Ni > F > Cd. But in site 3

Table 1. Various parameters related to soil fertility detected across five distinct dumping sites within Midnapore Municipality

Parameters/ Sites	pH	Moisture content (%)	Organic carbon %	N (%)	P (mg/kg)	K (%)	B (mg/kg)	Na (%)	Ca (mg/kg)
Site 1	8.69	8.82	4.27	0.178	70.21	0.258	0.596	0.354	159.14
Site 2	8.29	9.95	3.06	0.16	71.274	0.29	0.562	0.37	165.09
Site 3	8.61	8.59	4.06	0.13	44.91	0.44	0.58	0.45	177.51
Site 4	8.2	9.91	7.24	0.24	82.15	0.31	0.91	0.37	181.5
Site 5	8.41	8.35	2.48	0.12	49.25	0.243	0.49	0.51	156.2
Mean ± SD	8.44 ± 0.207	9.124 ± 0.754	4.222 ± 1.838	0.165 ± 0.047	63.558 ± 15.826	0.308 ± 0.078	0.627 ± 0.162	0.410 ± 0.066	167.88 ± 11.167

Note: N, nitrogen; P, phosphorus; K, Potassium; Na, sodium; B, boron; Ca, calcium.

Table 2. The concentration of various heavy metals in different dump sites

Dumping Sites	Concentration of Cd (mg/kg)	Concentration of Copper (mg/kg)	Concentration of Pb (mg/kg)	Concentration of Ni (mg/kg)	Concentration of Zn (mg/kg)	Concentration of Mn (mg/kg)	Concentration of F (mg/kg)
Site 1	2.12	58.68	47.49	5.6	149.96	333.1	0.48
Site 2	1.76	54.9	53.39	5.24	162.28	354.98	0.46
Site 3	> 0.5	26.9	37.6	13.5	322.3	272.9	0.41
Site 4	> 0.5	88.2	73.8	23.5	182.9	731.1	0.44
Site 5	2.04	28.5	42.51	13.1	288.9	462.8	0.42
Mean ± SD	1.38 ± 0.1890	51.436 ± 25.219	50.958 ± 14.049	12.188 ± 7.453	221.268 ± 78.768	430.98 ± 181.27	0.442 ± 0.028

Note: Cu, copper; Pb, lead; Ni, nickel; Zn, zinc; Mn, Manganese; F, Fluoride.

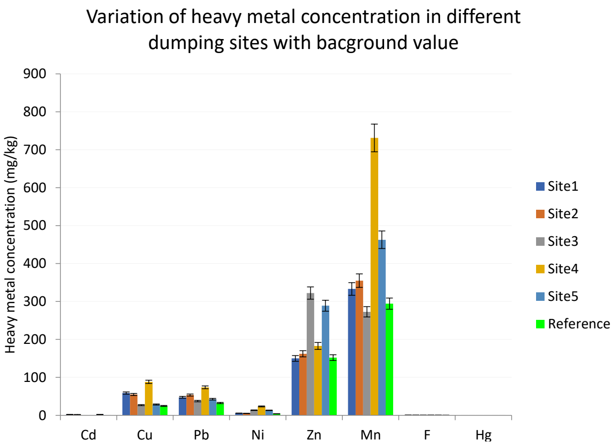

Figure 2. Bar diagram of the variation of heavy metals concentrations in different dumping sites

Table 3. Modified degree of contamination and pollution load index

Heavy metals	MDC	PLI
Cd	2.76	2.274
Cu	2.074	1.875
Pb	1.572	1.529
Ni	2.915	2.488
Zn	1.454	1.384
Mn	1.464	1.375
F	1.571	1.521

Cu, copper; Pb, lead; Ni, nickel; Zn, zinc; Mn, Manganese; F, Fluoride; Cd, Cadmium; MDC, Modified degree of contamination; PLI, pollution load index.

the order is like Zn > Mg > Cu > Pb > Ni > F > Cd and in the case of site 5 the order is like Mg > Zn > Pb > Cu > Ni > F > Cd.

Since the toxic response factor (T_r) for Cd and fluoride was not found, E_r calculation was not possible. The MDC and PLI for different heavy metals are accessible in Table 3. Nickel showed the highest values of those two indicators (MDC = 2.915 and 2.915 and PLI = 2.488). The increasing order of these two indices for various heavy metals is found as Zn > Mn > F > Pb > Cu > Cd > Ni.

Pollution indices like I_{geo}, E_r, and C_f for different heavy metals in different dumping sites are presented in Table 4. The I_{geo} values for heavy metals like Cu, Pb, Ni, Mg, and F were most at site 4. For Zn, the Geoaccumulation index is the highest at site 3, and for Cd, at site 1. Contamination factors (C_f) for heavy metals like Cu, Pb, Ni, and Mg were calculated as highest at site 4 whereas in the case of Zn, it is at site 3, and in the case of F and Cd, it is calculated as highest at site 1. E_r for Cu, Pb, and Ni is highest at site 4.

The results of the statistical analysis are presented in Tables 5-7.

Discussion

The diversity of different soil fertility parameters at five different dumping sites in Midnapore Municipality is shown in Table 1. The average pH of five dumping sites is 8.44, with a standard deviation of only ± 0.207. The highest pH (8.69) and the lowest one (8.2) were recorded in site 1 and site 4, respectively. According to the study of Oyedele et al, variations in pH are possible due to the different types of settling materials present in MSW (29). The pH of the soil can directly affect the nutrient availability in the soil for plant growth (13).

Table 4. Geoaccumulation index, ecological risk index, and contamination factor (Cf) for different heavy metals in different dumping sites

Heavy metals	Cu			Pb			Ni			Zn			Mn			F		Cd	
Dumping sites	I_{geo}	C_f	E_r	I_{geo}	C_f	E_r	I_{geo}	C_f	E_r	I_{geo}	C_f	E_r	I_{geo}	C_f	E_r	I_{geo}	C_f	I_{geo}	C_f
Site 1	0.49	2.366129	11.83065	0.29	1.465741	7.3287	0.251	1.339713	6.698565	0.118	0.98593	0.98593	0.178	1.131569	0.98593	0.29	1.655172	0.752	4.24
Site 2	0.47	2.21371	11.06855	0.341	1.64784	8.2392	0.223	1.253589	6.267943	0.152	1.06693	1.06693	0.206	1.205897	1.06693	0.341	1.586207	0.671	3.52
Site 3	0.16	1.084677	5.423387	0.189	1.160494	5.8025	0.634	3.229665	16.14833	0.45	2.119001	2.119001	0.092	0.927065	2.119001	0.189	1.413793	0.124	1
Site 4	0.675	3.556452	17.78226	0.482	2.277778	11.389	0.874	5.62201	28.11005	0.204	1.202498	1.202498	0.52	2.483609	1.202498	0.482	1.517241	0.124	1
Site 5	0.185	1.149194	5.745968	0.242	1.312037	6.5602	0.621	3.133971	15.66986	0.218	1.899408	1.899408	0.321	1.572171	1.899408	0.242	1.448276	0.735	4.08

Cu, copper; Pb, lead; Ni, nickel; Zn, zinc; Mn, Manganese; F, Fluoride; Cd, Cadmium; MDC, Modified degree of contamination; PLI, pollution load index; I_{geo}, Geoaccumulation index; Er, ecological risk index; C_f, contamination factor.

Table 5. Score deducted from raw score for ANOVA

Groups	Sum	Average	Variance
Cu	257.18	51.436	636.0355
Pb	254.79	50.958	197.3759
Ni	60.94	12.188	55.54772
Zn	1106.34	221.268	6204.518
Mn	2154.88	430.976	32857.58
F	2.21	0.442	0.00082

Cu, copper; Pb, lead; Ni, nickel; Zn, zinc; Mn, Manganese; F, Fluoride.

Table 6. ANOVA table for heavy metals excluding cadmium and mercury

Source of variation	SS	df	MS	F-statistic
Between groups	709871.3	5	141974.3	21.32223
Within groups	159804.2	24	6658.509	
Total	869675.5	29		

df, degrees of freedom; MS, mean sum of squares; SS, sum of squares.

The soil sample's moisture content suggests the existence of leachate, which is likely to originate from solid waste that has been disposed of. Inadequate leachate production frequently results in transpiring moisture in the summertime, whereas the residues linger in the ground, contaminating the attributes of the soil (30). The dampness of less than 20% content will not lead to an increase in gas production and is unable to tolerate microbial deterioration, which is accountable for the creation of landfill gas (29). The maximum moisture content (9.95%) is reported on site 2, while the mean moisture content is 9.125% as presented in Table 1. Uma et al, found an average of 6.5% to 7% moisture in different waste disposal sites in Tamil Nadu, India (13).

As shown in Table 1, the percentage of organic carbon varies from 2.48% (site 5) to 7.24% (site 4) with a low deviation of ± 1.838%. Organic carbon as well as organic substances will be found higher where domestic wastes are dumped. High concentrations or percentages of organic substances can cause serious trouble for mankind, and also, for vegetation (31). Maybe the dumping site at site 4 receives a greater proportion of biodegradable waste. In another study in Maharastra, India, Deshmukh and Aher also found 0.8% to 12.2% organic carbon in different MSW dumping sites, suggesting that MSW also contains a large amount of biodegradable waste in that municipality (16).

Nitrogen (N), phosphorus, and potassium (K) are all essential for plant growth. However, nitrogenous compounds like nitrosamines do have carcinogenic effects. Although plants used to take up nitrogen in the form of nitrite (NO_2), the increases in NO_3 (nitrate) and NO_2 have some potentially dangerous effects on soil properties (32). In a recent study by Amouei et al, it was revealed that electrocoagulation by an aluminum electrode at pH 5.5 can remove toxic nitrate up to 99.65% from leachates (33). The mean value of nitrogen is 0.165% with a very low deviation of ± 0.047% as presented in Table 1. It seems

Table 7. Correlation matrix of the tested metals and soil fertility parameters of the dumpsite soil

	pH	MC	OC	N	P	K	B	Na	Ca	Cu	Pb	Ni	Zn	Mn	F
pH	1														
MC	-0.72801	1													
OC	-0.33619	0.510516	1												
N	-0.47044	0.726539	0.904885	1											
P	-0.50959	0.837446	0.647881	0.908686	1										
K	0.217211	-0.07741	0.202327	-0.14134	-0.39696	1									
B	-0.51573	0.628882	0.979795	0.932874	0.716288	0.117387	1								
Na	0.097118	-0.72363	-0.52314	-0.73955	-0.84967	0.105924	-0.51698	1							
Ca	-0.32865	0.443784	0.76361	0.522092	0.227869	0.728283	0.74919	-0.24293	1						
Cu	-0.52595	0.793753	0.815233	0.983779	0.96717	-0.26598	0.866712	-0.78315	0.407759	1					
Pb	-0.7484	0.818197	0.801622	0.93573	0.888641	-0.23631	0.895184	-0.58359	0.48548	0.948723	1				
Ni	-0.50475	0.16666	0.731509	0.500595	0.159729	0.25342	0.755439	0.169352	0.699913	0.387009	0.570892	1			
Zn	0.235066	-0.68783	-0.3191	-0.67257	-0.90134	0.547356	-0.36664	0.886027	0.127392	-0.77542	-0.60849	0.272474	1		
Mn	-0.75021	0.480166	0.719791	0.744979	0.595621	-0.28337	0.812195	-0.13646	0.402762	0.722418	0.86907	0.812269	-0.24288	1	
F	0.105132	0.414972	0.087276	0.433485	0.698359	-0.56048	0.085921	-0.81467	-0.36023	0.537896	0.298046	-0.53893	-0.93276	-0.06402	1

Note: Cu, copper; Pb, lead; Ni, nickel; Zn, zinc; Mn, Manganese; F, Fluoride; Cd, Cadmium; MDC, N, nitrogen; P, phosphorus; K, Potassium; Na, sodium; B, boron; Ca, calcium; OC, organic carbon; MC, Moisture content.

the soils of dumping sites have a medium to low status of nitrogen percentage as per the Indian critical limits used for soil tests (34).

From the soil solution, phosphorus is taken up by the plant in the form of H_2PO_4. Phosphorus could be chemisorpted upon the interaction of phosphate ions with atoms like Al, Fe, or Ca (35). The leachate from the MSW dumping site can also cause an increased amount of phosphorus in the soil. In the present study, the amount of phosphorus varies from 44.91 to 82.15 mg/kg, and the average phosphorus in the dumping site is 63.558 ± 15.826 mg/kg. In a recent study, phosphorus content has been reported in the range of 15.3 to 78 kg/ha (16).

As considered, potassium is the second most important major element for soil crop productivity. So, it is not harmful if the amount of potassium is excess in the soil, as affirmed by Goswami and Sarma (36). As stated in the study of Eddy et al, due to the degradation of solid waste, the potassium content, which is one of the essential elements for healthy growth, is increased in the soil (37). In this study, the dumping sites have an average potassium percentage of 0.308%, which is only deviated 0.078% from the actual mean, suggesting that the dumping sites are consistent in their potassium content, as presented in Table 1.

The higher availability of Boron in the surface soil in contrast to subsurface soil is related to increased organic matter in the soil (31,38). Boron contamination, as a serious environmental problem, can affect both ecosystems and human ecology. MSW can be a reason for boron accumulation in the surface and/or deeper layer of the soil (39). Boron deficiency in soil is more likely than boron toxicity. Boron toxicity can be caused by MSW leaching, which degrades soil quality and fertility. Boron serves as an essential element for plant growth by helping in cell wall synthesis and structural integrity (40). In the five different dumping sites, the amount of boron varies from 0.49 to 0.91 mg/kg of soil, with an average of 0.627 mg/kg, as presented in Table 1. According to the study by Kloke, the concentration of boron does not indicate boron toxicity in the soil of dumping sites in Midnapore municipality (41).

The Na percentage in the dumping sites of this study varies from 0.354% (site1) to 0.51% (site 5), which has an average value of 0.410% with a very low deviation of ± 0.066 as shown in Table 1. Na is not a major essential element for plant growth and promotion, but it can be helpful when the potassium ion (K^+) is deficient in the soil (42). Variable Na concentrations in soil can often lead to variations in soil salinity as well as pH.

In contrast to other elements, calcium is one of the most important elements in terms of plant productivity. Being a divalent cation (Ca^{2+}), it is required for cell wall and cell membrane synthesis and is also required as a countercation for inorganic and organic anions present in the plant vacuole (43). Ca concentration has an average value of 167.88 mg/kg of soil with a strong deviation of ± 11.167 mg/kg, as shown in Table 1. The studied dumping site suggests that the soil contains a good and significant amount of Ca for better crop productivity.

The assessment of heavy metal contamination showed that a very low concentration (> 0.001 mg/kg) of Hg is present in all five separate dumpsites. So, contamination by Hg is not a significant aspect to assess. The concentrations of other heavy metals in the dumping sites are higher, and they were assessed by different soil contamination indices like I_{geo}, C_f, E_r, MDC, and PLI.

According to the results of Table 4, at each site, the I_{geo} values for different heavy metals are > 1 but < 0, so it belongs to Class I ($0 < I_{geo} < 1$), and it can be stated that the dumping sites are uncontaminated to moderately contaminated (22). Based on C_f values, it can be stated that sites 3 and 4 have a moderate C_f, whereas site1, site2, and site5 have considerable C_f due to Cd (23). According to Table 3, the values of MDC suggest a moderate pollution index, but PLI suggests that strong Cd pollution has taken place (26,28). Except for PLI, all other pollution indices suggest that the Cd contamination at the dumping sites is at a low to moderate level. In a recent study, Khan et al, have reported Cd concentrations were higher (44). Discharge of waste without any treatment can increase the heavy metal concentration in the dumping ground soils.

Based on C_f values for Cu, site 4 has a considerable contaminant factor, and the other sites have a moderate C_f according to the reference values of Hokanson (23). As the values of E_r at all the sites are less than 40 (< 40) (Table 4), it can be stated that there is a very low ecological risk due to Cu contamination (23). As presented in Table 3, the values of MDC ($2 \leq MDC < 4$) and PLI ($1 \leq PLI < 2$) suggest a moderate level of contamination by Cu (26-28). Different anthropogenic activities can lead to the accumulation of Cu. As Cu is used in the tires of motor vehicles, the waste from motor vehicles can also increase the concentration of Cu in dumping sites.

Pb contamination analysis revealed that there is likewise a moderate degree of contamination. The I_{geo} and C_f suggest that the dumping site soils are moderately contaminated by Pb (18,19). Ecological risk due to lead contamination in soil is very low because the E_r value is < 40 (23). The MDC value ($1.5 \leq MDC < 2$) suggests that there is a low degree of contamination by Pb (26) and the PLI value ($1 \leq PLI < 2$) suggests that the soil is moderately polluted by Pb (28). The findings of this study were similar to those of previous studies (44,45). High levels of Pb accumulation in site 4 may be due to unused batteries and welding activities.

The contamination of soil caused by nickel concentration showed variability, although this variability is not enough to influence the I_{geo}. The E_r values of all five sites are under 40, so the ecological risk due to nickel is in a low state (23). In site 3, site 4, and site 5, there is a considerable amount of contamination as the C_f value is $3 \leq C_f < 6$, but in site 1 and site 2 contamination caused by nickel is at a moderate level (23). The MDC index suggests that a moderate level of contamination is due to the concentration of nickel as $2 \leq MDC < 4$ as shown in Table 3 (26). Most importantly, the PLI suggests that as the index value is greater than two and less than three ($2 \leq PLI < 3$), hence, the soil is heavily polluted by the accumulation of nickel (28).

Analysis of the C_f for Zn suggests that site 1 is relatively low-contaminated ($C_f < 1$) with the rest of all the sites having a moderate C_f ($1 \leq C_f < 3$) (23). The ecological risk index is well under 40; hence, there is no potential ecological risk due to Zn contamination (23). The MDC and PLI values in Table 3 suggest that soil contamination is at a low and moderate level, respectively, due to Zn (26,28).

From the calculated values in Table 4, it can be stated that Mn contamination in site3 is very low ($C_f < 1$) but in other sites, the contamination of Mn is moderate ($1 \leq C_f < 3$) (23). Ecological risk due to Mn contamination is well under threat, as indicated by the ecological risk index $E_r < 40$ (23). The MDC value is less than 1.5 (Table 3), suggesting a nil to shallow degree of contamination (26). The PLI value in Table 3 is greater than one and less than two ($1 \leq PLI < 2$), which suggests that there is a moderate degree of contamination caused by Mn (27,28).

The concentration of fluoride in different dumping sites is pretty consistent; hence, the different pollution indices are also consistent. All the pollution indices suggest that low to moderate fluoride contamination is occurring in the dumping site soil. According to Table 4, $1 \leq C_f < 3$, this suggests that moderate contamination is caused by fluoride accumulation (23). The MDC value ($1.5 \leq MDC < 2$) suggests that there is a low degree of contamination by fluoride (26) and the PLI value ($1 \leq PLI < 2$) suggests that the soil is moderately polluted by fluoride (28).

To determine the relationship between the heavy metals and physical and other chemical parameters assessed during the study period, Pearson's correlation coefficient was calculated and tabulated in Table 7. As stated by the Rollinson correlation coefficients between 0.9–1, 0.7–0.9, 0.5–0.7, 0.3–0.5, and < 0.3 are respectively termed as very high, high, moderate, low, and very low (43), and according to the study of Zhai et al, the strong correlation between two variables suggests that the same geochemical process or reaction may influence the distribution of the variables (42). In the present study, there are several strong positive and negative correlations, as described in Table 7. There is a very strong positive correlation between organic carbon with nitrogen and boron (B). Cu and phosphorus are also in well-built positive correlation. Nitrogen with Cu, and Pb also have a sturdy positive correlation. A strong correlation was also found in the case of Pb and Cu concentrations in soil. Not only positive correlations but also several strong negative correlations. The correlation between Zn with fluoride and Zn with phosphorus is strongly negative. In most cases, potassium is not correlated to the other parameters except in the case of Ca, Zn, and fluoride.

The results obtained from the analysis of variance are presented in Table 5 and Table 6. According to the results of ANOVA analysis, the average heavy metal concentration at five different dumping sites differs significantly ($P < 0.01$). It can thus be stated that the dumping of solid waste has a significant influence on the heavy metal accumulation in the dumping site soils.

Conclusion

According to the results of this study, the soil fertility parameters in the dumping ground did not deviate much; the only issue was a low to moderate level of heavy metal contamination. This could be because most of the MSW dumped in the dumping sites of Midnapore municipality is domestic waste. The lack of a major industry in the municipal region can also help support this conclusion. Since E_r levels never went beyond forty, the ecological concern posed by heavy metal contamination was not taken into account. However, management needs to act quickly to prevent additional increases in the indices. Considering the huge amount of daily waste production and the increasing demand for fossil fuels, landfill gas (LFG) plants can be a solution for waste management and also in terms of fuel (economic perspective) support. The leaching of heavy metals into the adjacent water bodies clears up the status of the threat to human civilization around the dumping site. As there is no significant contamination of heavy metals, this dumping area soil has the potential to have better fertility power. Further study can also be done in the aspect of biomaterial extraction from waste substances.

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Competing interests

The authors declare that they have no competing interests.

Ethical issues

The data presented in this manuscript are original and collected during the entire period of study. No data have been published or never will be published again.

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References

1. Lagerkvist A, Dahlén L. Solid waste generation and characterization. In: Meyers RA, ed. Encyclopedia of Sustainability Science and Technology. New York, NY: Springer; 2012. p. 10000-13. doi: 10.1007/978-1-4419-0851-3_110.
2. Lebreton L, Andrady A. Future scenarios of global plastic waste generation and disposal. Palgrave Commun. 2019;5(1):6. doi: 10.1057/s41599-018-0212-7.
3. Mohammadi A, Malakootian M, Dobaradaran S, Hashemi M, Jaafarzadeh N, Parniani N. Determination and seasonal analysis of physicochemical characterization and metal(oid)s of landfill leachate in Bushehr port along the Persian Gulf. Toxin Rev. 2023;42(1):161-75. doi: 10.1080/15569543.2022.2027454.
4. Sari AR, Harryes RK, Anggraini FA, Alamsyah MA, Ahadi D. The effectiveness of heavy metals Pb, Cd and Zn reduction in NPK fertilizer waste combined with biofilters of seaweed (*Gracillaria* sp.), blood clam (*Anadara* sp.), and zeolite. IOP Conf Ser Earth Environ. Sci. 2019;236(1):012056. doi: 10.1088/1755-1315/236/1/012056.
5. El-Kady AA, Abdel-Wahhab MA. Occurrence of trace metals in foodstuffs and their health impact. Trends Food Sci Technol. 2018;75:36-45. doi: 10.1016/j.tifs.2018.03.001.
6. Awokunmi EE, Asaolu SS, Ipinmoroti KO. Effect of leaching on heavy metals concentration of soil in some dumpsites. Afr J Environ Sci Technol. 2010;4(8):495-9.
7. Akhbarizadeh R, Dobaradaran S, Spitz J, Mohammadi A, Tekle-Röttering A, De-la-Torre GE, et al. Metal(loid)s in herbal medicines and their infusions: levels, transfer rate, and potential risks to human health. Hyg Environ Health Adv. 2023;5:100042. doi: 10.1016/j.heha.2022.100042.
8. Balkhair KS, Ashraf MA. Field accumulation risks of heavy metals in soil and vegetable crop irrigated with sewage water in western region of Saudi Arabia. Saudi J Biol Sci. 2016;23(1 Suppl):S32-44. doi: 10.1016/j.sjbs.2015.09.023.

9. Ighravwe DE, Babatunde DE. Evaluation of landfill gas plant siting problem: a multi-criteria approach. Environ Health Eng Manag. 2019;6(1):1-10. doi: 10.15171/ehem.2019.01.
10. Rodríguez Eugenio N. The global soil partnership: tackling global soil threats through collective action. In: Ginzky H, Dooley E, Heuser IL, Kasimbazi E, Kibugi R, Markus T, et al, eds. International Yearbook of Soil Law and Policy 2019. Cham: Springer; 2021. p. 197-221. doi: 10.1007/978-3-030-52317-6_11.
11. Desai BH. United Nations Environment Program (UNEP). Yearb Int Environ Law. 2019;28:498-505. doi: 10.1093/yiel/yvy072.
12. Agbeshie AA, Adjei R. Land suitability of the Nkrankwanta lowland for rice cultivation in the Dormaa West district, Ghana. Adv Res. 2019;20(4):1-15. doi: 10.9734/air/2019/v20i430162.
13. Uma RN, Prem Sudha R, Murali K. Assessment of soil quality at municipal solidwaste dump site in Coimbatore-Tamilnadu, India. Int J Adv Eng Technol. 2016;7(2):1301-7.
14. Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. In: Page AL, ed. Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties. John Wiley & Sons; 1983. p. 539-79. doi: 10.2134/agronmonogr9.2.2ed.c29.
15. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Curr Sci. 1956;25:259-60.
16. Deshmukh KK, Aher SP. Assessment of soil fertility around municipal solid waste disposal site near Sangamner city, Maharashtra, India. Curr World Environ. 2017;12(2):401-10. doi: 10.12944/cwe.12.2.24.
17. Klute A, Page AL. Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods; Part 2. Chemical and Microbiological Properties. Madison, WI: American Society of Agronomy (ASA); 1986.
18. Mohammed YI, Garba K, Umar S. Analytical determination of boron in irrigation water using azomethine-H: Spectrophotometry. IOSR J Appl Chem. 2014;7(3):47-51. doi: 10.9790/5736-07314751.
19. Bakirdere S, Yaman M. Determination of lead, cadmium and copper in roadside soil and plants in Elazig, Turkey. Environ Monit Assess. 2008;136(1-3):401-10. doi: 10.1007/s10661-007-9695-1.
20. Kashem MD, Singh BR. Heavy metal contamination of soil and vegetation in the vicinity of industries in Bangladesh. Water Air Soil Pollut. 1999;115(1):347-61. doi: 10.1023/a:1005193207319.
21. Sakan SM, Dordević DS, Manojlović DD, Predrag PS. Assessment of heavy metal pollutants accumulation in the Tisza river sediments. J Environ Manage. 2009;90(11):3382-90. doi: 10.1016/j.jenvman.2009.05.013.
22. Muller G. Index of geoaccumulation in sediments of the Rhine river. GeoJournal. 1969;2:108-18.
23. Håkanson L. An ecological risk index for aquatic pollution control. A sedimentological approach. Water Res. 1980;14(8):975-1001. doi: 10.1016/0043-1354(80)90143-8.
24. Chai L, Li H, Yang Z, Min X, Liao Q, Liu Y, et al. Heavy metals and metalloids in the surface sediments of the Xiangjiang river, Hunan, China: distribution, contamination, and ecological risk assessment. Environ Sci Pollut Res Int. 2017;24(1):874-85. doi: 10.1007/s11356-016-7872-x.
25. Suresh G, Sutharsan P, Ramasamy V, Venkatachalapathy R. Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric contents of Veeranam lake sediments, India. Ecotoxicol Environ Saf. 2012;84:117-24. doi: 10.1016/j.ecoenv.2012.06.027.
26. Abrahim GM, Parker RJ. Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. Environ Monit Assess. 2008;136(1-3):227-38. doi: 10.1007/s10661-007-9678-2.
27. Chon HT, Cho CH, Kim KW, Moon HS. The occurrence and dispersion of potentially toxic elements in areas covered with black shales and slates in Korea. Appl Geochem. 1996;11(1-2):69-76. doi: 10.1016/0883-2927(95)00061-5.
28. Zarei I, Pourkhabbaz A, Bashiri Khuzestani R. An assessment of metal contamination risk in sediments of Hara Biosphere Reserve, southern Iran with a focus on application of pollution indicators. Environ Monit Assess. 2014;186(10):6047-60. doi: 10.1007/s10661-014-3839-x.
29. Oyedele DJ, Gasu MB, Awotoye OO. Changes in soil properties and plant uptake of heavy metals on selected municipal solid waste dump sites in Ile-Ife, Nigeria. Afr J Environ Sci Technol. 2008;2(5):107-15.
30. Eddy NO, Odoemelem SA, Mbaba A. Elemental composition of soil in some dumpsites. Electron J Environ Agric Food Chem. 2006;5(3):1349-63.
31. Prem Sudha R, Uma DR, Meiaraj D. Assessment of soil characteristics around municipal solidwaste disposal site in Sulur Block-Coimbatore town Panchayats-Tamilnadu, India. Int J Sci Eng Res. 2014;5(4):240-4.
32. Sönmez I, Kaplan M, Sönmez S. Investigation of seasonal changes in nitrate contents of soils and irrigation waters in greenhouses located in Antalya-Demn region. Asian J Chem. 2007;19(7):5639-46.
33. Amouei A, Pouramir M, Asgharnia H, Mehdinia M, Shirmardi M, Fallah H, et al. Evaluation of the efficiency of electrocoagulation process in removing cyanide, nitrate, turbidity, and chemical oxygen demand from landfill leachate. Environ Health Eng Manag. 2021;8(3):237-44. doi: 10.34172/ehem.2021.27.
34. Muhr GR, Datta NP, Shankarasubramoney H, Laley VK, Donahue KL. Soil Testing in India. New Delhi: US Agency for International Development (USAID); 1965. p. 120.
35. Orlov DS. Soil Chemistry. AA Balkema Publishers; 1992.
36. Goswami U, Sarma HP. Study of the impact of municipal solid waste dumping on soil quality in Guwahati city. Pollut Res. 2008;27(2):327-30.
37. Pillai S, Peter AE, Sunil BM, Shrihari S. Soil pollution near a municipal solid waste disposal site in India. In: International Conference on Biological, Civil and Environmental Engineering (BCEE-2014); 2014. Vol 1718. doi: 10.15242/iicbe.c0314080.
38. Camacho-Cristóbal JJ, Rexach J, González-Fontes A. Boron in plants: deficiency and toxicity. J Integr Plant Biol. 2008;50(10):1247-55. doi: 10.1111/j.1744-7909.2008.00742.x.

39. Brown PH, Bellaloui N, Wimmer MA, Bassil ES, Ruiz J, Hu H, et al. Boron in plant biology. Plant Biol. 2002;4(2):205-23. doi: 10.1055/s-2002-25740.
40. Kloke A. Orientierungsdaten fur tolerierbare Gesamtgehalte einiger Elemente in Kulturboden. Mitt VDLUFA. 1980;1:9-11.
41. Maathuis FJM. Sodium in plants: perception, signalling, and regulation of sodium fluxes. J Exp Bot. 2013;65(3):849-58. doi: 10.1093/jxb/ert326.
42. Zhai L, Liao X, Chen T, Yan X, Xie H, Wu B, et al. Regional assessment of cadmium pollution in agricultural lands and the potential health risk related to intensive mining activities: a case study in Chenzhou city, China. J Environ Sci. 2008;20(6):696-703. doi: 10.1016/s1001-0742(08)62115-4.
43. Rollinson HR. Using Geochemical Data: Evaluation, Presentation, Interpretation. 1st ed. London: Routledge; 1993. p. 23-89.
44. Khan MA, Ara MH, Dhar PK. Assessment of heavy metals concentrations in the soil of Mongla industrial area, Bangladesh. Environ Health Eng Manag. 2019;6(3):191-202. doi: 10.15171/ehem.2019.22.
45. Saha TR, Khan MA, Kundu R, Naime J, Karim KM, Ara MH. Heavy metal contaminations of soil in waste dumping and non-dumping sites in Khulna: human health risk assessment. Results Chem. 2022;4:100434. doi: 10.1016/j.rechem.2022.100434.