Assessment of soil pollution by heavy metals in the market gardening areas of Korsimoro

Abstract

The aim of this study was to assess heavy metal soil pollution in market garden areas in the commune of Korsimoro. The analysis focused mainly on zinc (Zn), nickel (Ni), chromium (Cr), copper (Cu), lead (Pb), cadmium (Cd), cobalt (Co), arsenic (As) and mercury (Hg). Composite samples of soil labels s_1 to s_{21} were taken from the market garden site around the dam at a depth of 0-20 cm. A total of 21 soil samples were taken. The soil samples were analysed using inductively coupled plasma mass spectrometry (ICP/MS) at the Bureau of Mines and Geology of Burkina Faso laboratory(BUMIGEB).

The enrichment factor (EF), contamination factor (CF), géoaccumulation index (Igeo) and pollution load index (PLI) were determined from the metal concentrations obtained.

The average concentrations of heavy metals vary as follows:

Cd > Co > Cr > Zn > Ni > Cu > Hg > Pb > As.

The average concentrations of cadmium (587.039mg/kg±20.546), mercury (29.048mg/kg±20,647), nickel (60.037 mg/kg±14,615) and cobalt (575.956mg/kg±66,693) exceed the WHO limit values for agricultural soils.

The calculated CF values show very high contamination of Co, Cd and Hg, considerable contamination of Cu, Cr, Zn, Ni and As, and no contamination of Pb.

The EF values show very severe enrichment for cobalt (Co), followed by overall extremely severe enrichment for cadmium (Cd) and mercury (Hg).

The calculated Igeo indicates extreme cadmium, mercury and cobalt contamination.

The calculated PLI values are all greater than one. These results show that all the soils are polluted.

The index determination approach makes it possible to predict the extent of soil pollution by the heavy metals considered in our study.

Keywords: Soil, Igeo, heavy metals, Pollution, Korsimoro

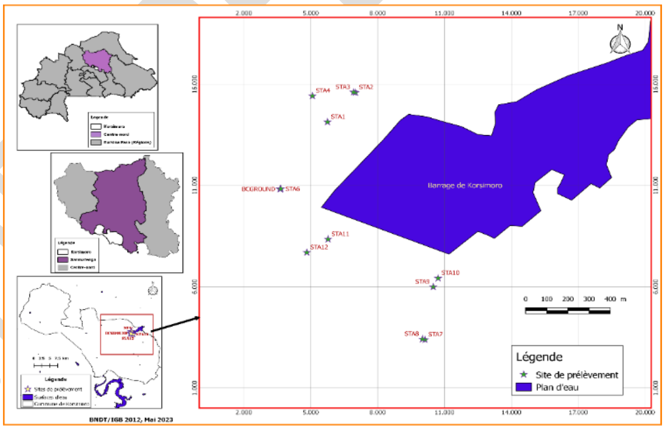
Introduction

Heavy metals such as lead, cadmium, mercury and many others are ubiquitous in our environment as a result of industrial use, intensive agriculture and various other human activities. However, their excessive presence in soils represents a serious environmental and health threat that is of growing concern to the scientific community and decision-makers around the world [1]. Soil contamination by heavy metals is a complex problem with potentially devastating consequences, affecting not only the health of terrestrial ecosystems, but also the quality of drinking water, food safety and human health [2]. The mining industry stands out as one of the main sources of heavy metals released into the ecosystem [3]. Ore extraction and crushing, as well as mineral concentration and disposal, are major causes of environmental pollution [4]. For example, high concentrations of heavy metals can be detected in the areas surrounding artisanal gold processing sites due to the release and dispersion of mining waste in soils, crops and watercourses. In the commune of Korsimoro, market gardening takes place mainly around the dam, which has an estimated water capacity of 4687900 m^3[5]. The installation of artisanal gold processing sites could contribute to soil pollution in the market gardening areas of the study zone. The aim of this study is to assess heavy metal soil pollution in the market garden areas of the municipality and to evaluate its impact on the environment. The heavy metals included in the study are chromium, cobalt, nickel, copper, zinc, arsenic, cadmium, mercury and lead. The authorities could use the conclusions of this study to formally consider banning the artisanal practice of gold processing near market gardening areas, which would prevent the risk of poisoning people growing on these soils through the food chain.

2. Materials and methods

2.1 Presentation of the study area

The study area is located approximately 30 km from the town of Kaya, capital of the Centre-Nord Region, and 70 km from OuagadougouBurkina Faso. Covering an area of 667km^2[6], the commune of Korsimoro is one of eleven (11) communes in the province. The commune's main activities are farming, livestock rearing and gold panning.



BNDT/IGB 2012, Mai 2023

Figure1: Geographical location of sampling sites

2.2 Sampling

Soil samples were taken between December 2022 and January 2023 in the market gardening sites identified around the Korsimoro dam. A total of 21 soil samples were taken from the 0-20 cm surface horizon using a spiral auger. It should be noted that each sample constitutes a composite sample that was taken from a rectangular plot 5 m long and 2 m wide, i.e., an area of 10 m2; this corresponds to a rate of 0.1% per hectare (ha). At each point, 1 kg of soil was taken and packaged in a clean, welllabelled plastic bag and taken to the BUMIGEB laboratory for analysis. The samples were numbered S1 to S21.

2.3. Preparation and analysis of samples

The samples taken were dried at room temperature in the laboratory and in the sun, then homogenised and placed in an oven at 105°C for 24 hours. Each sample was then crushed and sieved using a 2mm mesh sieve. The sieved material was then ground to a very fine powder with a diameter of 63 microns using a certified SAULAS sieve. Mineralization was carried out with 0.5 g of sample by adding 7.5mLof 35% concentrated hydrochloric acid and 2.5mLof 70% concentrated nitric acid on a hot plate and cooled in ambient air. The required quantity of each sample was then taken and run through the ICP/MS for the determination of heavy metals.

The analysis focused mainly on zinc (Zn), nickel (Ni), chromium (Cr), copper (Cu), lead (Pb), cadmium (Cd), cobalt (Co), arsenic (As) and mercury (Hg).

2.4. Methods for determining pollution intensity

The intensity of heavy metal contamination in soils was assessed using four indices: the enrichment factor (EF), the geoaccumulation index (Igeo), the contamination factor (CF) and the Pollution Load Index (PLI). Their principle is based on the comparison of measured values with reference values such as the average content of elements in the earth's crust.

2.4.1 Enrichment factor (EF)

The enrichment factor indicates the number of times an element is enriched relative to the abundance of that element in the reference material. The reference material used in our study is iron (Fe). The calculation of the EF was defined by relating the content of a contaminating element in the sample to the concentration of an element deemed to be relatively immobile in this sample, compared with the same ratio found in the reference material. Iron (Fe) was chosen as the immobile reference element for this calculation. This choice is based on the fact that iron is naturally present in the water and sediments of the study area. In addition, it is one of the reference materials widely used in the literature [4,7].

The standardised enrichment factor [8-10] is obtained using the following relationship:

$$\boldsymbol{EF} = \frac{{[\boldsymbol{M}]_{\text{é}\boldsymbol{ch}}}\Big/{[\boldsymbol{Fe}]_{\text{é}\boldsymbol{ch}}}}{{[\boldsymbol{M}]_{\boldsymbol{ref}}}\Big/{[\boldsymbol{Fe}]_{\boldsymbol{ref}}}}$$

With EF: Enrichment factor; [M]_éch: concentration of metal M in the sample; [Fe]_éch: concentration of iron in the sample; [M]_ref: concentration of metal M in the reference materials;

[Fe]_ech: concentration of iron in the sample; [M]_ref: concentration of metal M in the reference materials; [Fe]_ref: concentration of iron in the reference materials.

The EF values are interpreted according to the level of contamination (table 1) [11].

Table 1: Enrichment level according to EF values

Values	Enrichment level
FE> 50	Extremely severe enrichment
25 < FE < 50	Very severe enrichment
10 < FE < 25	Severe enrichment
05 < FE < 10	Moderately severe enrichment
03 < FE < 05	Moderate enrichment
01 < FE < 03	Minor enrichment
FE < 01	No enrichment

2.4.2 Contamination factor, CF

To assess the level of heavy metal contamination in soils, we calculated the contamination factor. This factor is calculated using the geochemical background. The degree of contamination was estimated in relation to the relative contents of the continental crust [12] (UCC: Upper Continental Crust) of Wedepohl (1995) (table 2).

Table 2: Relative contents of continental crust [12,13].

Elements	Cr	Co	Ni	Cu	Zn	As	Cd	Pb	Hg
UCC*	35,00	12,00	19,00	14	52	2,00	0,10	17,00	0,056

UCC : Upper Continental Crust

The contamination factor is calculated from the following formula [14-16] :

$$\boldsymbol{CF = \frac{C_n}{B_n}}$$

With Cn the concentration of the metal in the sample; Bn the geochemical background. The different levels of contamination according to FC values are shown in Table 3.

Table 3 : Level of contamination according to CF values.

CF value	Degree of Contamination
CF ≤ 1	Low contamination
1≤ CF ≤ 3	Moderate contamination
3≤ CF ≤ 6	Considerable contamination

CF ≥ 6	Very high contamination

2.4.3 Geoaccumulation index (Igeo)

A third criterion for assessing the intensity of metal pollution is the geoaccumulation index [17], which is used to estimate contamination by comparing pre-industrial and recent metal concentrations [18]. This method, which has been used by [17] since the late 1960s, has been applied to several trace metal studies in Europe. It can also be applied to the assessment of soil contamination. It is calculated using the following equation:

$$\boldsymbol{I_{géo} = \log_2\left(\frac{C_n}{1,5 \times B_n}\right)}$$

Where Igeo = geoaccumulation index; log2 = logarithm to base 2; n = element under consideration; Cn= concentration measured in the sample; Bn= geochemical background; 1.5 = geochemical background exaggeration factor, whose function is to take account of natural fluctuations in the geochemical background. A scale of values with six classes has been defined according to the intensity of the pollution [17,19] .

Table 4: Pollution scale associated with Igeo values.

Values	Pollution levels
$I_{géo} < 0$	Unpolluted
$0 \leq I_{géo} < 1$	Unpolluted to moderately polluted
$1 \leq I_{géo} < 2$	Moderately polluted
$2 \leq I_{géo} < 3$	Moderately to highly polluted
$3 \leq I_{géo} < 4$	Highly polluted
$4 \leq I_{géo} < 5$	Highly to extremely polluted
$I_{géo} \geq 5$	Extremely polluted

2.4.4. Pollution Load Index (PLI)

To assess the level of soil contamination, we calculated the PLI, which gives a quantitative estimate of the level of pollution of chemical elements in a given sample. Its expression is [20,21]:

$$PLI = \sqrt[n]{FC_1 \times FC_2 \times FC_3 \times \cdots\cdots\cdots\cdots \times FC_n}$$

where CF: contamination factor; n: number of metals. This method identifies two levels of pollution in the sample [22,23]. Thus, for PLI≈1: no pollution and for PLI>1: presence of pollution.

3 Results and discussion

3.1Distribution of heavy metals in agricultural soils

Table 5 presents the results of heavy metal concentrations in soils in the study area.

Table 5: Average concentration (mg/kg) of heavy metals in our study area

Elements	Cr	Co	Ni	Cu	Zn	As	Cd	Hg	Pb
Average	136,387	575,956	60,037	53,653	77,381	9,499	587,039	29,048	19,598
Maximum	177,705	670,195	90,520	69,720	117,115	13,655	633,685	81,035	24,785
Minimum	100,340	448,735	30,265	38,785	65,645	6,835	557,720	3,975	15,835
Standard deviation	16,345	66,693	14,615	6,660	7,210	1,468	20,546	20,647	2,140
Limit [24]	150	2	50	100	300	40	2	1	100

These results show that the concentrations (mg/kg) of the heavy metals studied vary as follows:

The concentration of the metal chromium varies from 100.340 to 177.705mg/kg with an average of 136.387mg/kg. The average value is below the limit of 150mg/kg. The soils studied are not contaminated by chromium.

Cobalt concentrations ranged from 448.735 to 670.195mg/kg, with an average of 575.956mg/kg. The average value is 288 times higher than the limit value of 2mg/kg. The soils studied are contaminated with cobalt.

The average nickel concentration is 60.037 mg/kg. The average value is higher than the regulatory limit value for agricultural soils. All the soils in the study area are contaminated by the metal nickel.

The elements copper, zinc, arsenic and lead have average concentrations of 53.653 mg/kg, 77.381 mg/kg, 9.499 mg/kg and 19.598 mg/kg respectively. The values do not exceed the limit values for agricultural soils. These results confirm that the soils studied are not contaminated by copper, zinc, arsenic or lead.

The average cadmium concentration was 587.039mg/kg, with a maximum of 633.685mg/kg and a minimum of 557.720mg/kg. All the soil samples taken in the study area have cadmium concentrations above the limit value. The average cadmium concentration was approximately 294 times higher than the limit value. This value indicates that the soil is contaminated by cadmium.

The average mercury concentration was 29.048mg/kg, with a maximum of 81.035mg/kg and a minimum of 3.975mg/kg. All the soil samples taken in the study area have mercury concentrations above the limit value. The average mercury concentration is approximately 29 times higher than the limit value. This value indicates that the soil is contaminated with mercury.

The descending order of soil contamination by heavy metals is as follows:

[Cd] > [Co] > [Cr] > [Zn] > [Ni] > [Cu] > [Pb] >[Hg] > [As].

3.2 Enrichment factor

The enrichment factor values for each metal calculated at a depth of 0-20 cm are shown in Table 6.

Table 6 Calculation of enrichment factors in market garden soil

Elements	Cr	Co	Ni	Cu	Zn	As	Cd	Hg	Pb
EF	2,134	37,307	2,310	2,867	1,177	3,533	4550,741	417,094	0,876

The EF for the element lead (Pb) shows no enrichment (EF<1) in market garden soils.

The enrichment factors for the elements chromium (Cr), copper (Cu), nickel (Ni) and zinc (Zn) are between 1 and 3, corresponding to minor enrichment of the soils by these elements.

The soils in the study area show moderate enrichment for the element arsenic (As), and very severe enrichment is noted for cobalt (Co).

Overall, the FE values indicate extremely severe enrichment for cadmium (Cd) and mercury (Hg).

3.3Geoaccumulation index

Geoaccumulation indices for heavy metals in soils range from 0.935 to 1.759 for chromium, with an average of 1.362. These indices vary for cobalt between 4.689 and 5.267, with an average of 5.035. The Geo Index for nickel is 1.031. Copper has a Geo Accumulation Index ranging from 0.855 to 1.701, with an average of 1.306. Some TMEs, such as zinc, have a Geo Index ranging from -0.249 to 0.586, with an average of -0.024. Arsenic varies from 1.188 to 2.186, with an average of 1.638. Cadmium has an Igeo ranging from 11.832 to 12.016, with an average of 11.905. The Igeo for mercury varies between 5.564 and 9.914, with an average value of 7.720. Lastly, the Igeo for lead varies between -0.687 and -0.041, with an average of -0.391.

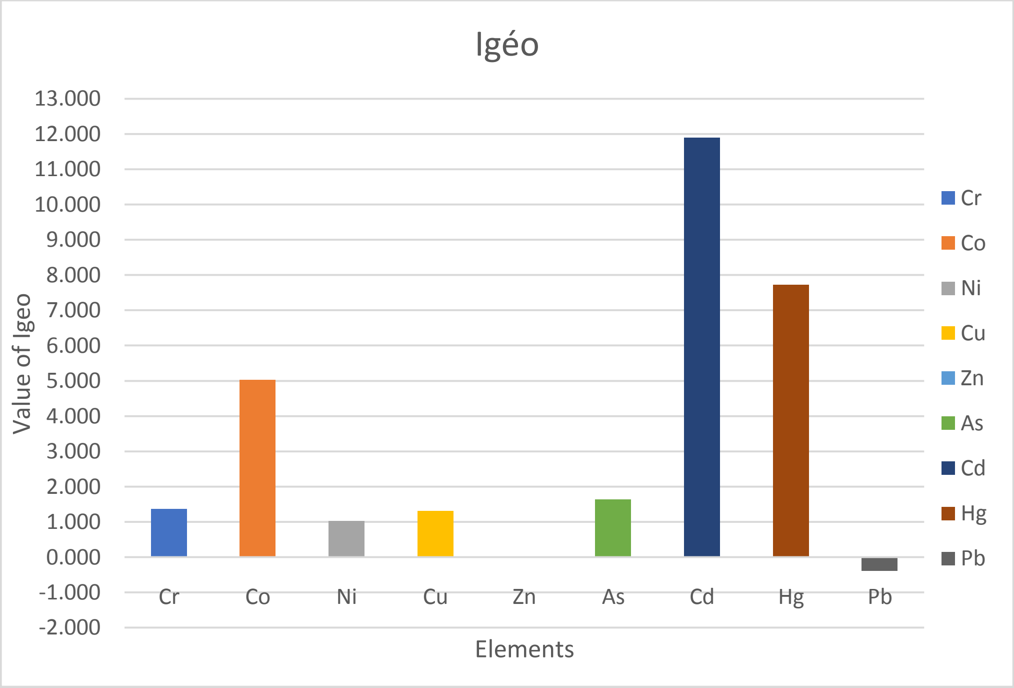


Figure 2: Geoaccumulation index for heavy metals in soils in our study area

The negative Igeo values (Igeo< 0) for certain metals such as lead (Pb) and zinc (Zn) show that the soils studied are not polluted by these metals. The average Igeo for chromium, nickel, copper and arsenic is between 0 and 1 (0 ≤ Igeo< 1), indicating that the soil is moderately polluted with these metals. The Igeo for cadmium (11.905), mercury (7.720) and cobalt (5.035) are significantly greater than five (Igeo>5) and indicate extreme contamination of the soil in the market gardening area by these metals. The results of the Igeo confirm those of the FE in the present study. Heavy metal contamination is closely linked to the use of chemical inputs for soil fertilisation.

3.4 Contamination factors

The contamination factors for the various heavy metals in the soil samples are shown in Table 7.

Table 7: Contamination factors for heavy metals in soils from our study area

Sol	Contamination factor								
	Cr	Co	Ni	Cu	Zn	As	Cd	Hg	Pb
Sol 1	4,589	57,775	4,487	4,349	5,733	5,733	5508,529	767,054	1,316
Sol 2	4,663	54,987	3,902	4,170	5,390	5,390	5579,216	112,500	1,236
Sol 3	3,241	53,183	3,184	3,646	5,578	5,578	5664,951	1447,054	1,155
Sol 4	3,872	54,224	4,017	4,005	5,190	5,190	5549,559	83,304	1,282
Sol 5	3,108	52,217	2,952	3,585	5,050	5,050	5724,363	768,125	1,190
Sol 6	4,077	53,916	3,619	3,862	4,933	4,933	5674,951	90,714	1,289
Sol 7	3,636	48,695	2,924	3,340	4,593	4,593	5817,157	786,518	1,070
Sol 8	3,719	53,126	3,651	3,731	5,110	5,110	5564,804	764,911	1,212
Sol 9	3,894	57,232	4,841	4,033	5,823	5,823	5467,843	85,000	1,458
Sol 10	4,058	57,022	3,833	3,817	6,828	6,828	5504,412	751,696	1,450
Sol 11	3,525	52,046	3,649	3,516	4,873	4,873	5587,157	779,107	1,263

Sol 12	4,090	54,144	3,871	4,364	5,448	5,448	5581,373	76,250	1,119
Sol 13	3,722	39,064	1,849	2,895	3,458	3,458	6103,137	812,411	0,990
Sol 14	3,391	39,920	2,110	3,073	3,913	3,913	6100,833	812,143	1,044
Sol 15	2,867	40,929	2,014	4,876	3,688	3,688	6002,500	811,964	1,061
Sol 16	3,400	38,684	1,618	3,565	3,418	3,418	6212,598	70,982	1,076
Sol 17	3,483	41,319	2,218	2,712	3,663	3,663	5996,275	791,875	0,931
Sol 18	4,755	49,691	3,635	3,394	4,223	4,223	5768,235	101,161	0,985
Sol 19	4,341	41,030	1,946	2,923	3,770	3,770	5943,922	87,232	0,972
Sol 20	5,077	56,273	4,017	4,519	4,660	4,660	5541,176	89,911	1,088
Sol 21	4,324	47,202	3,083	4,416	4,408	4,408	5967,941	803,125	1,023
Minimum	2,867	38,684	1,618	2,712	3,418	3,418	5467,843	70,982	0,931
Maximum	5,077	57,775	4,841	4,876	6,828	6,828	6212,598	1447,054	1,458
Average	3,897	49,651	3,211	3,752	4,750	4,750	5755,282	518,716	1,153

Heavy metal CF values for lead ranged from 0.931 to 1.458, with an average of 1.153. The soil samples taken are moderately contaminated with lead.

The CF values obtained for Cu, Cr, Zn, Ni and As were respectively 3.752, 3.897, 4.750, 3.211 and 4.750. These values indicate that the contamination is considerable. However, there was very high contamination of Co, Cd and Hg. Generally speaking, the soil is severely contaminated with cobalt, cadmium and mercury. There is a risk of these metals being transferred to plants and groundwater, with harmful consequences for the environment and human health.

3.5 Assessment of the PLI of the soils in ourstudy

Figure 3 shows the histograms of the pollution Load indices for the soils in the study area.

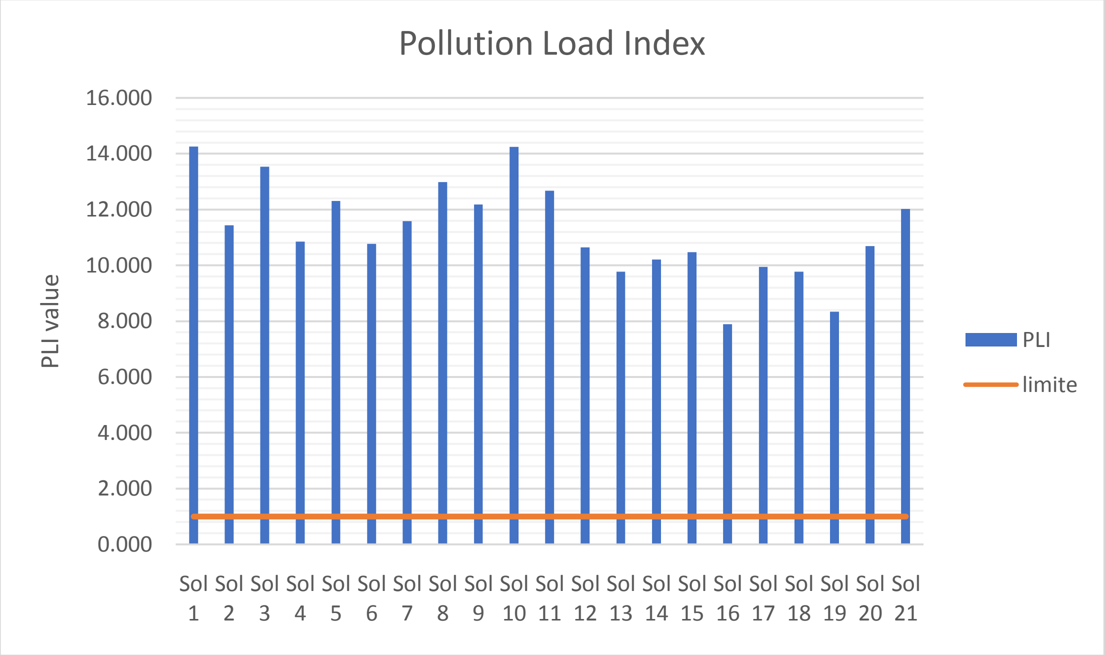


Figure 3: Pollution load index soil in the study area

Analysis of the histogram (Figure 3), showing the variation in PLI in the 21 soil samples, shows PLI values all greater than 1 (PLI>1). The soils in the study area therefore have a high pollution load.

4. Conclusion

This study assessed the Degree of Contamination in zinc, nickel, chromium, copper, lead, cadmium, cobalt, arsenic and mercury in the market gardening areas of Korsimoro. The results obtained for the twenty-one (21) soil samples show that the concentration values are very varied.

They vary according to the metallic element. The average concentrations of the heavy metals cobalt, cadmium, nickel and mercury exceeded the reference limit values, suggesting contamination.

The results of theEF calculations show a very severe enrichment for cobalt (Co) and then indicate an extremely severe enrichment overall for cadmium (Cd) and mercury (Hg).

The results of the contamination factor calculation showed a high level of Cd, Co and Hg contamination, indicating an anthropogenic origin.

In addition, the extent of metal pollution in the soil was assessed using the PLI calculation. The results obtained show that soils in the study area are contaminated by metallic pollutants. The minimum PLI is 7.89 and the maximum is 14.26. This index, greater than 1, indicates a high level of pollution.

Contamination of these soils could pose a risk of poisoning through the food chain for people who use them to grow their crops, as well as a risk of contamination of groundwater.

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