Nigerian Research Journal of Chemical Sciences (ISSN: 2682-6054)
Volume 13, Issue 2, 2025

Assessment of Heavy Metal Contamination and Associated Health Risks in Soil and Water Samples of a Mechanic Village in Southeastern Nigeria

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Accepted: September 29, 2025. Published Online: October 7, 2025

ABSTRACT

This study assessed the heavy metal concentrations in soils and water samples from Orji Mechanic village, Imo State, Nigeria, to evaluate associated environmental and health risks. Soil samples (2 per zone) and five water samples, including respective controls were analyzed for lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), nickel (Ni), iron (Fe) and manganese (Mn) using an atomic spectrometer. Soil samples from the open dump zone exhibited elevated levels of Pb (67.2 mg/kg), Cd (5.6 mg/kg) and Cr (126.6 mg/kg) surpassing WHO limits. Contamination factors (CFs) for Pb, Cd and Cr were 21, 11.2 and 84.4 respectively with a geo-accumulation (I_geo) index indicating extreme contamination (Cr = 5.82). Hazard quotients (HQs) for Pb and Cr exceeded 1 in all the zones with the highest values recorded in the open dump zone (Pb = 2.15, Cr = 1.80). Water samples from surface drainage 1 zone showed significant contamination with Pb (115), Cd (20.4) and Cr (5.68) hazard quotients. Geo-accumulation indices for Pb, Cd and Fe were high across all the zones. This study highlights severe contamination and associated risks, emphasizing the need for urgent remediation and policy interventions.

Keywords: Contamination factor, hazard quotient, hazard index, geo-accumulation index, digestion.

INTRODUCTION

Heavy metals are persistent environmental pollutants that pose a major threat to ecosystems and human health due to their toxicity, non-biodegradability and bio-accumulative nature. Activities in informal industrial regions such as mechanic villages contribute heavily to metal pollution particularly in developing countries like Nigeria, where environmental regulations are often unenforced [1].

Orji mechanic village situated in Imo State, southeastern Nigeria is a densely populated automotive repair center servicing thousands of vehicles weekly [2]. Waste materials form used engine oil, brake fluids, battery acids and metallic components are discharged directly into the environment, contaminating the surrounding soil and water bodies. These pollutants could migrate to the agricultural zones or enter ground water used for domestic consumption, posing long term dangers [3].

Notable studies have been carried out on the assessment of heavy metal contamination at Orji mechanic village and its surrounding towns. Ogoko focused on soil pollution in Owerri including Orji mechanic village. The study reported varying concentrations of heavy metals but was limited by the assessment of soil samples and did not include water samples or detailed risk assessment [4]. Nkwoada assessed heavy metal concentrations and ecological risks in Nekede mechanic village, a neighboring area to Orji. The study found significant contamination and ecological risks particularly in iron and cadmium. However, the study focused on reclaimed areas and did not provide a direct comparison with active mechanic villages [5]. Ibe *et al.* focused on the polycyclic aromatic hydrocarbons in abandoned sections of Orji mechanic village, highlighting ecological risks. The study did not assess heavy metals or include water samples in its analysis [6]. Orisakwe *et al.* assessed heavy metal concentrations in food and crops in Owerri including areas near mechanic villages. The study revealed elevated levels of Pb, Cd and Ni posing health risks through dietary intake. However, the study did not focus on soil and water samples or provide detailed risk assessments [7].

This current study advances previous researches by incorporating both soil and water samples to assess comprehensive contamination levels, utilizing contamination factors, hazard quotients and hazard indices (HIs) for a detailed risk assessment, particularly among the vulnerable group (children). Furthermore, it provided a direct comparison between active mechanic village and control sites, offering insights into both environmental and public health risks associated with heavy metal contamination.

The objective of this research is to: assess the concentration of selected heavy metals in soil and water at Orji mechanic Village, compare the results to international guidelines (WHO and FAO), assess the potential health and ecological risks and recommend sustainable remediation strategies.

MATERIALS AND METHODS

Study Area

Orji mechanic village is situated at Orji in Owerri North, a town which is a few kilometers off the capital city of Imo State, Nigeria, at approximately 5.53^{o}N and 7.07^{o}E. It covers a large expense of land and accommodates hundreds of informal auto repairer shops. The site has a poor drainage, no centralized waste disposal system and the soil predominantly composed of sandy – loam [8].

Sample Collection

Collection of Soil Samples

A total of ten soil samples were collected from five strategic zones. Two samples were collected from each zone. The zones include: oil changing region, engine repair section, open dump area, car washing zone and central pathway. In addition, a control soil sample was taken 2 km away from the mechanic village in a vegetated uncontaminated area. Each soil sample was collected at depths of 0 – 15 cm using a stainless steel auger and stored in labelled polythene bags [9].

Collection of Water Samples

Five (5) water samples were collected. Two of the water samples were obtained from surface drainage systems, another two samples were obtained from shallow wells and one water sample was obtained from the car washing zone. A control water sample was taken from a borehole in a residential area upstream of the mechanic village. Water samples were collected in acid-washed 1 liter bottles and acidified to a pH < 2 with 2 mL of concentrated trioxonitrate (V) acid (HNO_3) to inhibit metal precipitation. The water samples were stored at 4^{o}C prior to analysis [10].

Sample Preparation and Digestion

Soil Sample Digestion (*Aqua Regia* Method)

Air-dried and sieved (2 mm mesh) soil sample (1 g) was weighed using an electronic balance and placed in a digestion tube. *Aqua regia* (HCl: HNO_3 = 3:1) (10 mL) was added to the soil sample. The mixture was heated at 96^{o}C for 2 hours in a fume hood. After cooling, the mixture was filtered and diluted to 50.0 mL with deionized water [11].

Water Sample Digestion

Water sample (100 mL) was mixed with 50 mL concentrated trioxonitrate (V) acid in a 500 mL flask. The mixture was heated to 92^{o}C for 1 hour. After cooling, it was filtered and diluted to 50 mL with deionized water [12].

Instrumentation

An Agilent Technologies 240 AA Atomic Absorption Spectrophotometry (AAS) equipped with a deuterium background corrector and air-acetylene flame was employed in this study. Hollow cathode lamps were used for each metal. Each metal was analyzed using a specific wavelength, slit width and lamp current with air-acetylene flame as the energy source [13].

Lead was measured at 283.5 nm with a 0.7 nm slit and 10 mA lamp current. Cadmium was measured at 229.1 nm, 0.7 nm slit and 8 mA current. Chromium was determined at 358 nm with 0.9 nm slit and 7 mA. Nickel was determined at 233 nm, 0.2 nm slit and 7 mA. Iron was analyzed at248 nm, 0.2 nm slit and 5mA. Copper was determined at 324. 9 nm, 0.5 nm slit and 3 mA, while zinc was measured at 214 nm, 1.0 nm slit and 5 mA. Calibration curves were prepared using multi-element standard solutions at 0.1, 0.5, 1.0, 2.0 and 5.0 mg/L [14]. Blanks and certified reference materials were analyzed to ensure quality assurance [15]. Each sample was measured in triplicate to minimize instrumental error.

Contamination Factor

The contamination factor is a ratio that relates the concentration of a metal in a sample to that in a clean or background environment [20]. It is commonly used to access the level of heavy metal contamination in environmental samples such as soil and water. The formulas are similar for both with slight contextual differences. The contamination factor for heavy metals in soils is calculated with the equation 1 [21].

$$C.F = \frac{C_{\_sample}}{C\_control} \quad (1)$$

Where $C_{\_sample}$ is the concentration of a metal in a sample, and C_control is the concentration of a metal in a clean or background environment.

Table 1 gives the contamination factors of pollutants and their interpretations

Table 1: Contamination Factor and Interpretation

C.F Value	Interpretation
CF > 1	Low contamination
1 ≤ CF < 3	Moderate contamination
3 ≤ CF < 6	Considerable contamination
CF ≥ 6	Very high contamination

For water samples the formula in equation 1 for calculating the contamination factor is modified as equation 2

$$C.F = \frac{C_{measured}}{C_{standard}} \quad (2)$$

$C_{measured}$ = Measured concentration of the heavy metal in water (usually in mg/L or µg/L).

$C_{standard}$= Guideline or permissible concentration (e.g. WHO, EPA standard) for that metal in drinking or surface water (in mg/L or µg/L) [22].

Geo-accumulation Index

The geo-accumulation Index given by equation 3 evaluates how much a location has been polluted compared to its natural background levels, considering geological variability [23].

$$I\_geo = \log_2 \left(\frac{C\_sample}{1.5 \times C\_background} \right) \quad (3)$$

The factor 1.5 accounts for natural variations in metal levels due to rock and soil differences. The interpretations of the values of I_geo are given in Table 2 [24].

Table 2: Interpretation of I_geo Values

I_geo Values	Contamination Levels
≤ 0	Uncontaminated
0 – 1	Uncontaminated to moderately contaminated
1 – 2	Moderately contaminated
2 – 3	Moderately contaminated to strongly contaminated
3 – 4	Strongly contaminated
4 -5	Strongly to extremely contaminated
≥ 5	Extremely contaminated

Hazard Quotient

The hazard quotient assesses non-carcinogenic health risks due to exposure to a single contaminant: such as ingestion of a specific metal. It is calculated based on exposure levels and a reference dose using equations 4 and 5 [25].

$$HQ = \frac{ADD}{RfD} \quad (4)$$

$$ADD = \frac{C\_metal \times IR \times EF \times ED}{BW \times AT} \quad (5)$$

C_metal: Concentration of metal (mg/kg for soil or mg/L for water)

IR: Ingestion rate (kg/day, 200 mg/day soil ingestion rate for children)

EF: Exposure Frequency (350 days)

ED: Exposure Duration (6 years)

BW: Body Weight (kg, 15 kg average child weight)

AT: Averaging Time (Days, 365 daysx ED = 2190 Days)

RfD: Reference Dose Safe Daily Exposure Levels (mg/kg body weight/day).

For water analysis, the hazard quotient for each metal can be calculated with equation 6 [21].

$$HQ = \frac{CDI}{RfD} \quad (6)$$

CDI: chronic daily intake (mg/kg/day)

RfD: Reference dose (mg/kg/day) on a safe daily exposure level.

CDI is estimated using a simplified formula given by equation 7 assuming oral ingestion:

$$CDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (7)$$

C: metal concentration in water (mg/L)

IR: Ingestion rate (1 L/day drinking water intake)

EF: Exposure Frequency (350 days)

ED: ED: Exposure Duration (6 years)

BW: Body Weight (15 kg)

AT: Averaging time (6 yearsx 365 = 2190 days)

The RfD values for metals shown in Table 3 were provided by United States Environmental Protection Agency (USEPA) and the World Health Organization (WHO) [22].

Table 3: Reference Doses (RfD) for Selected Metals

Metal	RfD (mg/kg/day)-adult	RfD (mg/kg/day)-child
Pb	0.0035(inferred, not an official EPA RfD)	0.0004 (inferred, not an official EPA RfD)
Cd	0.001	0.0005
Cr	0.0009 (Cr(VI))	0.0009 (Cr(VI))
Fe	0.7	0.7
Zn	0.3	0.3
Cu	0.04	0.04
Ni	0.02	0.02
Mn	0.14 (adult), 0.07 (child)	

The values of hazard quotient are interpreted in Table 4:

Table 4: Hazard Quotient Interpretation

HQ Value	Interpretation
HQ < 1	No significant non-carcinogenic risk
HQ = 1	Threshold level; potential for non-carcinogenic effects
HQ > 1	Possible non-carcinogenic health risk; further investigations needed.

Hazard Index

The hazard index is the sum of individual hazard quotient values for all contaminants of to evaluate health risk as given by equation 8. It is used to assess the combined risk from multiple contaminants. The H.I is used when an individual may be exposed to more than one contaminant, which can cause additive effects [23].

$$HI = \sum HQ_{metal1} + HQ_{metal2} + \ldots\ldots\ldots\ldots\ldots + HQ_{metaln} \quad (8)$$

Table 5: Hazard Index Interpretation

HI Value	Interpretation
HI < 1	No expected adverse effects from combined exposure
H = 1	Caution threshold, close to risk level
HI > 1	Potential adverse health effects due to cumulative exposure

Data Analysis and Interpretations

Concentrations were obtained automatically by Agilent AAS software using calibration curves [16]. Final concentrations in mg/L for water and mg/Kg for soil were computed. Results were corrected for blank values and the data generated from the study were analyzed using Descriptive Statistics Computer employing SPSS v25 and Excel [17]. The heavy metal concentrations were compared to World Health organization (WHO) and Food and Agricultural Organization (FAO) Limits. Pollution indices were calculated using contamination factor and Geo-accumulation index [18]. Health risk indices were determined using Hazard Quotient and Hazard Index based on the United States' exposure models [19].

RESULTS AND DISCUSSION

Table 6 reveals the heavy metal concentrations in all the analyzed soil samples.

Table 6: Heavy Metal Concentrations in Soil Samples in mg/kg

S/N	Metal	O.C.A	E.R. S	O.D.Z	C.W.A	C.P	C	WHO limits (mg/kg)
1.	Pb	60.5 ±1.50	56.4±1.48	67.2±1.85	54.5±1.37	51.8±1.25	3.2±0.10	50
2.	Cd	5.0±0.14	4.8±0.13	5.6±0.17	3.7±0.11	4.2±0.12	0.5±0.01	3
3.	Cr	123.4±3.52	124.8±3.59	126.6±3.73	118.9±3.48	117.5±3.43	1.5±0.04	100
4.	Cu	19.6±0.64	18.2±0.53	21.3±0.64	16.8±0.47	14.7±0.41	3.0±0.08	36
5.	Zn	36.7±1.28	34.5±1.11	38.9±1.34	32.4±1.03	30.2±0.95	9.5±0.26	90
6.	Ni	13.2±0.40	2.6±0.08	14.1±0.42	12.0±0.39	11.8±0.33	2.1±0.06	35
7.	Fe	158.9±4.47	154.4±4.08	161.2±5.04	150.2±3.88	145.7±3.61	30.7±0.95	30,000
8.	Mn	21.2±0.57	20.4±0.56	22.1±0.61	18.9±0.49	17.3±0.47	3.8±0.12	2,000

Values are expressed as mean ± standard deviation (n = 3)

O.C.A = Oil Changing Area, E.R.S = Engine Repair Section, O.D.Z =Open Dump Zone, C.W.A = Car Washing Area, C.P =Central Pathway, C= Control.

The concentrations of lead, cadmium, and chromium exceeded the WHO permissible limits in all zones analyzed except for the control zones. They were observed to be highest in the open dump zones with values of: 67.2 mg/kg, 5.6 mg/kg and 126.6 mg/kg respectively. The concentrations of these three heavy metals ranged above the WHO permissible limits for Pb (50.0 mg/kg), Cd (3.0 mg/kg) and Cr (100.0 mg/kg), thereby making them potent contaminants. Elevated lead, cadmium and chromium concentrations in active mechanical areas suggest pollution from oil, batteries, parts and mechanical wastes. Other metals (Cu, Zn, Ni, Fe and Mn) are well within the safe limits. The control sites show the lowest concentrations confirming its role as an uncontaminated reference. Most standard deviations are < 5% of the means, indicating low variability and good precision in sampling and analysis.

Table 7 revealed the calculated Contamination Factor of the analyzed soil samples for lead, cadmium and chromium.

Table 7: Contamination Factor for Data Collected from Soil Analysis

Location	C.F (Pb)	C.F (Cd)	C.F (Cr)
Oil Changing Area	18.9	10.0	82.27
Engine Repair Section	17.6	9.60	83.2
Open Dump Zone	21.0	11.2	84.4

Car Washing Area	17.0	7.40	79.3
Central Pathway	16.2	8.40	78.3

All sites exhibited very high contaminations (C.F > 6) for Pb, Cd and Cr.

Table 8 revealed the Geo-accumulation Index for data collected from soil samples for lead, cadmium and chromium.

Table 8: Geo-accumulation Index for Data Collected from Soil Analysis

Location	I_geo (Pb)	I_geo (Cd)	I_geo (Cr)
Oil Changing Area	3.66	2.74	5.78
Engine Repair Section	3.39	2.68	5.79
Open Dump Zone	3.81	2.90	5.82
Car Washing Area	3.51	2.30	5.72
Central Pathway	3.43	2.49	5.71

I_geo values are all above 2, with chromium reaching over 5.8 indicating extreme contamination. Cadmium poses the most critical risk being highly toxic even at low levels. The open dump zone is the most contaminated site while the oil changing section is also heavily impacted.

Table 9 revealed the hazard quotient – Child (Soil Pathway) while Table 10 revealed Hazard Index – Child (sum of the HQs per location). All sites presented effectively high HQs and HI values, especially for lead and chromium.

Table 9: Hazard Quotient – Child (Soil Pathway)

Location	HQ (Pb)	HQ (Cd)	HQ (Cr)
Oil Changing Area	1.93	0.128	1.75
Engine Repair Section	1.80	0.123	1.77
Open Dump Zone	2.15	0.143	1.80
Car Washing Area	1.77	0.0946	1.69
Central Pathway	1.66	0.107	1.67
Control	0.102	0.0128	0.0213

Table 10: Hazard Index – Child (sum of the HQs per location)

Location	H.I = ∑HQs
Oil Changing Area	3.81
Engine Repair Section	3.69
Open Dump Zone	4.09
Car Washing Area	3.55
Central Pathway	3.44
Control	0.136

The open dump section has the highest Hazard Index value, posing health risk to children. The HQ and HI values were calculated in accordance to United States Environmental Protection Agency (USEPA) guidelines.

Table 11 shows the heavy metal concentrations in water samples in mg/L.

Table 11: Heavy Metal Concentrations in Water Samples in mg/L

S/N	Metal	Surface drainage 1	Surface drainage 2	Shallow well 1	Shallow well 2	Car washing zone	Control	WHO Limits (mg/L)
1.	Pb	0.72±0.0110	0.68±0.0076	0.60±0.0085	0.63±0.0762	0.55±0.0088	0.02±0.0046	0.01
2.	Cd	0.16±0.0074	0.13±0.0092	0.14±0.0074	0.12±0.0084	0.17±0.0084	0.03±0.0051	0.003
3.	Cr	0.08±0.0057	0.07±0.0061	0.05±0.0064	0.06±0.0058	0.05±0.0045	0.01±0.0045	0.05
4.	Cu	0.14±0.0058	0.12±0.0094	0.13±0.0055	0.15±0.0088	0.10±0.0085	0.02±0.0042	2.00
5.	Zn	0.29±0.0075	0.27±0.0084	0.24±0.0078	0.22±0.0074	0.25±0.0074	0.05±0.0057	3.00
6.	Ni	0.08±0.0063	0.09±0.0072	0.07±0.0088	0.06±0.0077	0.09±0.0065	0.01±0.0075	0.07
7.	Fe	1.15±0.0074	1.11±0.0063	1.08±0.0077	1.10±0.0085	1.12±0.0076	0.16±0.0076	0.30
8.	Mn	0.20±0.0076	0.18±0.0081	0.22±0.0075	0.19±0.0080	0.23±0.0072	0.04±0.0058	0.40

Values are expressed as mean ± standard deviation (n = 3)

In the analysis of lead, all zones including the control zone (0.02 mg/L) greatly exceeded the permissible limit (0.01 mg/L). Lead is highly toxic and its presence at these levels suggest serious contamination, likely due to mechanical and industrial activities. In the analysis of cadmium, all samples exceeded the WHO limit including the control zone. Cadmium is associated with battery, metal plating and plastic industries posing severe health risks especially to kidneys. For chromium, all zones except the control and shallow well 1 zone (0.05 mg/L) exceeded or are at the threshold. Chromium contamination can result from machinery parts and corrosion inhibitor. It is potentially carcinogenic. For Nickel, the surface drainage 1 and 2 and the car wash zone exceeded the WHO limit slightly. Nickel at elevated levels can be toxic, long term exposure should be avoided. In the analysis of iron, all zones, except for the control exceeded the WHO limits. Iron in such high concentrations can cause taste issues, staining and could indicate corrosion from vehicles and equipment metals.

Table 12 revealed the contamination factor for data collected from water analysis.

Table 12: Contamination Factor for Data Collected from Water Analysis

Location	CF(Pb)	CF(Cd)	CF(Cr)	CF(Ni)	CF(Fe)
Surface Drainage 1	72.0	53.3	1.60	1.14	3.83
Surface Drainage 2	68.0	43.3	1.40	1.29	3.70
Shallow Well 1	60.0	46.7	1.20	1.0	3.60
Shallow Well 2	63.0	40.0	1.20	0.857	3.67
Car Washing Zone	55.0	56.7	0.857	1.29	3.73
Control	2.0	10.0	0.20	0.143	0.533

Lead and cadmium had extremely high concentration factors with lead reaching up to 72 times the safe limit and cadmium up to 53.3. This is alarming and indicates acute pollution posing serious neurological, renal and carcinogenic risks to humans. Iron (Fe), across zones showed contamination factor values around 3.6 – 3.8, suggesting considerable contamination possibly due to rusting or metal leaching. Chromium and nickel have contamination factor values in the 0.85 – 1.6 range, including moderate health concerns, especially with long term exposure.

Table 13 revealed the geo-accumulation Index for data collected from water analysis. The geo-accumulation index of lead ranged from 5.2 – 5.6, indicating extreme pollution. For cadmium, the index ranged from 4.7 – 5.2 and this could be classified as strong to extreme contamination. Geo-accumulation index values iron ranged from 1.2 – 1.4. These values indicate moderate pollution.

Table 13: Geo-accumulation Index for Data Collected from Water Analysis

Location	I_geo (Pb)	I_geo (Cd)	I_geo (Cr)	I_geo (Ni)	I_geo (Fe)
Surface Drainage 1	5.58	5.15	0.0976	-	1.36
Surface Drainage 2	5.50	4.85	-	-	1.30
Shallow Well 1	5.32	4.95	-	-	1.26
Shallow Well 2	5.39	4.74	-	-	1.29
Car Washing Zone	5.20	5.24	-	-	1.32

Table 14 revealed the Hazard Quotient for water sample analysis from surface drainage 1 zone.

Table 14: Hazard Quotient – Child (Surface Drainage 1)

Metal	Concentration(C) (mg/L)	CDI (mg/kg/day)	RfD	HQ = CDI/RfD
Pb	0.72	0.0460	0.0004	115
Cd	0.16	0.0102	0.0005	20.4
Cr	0.08	0.00511	0.0009	5.68
Ni	0.08	0.00511	0.020	0.256
Fe	1.15	0.0735	0.70	0.105

Lead had the highest value (HQ = 115). Cadmium (HQ = 20.4) and chromium (HQ = 5.68). The overall hazard index (HI = $\sum HQ_S$) approximately 141 in the surface drainage 1 zone suggested potential adverse health effects due to cumulative exposure.

The health impacts of lead include: influence on the nervous systems, especially in children – causing developmental delays, learning difficulties and reduced intelligence quotient (IQ). In adults, it can cause hypertension, kidney damage and reproductive issues. On the environment, lead accumulates in soil and water, plants and animals. It can enter the food chain leading to bio- magnification.

Cadmium is toxic to kidneys and bones. Long term exposure to cadmium can cause bone demineralization and kidney dysfunction. It is also a known human carcinogen. On the environment, cadmium contaminates soils and water, affecting crop quality and posing risks to aquatic life.

Chromium (particularly Cr (VI)), is highly toxic and carcinogenic, affecting the respiratory tract, liver and kidneys. Skin contact can cause ulcers and allergic reactions. It contaminates water sources, harms aquatic organisms and reduces soil fertility.

CONCLUSION

The study found alarming levels of heavy metals in both soil and water samples from Orji mechanic village with concentrations of Pb, Cd and Cr exceeding WHO permissible limits. The calculated contamination factors, geo-accumulation indices and hazard quotients indicate severe environmental pollution and potential health risk especially to children. In addition, this study provided data on heavy metal contamination in a mechanic village setting, contributing to the understanding of industrial pollution in urban areas. It highlighted the need for stringent environmental monitoring and enforcement of pollution control measures. While similar studies have been conducted in other regions, this research focused on a mechanic village, an area often overlooked in environmental assessments. The comprehensive analysis using multiple indicators (CF, I_geo, HQ and HI) add depth to the understanding of contamination levels and associated risks. However, the study was limited to a specific geographic area and may not represent broader regional trends.

Implementation of soil and water decontamination strategies such as phytoremediation and soil washing are recommended. Policy enforcement in order to strengthen regulations on waste disposal and emissions from mechanic workshops as well as public awareness about the risks of heavy metal exposure and promotion of safe practices are crucial. Further research to monitor the effectiveness of remediation efforts and track changes in contamination levels should be conducted.

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