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EVALUATION OF REMEDIAL OPTION'S EFFECTIVENESS OF LEAD CONTAMINATED SITE IN BAGEGA COMMUNITY, ZAMFARA STATE, NIGERIA

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Abstract
The study evaluates the remedial option's effectiveness of lead contaminated site in Bagega community, Zamfara state. Samples of soil and water were collected from residential compounds (BRC), residential garden (BRG), village common area (BVC), processing areas (BPA), farmland areas (BFA), wells (BWE), boreholes (BBH) and ponds (BPO)water at the same locations before and after remediation using standard procedures of ASTM D6907 and APHA respectively. The concentrations of lead metal in soil and water samples before and after remediation were determined using Atomic Absorption Spectrophotometer (AAS) in accordance with ASTM D 3559 and ASTM D1976 standard methods. The results revealed that soil samples recorded the highest lead concentration reduction of 96.1 % in BRG while the least lead concentration reduction of 51.7 % was recorded in BFA after remediation. Water samples recorded least lead concentration reduction of 21.0 % in BBH and highest lead concentration reduction of 70.8 % in BPO after remediation. On the health risk analyses, BPA/01, 07 and 11; BFA/04, 07 and 08 posed health risk to the people while BPO/02, 06 and 09 posed no health risk to the people after remediation. The study therefore concluded that remediation was completely effective at BRC, BRG and BVC but it was not completely effective at BPA and BFA.

Key Words: *Health risks, Lead concentration, Lead poison, Remediation*

Introduction

Dooyema *et al.* (2010) reported that the extraction and processing of gold by artisanal gold miners began many years ago in Zamfara state with substantial revenue for the miners. He stressed that many of the miners acknowledged improvement in their standard of living since inception of gold processing in their area. This good news was suddenly changed precisely in 2010 when Medecins Sans Frontieres (MSF, 2012) discovered the high mortality rate of children during the immunization programme in nine communities from two Local Government Areas (LGAs) of Zamfara State. The causes of the imminent death were attributed to the engagement of unemployed youths in artisanal gold mining using unconventional methods which was responsible for the enormous lead contamination across the study area (Plumlee *et al.*, 2013). According to

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Alaba and Opafunso (2016) long time grinding of lead gold-rich ore into fine particles resulted into widespread of lead dust in the affected communities which was responsible for the lead contaminated site. Bartrem *et al.* (2014) described a lead contaminated site as the areas of land, water, groundwater, or sediments with the lead levels of contaminants above background concentrations that presents, or have the potential to present, a risk of harm to human health or the environment.

In May, 2010 the number of death and illness recorded in the study area were intolerable for both local and international stakeholders. The local and international stakeholder team up to develop remediation and medical response to tackle the menace of lead poison (CDC, 2010).The remediation of soil and water samples in the study area was carried out by the trained youths with technical advice provided by the Blacksmith Institute and its implementing partner, Terra Graphics Environmental Engineering (BI, 2011). Tirima *et al.* (2016) enumerated the remediation options adopted in the remediation of the soil samples as soil excavation and replacement; solidification and stabilization of soil while leaching, pumping and sediment excavation were used for remediation of water samples, which was completed in August, 2013. According to Tirima *et al.* (2016), a total of 820 compounds, 181 common areas, 31 ponds and Industrial Area at Bagega were remediated. The result revealed that mean soil concentrations before and after remediation are 1,311 mg/kg and 94 mg/kg respectively. Meanwhile, the study carried out by Udiba *et al.* (2012) in Dareta revealed that lead, cadmium and copper in soil after remediation are sufficiently high to cause significant health challenges. The study therefore evaluated the remedial option's effectiveness carried out in soil and water samples of the study area in order to avert health challenges that may arise after remediation.

Material and Methods

Description of the Study Area

Bagega Community is located in Anka Local Government Areas in Zamfara State which is one of the seven states that form the Northwest geopolitical zone of Nigeria (Alaba and Opafunso, 2016). The longitude and latitude of Bagega Community are between 5.999E and 6.049E; 11.873N and 11.861N respectively as shown in Figure 1.

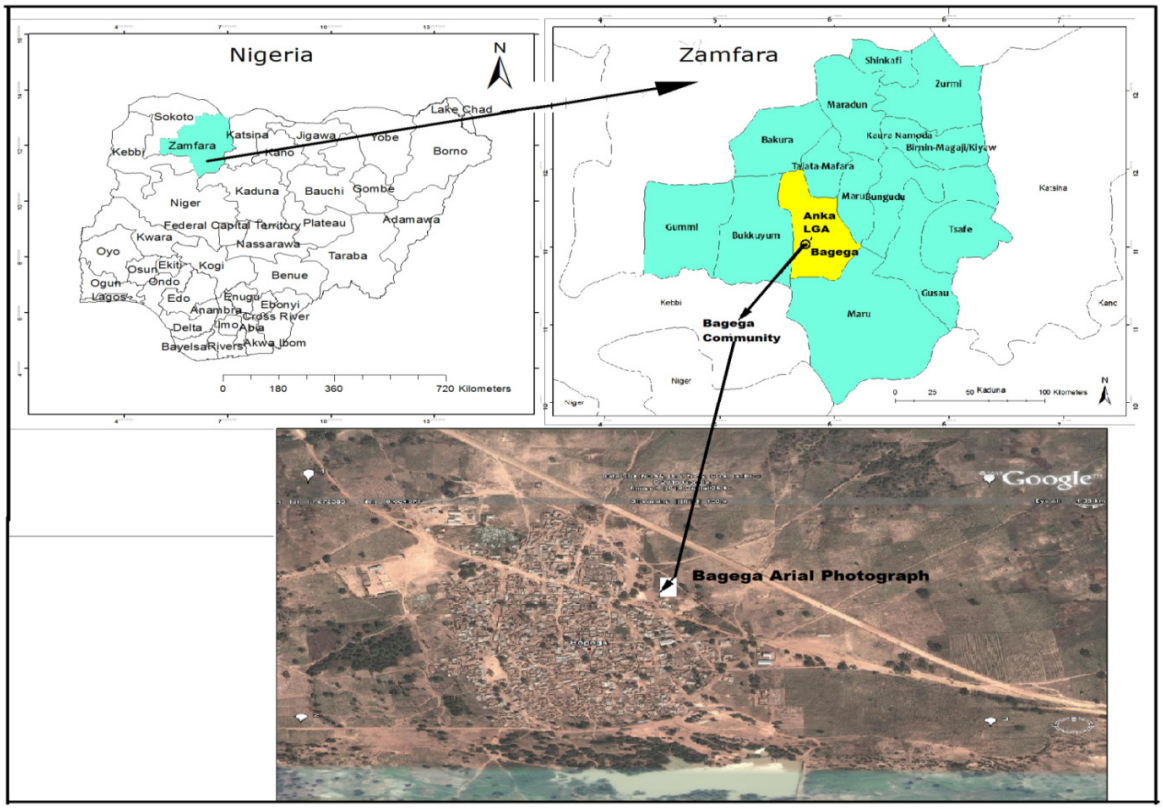


Fig. 1: Location of the Study Area (Source: Google Earth, 2010)

Agriculture is the main occupation of the people in the study area until recent time when artisanal gold mining becomes important socio-economic activities of the people due to rise in worldwide gold prices (JUNEP/OCHA, 2010). The major agricultural produce includes carrot, sweet potatoes, millet, guinea-corn, maize, rice, groundnuts, cotton, vegetables, tobacco and beans. The climate of the study area is warm tropical with temperature rising to 38oC between March to June. The rainy season typically lasts from July to September while the cold season known as Harmattan lasts from December to February (JUNEP/OCHA, 2010). The major groups of people in the study area are the Zamfarawa, Fulani and Gobirawa people (Alaba and Opafunso, 2016).

Samples Collection and Analyses

The remediation of soil and water in the study area was carried out by the trained youths with technical advice provided by the Blacksmith Institute and its implementing partner, TerraGraphics Environmental Engineering (BI, 2011). Soil excavation and replacement; solidification and stabilization of soil were the remediation options adopted in the remediation of soil while leaching, pumping and sediment excavation were used for remediating water which was completed in August, 2013. Soil and water samples were collected at the same locations before and after remediation. Soil samples were taken from ten residential compounds (BRC), three residential gardens (BRG), six village common areas (BVC), ten processing

areas (BPA) and six farmland areas (BFA) at a depth of 0 – 15 cm in accordance with standard methods of ASTM D6907. Water samples were collected from four wells (BWE), two boreholes (BBH) and seven ponds (BPO) with standard methods of APHA (2005).The digestion of soil sample was carried out in accordance with ASTM D5513 standard methods while the liquid digestion of water sample was carried out in accordance with ASTM D1971 standard procedures. The concentrations of lead metal in soil and water samples before and after remediation were determined using Atomic Absorption Spectrophotometer (AAS) in accordance with ASTM D 3559 and ASTM D1976 standard methods. The health risk analysis of soil and water samples was estimated using equations (1) and (2) in accordance with US EPA (2013) while the results of soil and water samples were compared before and after remediation using descriptive and inferential statistics.

$$HRI_S = \frac{IR_s * C_s * EF * CF * ED}{BW * AT * 365\ days/yr} * \frac{1}{RfD} \quad (1)$$

$$HRI_W = \frac{IR_W * C_W * EF * ED}{BW * AT * 365 days/yr} * \frac{1}{RfD_{oral}} \quad (2)$$

Where, HRI_S *and* HRI_W is health risk index of metal ingestion in soil and water; IR_s *and* IR_w is the daily soil and water ingestion rate [mg/day; litre/day]; CF is the conversion factor [1E-06, kg/mg]; C_s *and* C_w is the concentration of lead in soil and water [mg/kg]; EF is exposure frequency [days/year]; ED is the exposure duration [years]; BW is body weight [kg]; AT is the average time (years); and RfD is reference dose (mg/kg-day)

Results and Discussion

Remedial Option Effectiveness in Soil Sample at BRC

Table 3 shows that the mean value of lead concentration was decreased from 4157.89 mg/kg to 291.23 mg/kg after remediation at BRC, which justifies that there is 92.9 % of lead reduction after remediation. Meanwhile, the proportion of lead concentration shows that for every concentration of lead before remediation, there will be 0.12 mg/kg of lead concentration after remediation. The coefficient of variation (CoV) demonstrates that there was more variation in lead concentration before remediation than after remediation. The values of standard deviation and the range also confirmed that there is increased variability of lead concentration before remediation than after remediation.

Table 3: Descriptive output for Lead Concentration in Sample at BRC

Item	BEF_{REM}	AFT_{REM}	% Change	Ratio
Mean	4157.89	291.23	92.9	0.12
Std. Deviation	4912.29	230.09	95.3	0.09
Range	17143.78	706.77	95.8	0.30
CoV (%)	84.6	79.0		

BEF_{REM} - Before remediation; AFT_{REM} - After remediation; CoV - Coefficient of Variation

On the health risk analysis, Figure 2 shows that none of the residential compounds (BRC) posed health risk to their users after remediation as their values were below the 1.00E+00 USEPA health risk index standard unlike when their values were above USEPA standard before remediation. Hence, the remediation at residential compounds was completely effective.

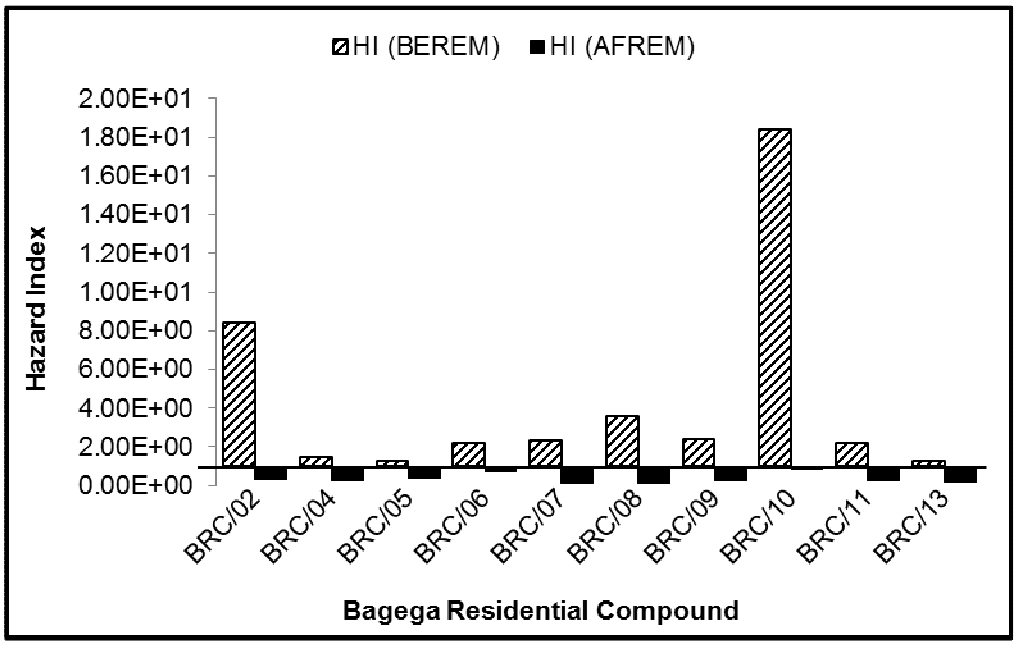


Fig. 2: Health Risk Before and After Remediation in Sample at BRC

Remedial Option Effectiveness in Soil Sample at BRG

Table 4 shows that there is 96.1 % of lead reduction in the sampled residential gardens (BRG) after remediation as the lead values reduced from 4628.35 mg/kg to 179.79 mg/kg after remediation. Consequently, for every lead concentration before remediation, there will be 0.04 mg/kg of lead concentration after remediation. The variation of lead concentration as measured by the coefficient of variation (CoV) was more varied before remediation than after remediation. The values of standard deviation and the range also confirmed that there is increased variability of lead concentration before remediation than after remediation.

Table 4: Descriptive output for Lead Concentration in Sample at BRG

Item	BEF_{REM}	AFT_{REM}	% Change	Ratio
Mean	4628.35	179.79	96.1	0.04
Std. Deviation	1822.32	58.76	96.8	0.01
Range	3644.18	111.38	96.9	0.01
CoV (%)	39.4	32.7		

BEF_{REM} - Before remediation; AFT_{REM} - After remediation; CoV - Coefficient of Variation

Figure 3 shows that the three residential gardens posed no health risk to their users after remediation as their values were below the 1.00E+00 USEPA health risk index standard unlike when their values above USEPA standard before remediation. Hence, the remediation of these residential gardens was completely effective.

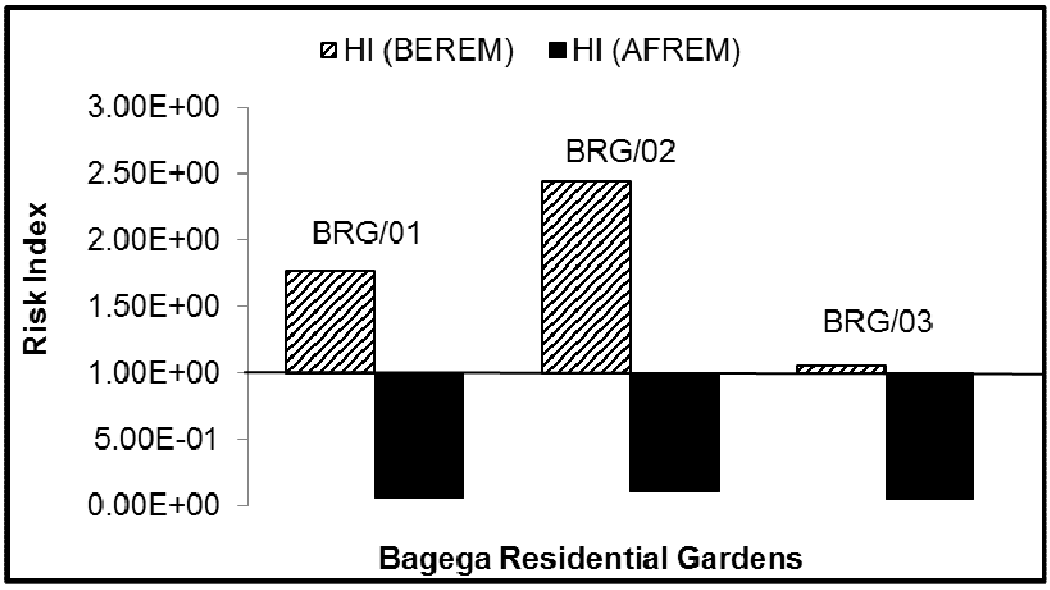


Fig. 3: Health Risk Before and After Remediation in Sample at BRG

Remedial Option Effectiveness in Soil Sample at BVC

In the sampled village common areas (BVC), the lead concentration was reduced to 209.39 mg/kg from 5451.93 mg/kg after remediation. This implies 92.2 % reduction in lead concentration after remediation as shown in Table 5. Also, in every lead concentration before remediation, there will be 0.04 mg/kg of lead concentration after remediation. The variation of lead concentration as measured by the coefficient of variation (CoV) was more varied with lead concentration before remediation than after remediation. The values of standard deviation and the range also confirmed that there is increased variability of lead concentration before remediation than after remediation.

Table 5: Descriptive output for Lead Concentration in Sample at BVC

Item	BEF_{REM}	AFT_{REM}	% Change	Ratio
Mean	5451.93	209.39	96.2	0.04
Std. Deviation	1881.46	82.92	95.6	0.01
Range	5117.37	186.95	96.3	0.03
CoV (%)	39.6	34.5		

BEF_{REM} - Before remediation; AFT_{REM} - After remediation; CoV - Coefficient of Variation

Figure 4 ascertained that none of the village common areas posed health risk to people after remediation as their values were below the 1.00E+00 USEPA health risk index standard unlike when their values above USEPA standard before remediation. Therefore, the remediation carried out in the villages common areas were completely effective.

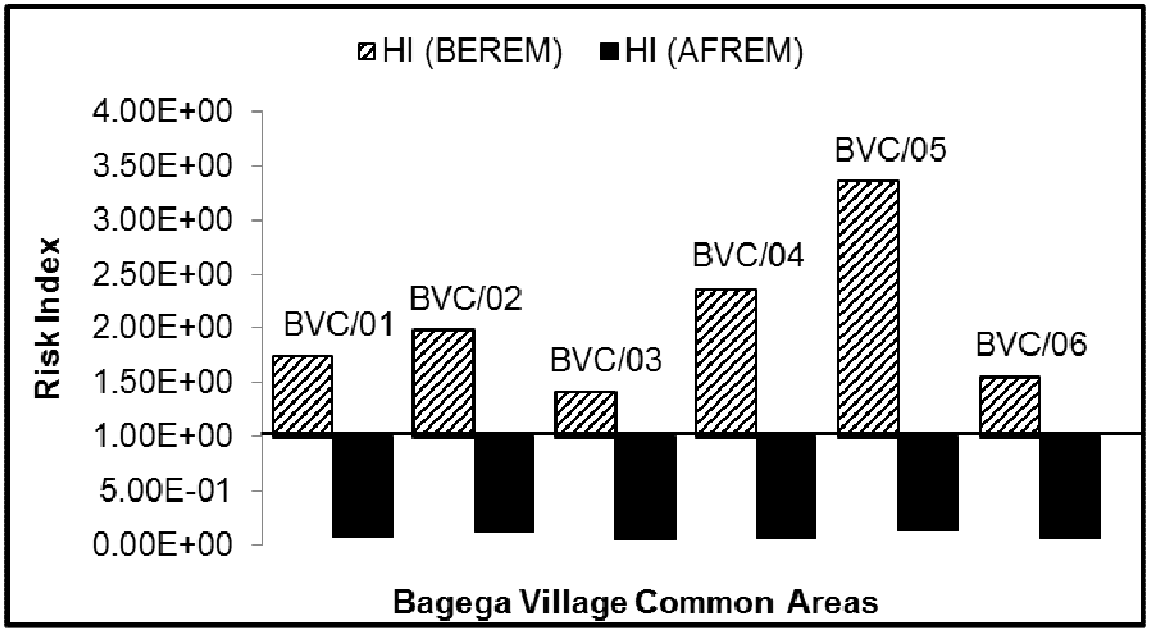


Fig. 4: Health Risk Before and After Remediation in Sample at BVC

Remedial Option Effectiveness in Soil Sample at BPA

Table 6 shows there is 81.0 % of lead reduction after remediation as the lead concentration before remediation was reduced to 1855.21 mg/kg after remediation. Consequently, for every lead concentration before remediation, there will be 0.21 mg/kg of lead concentration after remediation. The variability of lead concentration as measured by the coefficient of variation displays that lead concentration is more varied before remediation than after remediation. The values of standard deviation and the range also confirmed that there is increased variability of lead concentration before remediation than after remediation.

Table 6: Descriptive output for Lead Concentration in Sample at BPA

Item	BEF_{REM}	AFT_{REM}	% Change	Ratio
Std. Deviation	5815.56	1847.32	68.2	0.20
Range	16058.36	4918.39	69.4	0.57
CoV (%)	59.5	99.7		

BEF_{REM} - Before remediation; AFT_{REM} - After remediation; CoV - Coefficient of Variation

Consequently, out of the ten processing areas, only three (BPA/01, 06 and 10) still posed health risk to their workers as their values were above US EPA standard while the remaining seven were no longer posed health risk to their workers after remediation as shown in Figure 5. The remediation that was carried out at BPA/01, 06 and 10 was not effective despite there was a reduction in their health risk effect. Therefore, these sites were recommended for remediation in order to prevent recurrence of lead contaminated sites in the community.

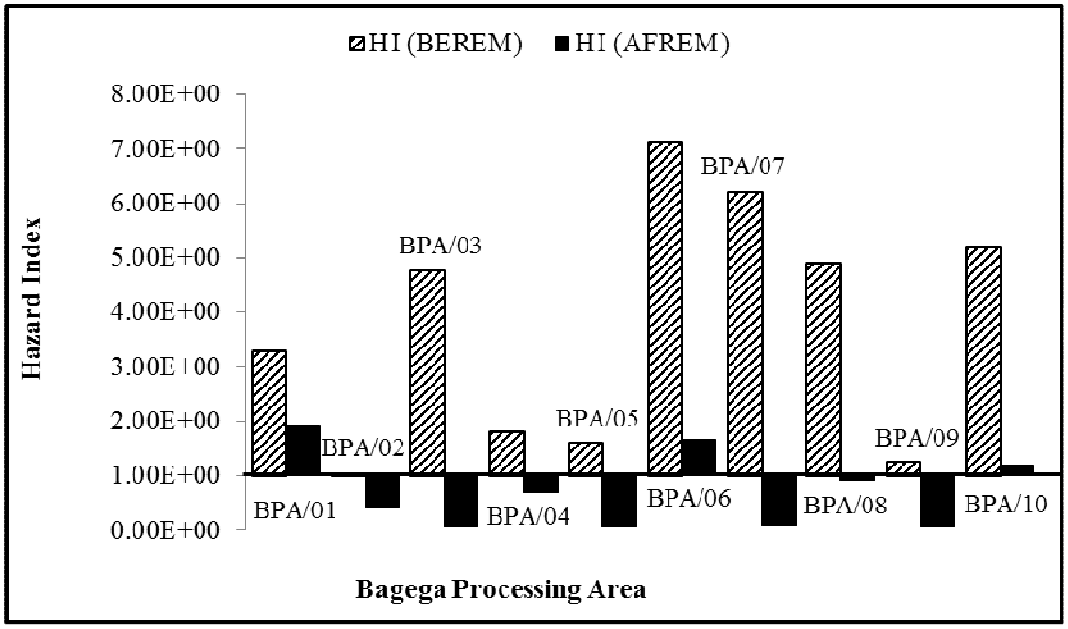


Fig. 5: Health Risk Before and After Remediation in Sample at BPA

Remedial Option Effectiveness in Soil Sample at BFA

Table 7 shows that the mean value of lead concentration was decreased to 3972.58 mg/kg after remediation from 9251.75 mg/kg before remediation, which substantiates that there was 57.1 % of lead reduction after remediation. Meanwhile, the proportion of lead concentration shows that for every concentration of lead before remediation, there would be 0.37 mg/kg of lead after remediation. The level of lead concentration as measured by the coefficient of variation (CoV) was more varied before remediation than after remediation. The values of standard deviation and the range also confirmed that there was increased variability of lead concentration before remediation than after remediation.

Table 7: Descriptive output for Lead Concentration in Sample at BFA

Item	BEF_{REM}	AFT_{REM}	% Change	Ratio
Mean	9251.75	3972.58	57.1	0.37
Std. Deviation	4727.14	3781.07	20.0	0.33
Range	12048.09	9538.14	20.8	0.84
CoV (%)	95.2	51.1		

BEF_{REM} - Before remediation; AFT_{REM} - After remediation; CoV - Coefficient of Variation

More so, out of the six farmlands, three (BFA/02, 05 and 06) still posed health risk to the farmers and the remaining three (BFA/01, 03 and 04) were no longer posed health risk to the farmers after remediation as shown in Figure 6. This implies that remediation that was carried out at BFA were only effective at BFA/01, 03 and 04. Though, the remediation that was carried out at BFA/02, 05 and 06 was not effective but there was reduction in their health risk effect. The sites were therefore recommended for remediation in order to prevent recurrence of lead contaminated sites in the community.

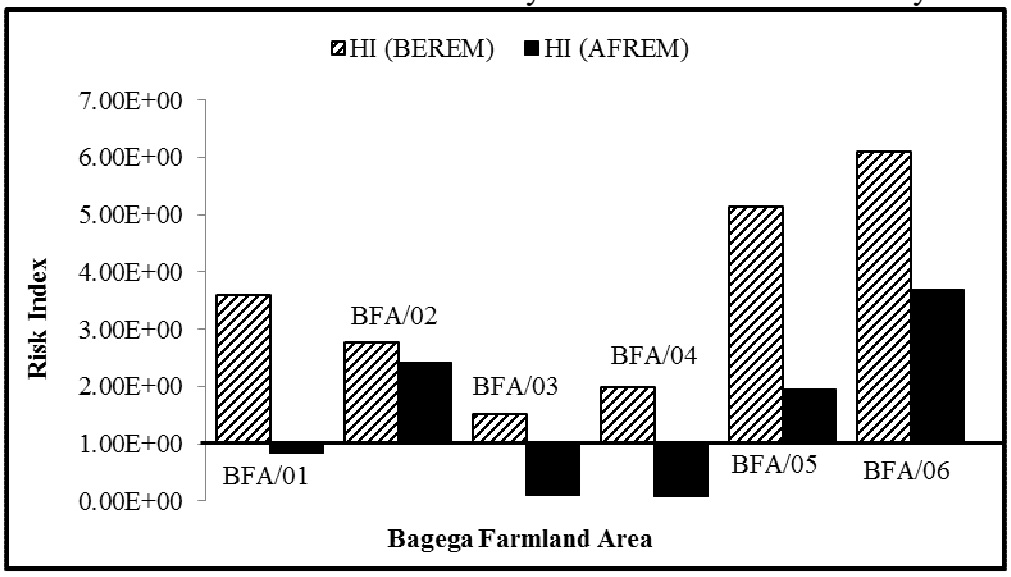


Fig. 6: Health Risk Before and After Remediation in Sample at BFA

Health Risk (HR) before and after Remediation in Soil Sample

The paired sample t-test statistic was used to test whether there is a significant difference in the health risk posed by lead concentration before and after remediation in each soil sample. Table 8 presents the respective t-value (t), the degrees of freedom (df), and the statistical significance (2-tailed p-value) of the paired t-test in each of soil sample (BRC, BRG, BVC, BPA and BFA). As the p-value is less than 0.05 ($p < .05$) in each of soil sample, it can be concluded that there is a statistically significant difference in the health risk posed by lead concentration before and after remediation in each soil sample. On average, the difference in health risk posed to the people are in descending order of BRC>BPA>BFA>BVC>BRG as presented by the mean difference.

Table 8: Paired Sample t-test for HR before and after Remediation in Soil Sample

Site ID	Paired Differences					t	df	Sig. (2-tailed; p-value)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
BRC (BEF_{REM})– BRC (AFT_{REM})	3.742	5.033	1.518	0.361	7.124	2.466	10	0.033
BRG (BEF_{REM})– BRG (AFT_{REM})	1.692	0.674	0.389	0.017	3.365	4.347	2	0.049
BVC (BEF_{REM}) – BVC (AFT_{REM})	1.995	0.695	0.284	1.266	2.724	7.035	5	0.001
BPA (BEF_{REM}) – BPA (AFT_{REM})	3.016	2.047	0.647	1.551	4.480	4.658	9	0.001
BFA (BEF_{REM}) – BFA (AFT_{REM})	2.009	1.022	0.417	0.936	3.082	4.812	5	0.005

Significant at 0.05; BEF_{REM} – before remediation; AFT_{REM} – after remediation

Effectiveness of Remedial Option in Water

Remedial Option Effectiveness in Water Sample at BW

Table 9 shows there is 31.8 % of lead reduction in the sample collected at BWE after remediation as the 286.64 µg/l concentration of lead before remediation was reduced to 195.48 µg/l after remediation. Consequently, for every lead concentration before remediation, there will be 0.71 µg/l of lead after remediation. The variability of lead concentration as measured by the coefficient of variation displays that lead concentration is more varied before remediation than after remediation. The values of standard deviation and the range also confirmed that there is increased variability of lead concentration before remediation than after remediation.

Table 9: Descriptive output for Lead Concentration in Sample at BWE

Item	BEF_{REM}	AFT_{REM}	% Change	Ratio
Mean	286.64	195.48	31.8	0.71
Std. Deviation	181.26	106.22	41.4	0.10
Range	374.17	213.40	42.9	0.24
CoV (%)	63.2	54.3		

BEF_{REM} - Before remediation; AFT_{REM} - After remediation; CoV - Coefficient of Variation

Out of the four sampled wells water, two (BWE/01, and 03) still posed health risk to their users while the remaining two wells were no longer posed health risk to their workers after remediation as shown in Figure 7. Therefore the remediation that carried out at BWE was not effective at BWE/01and 03.

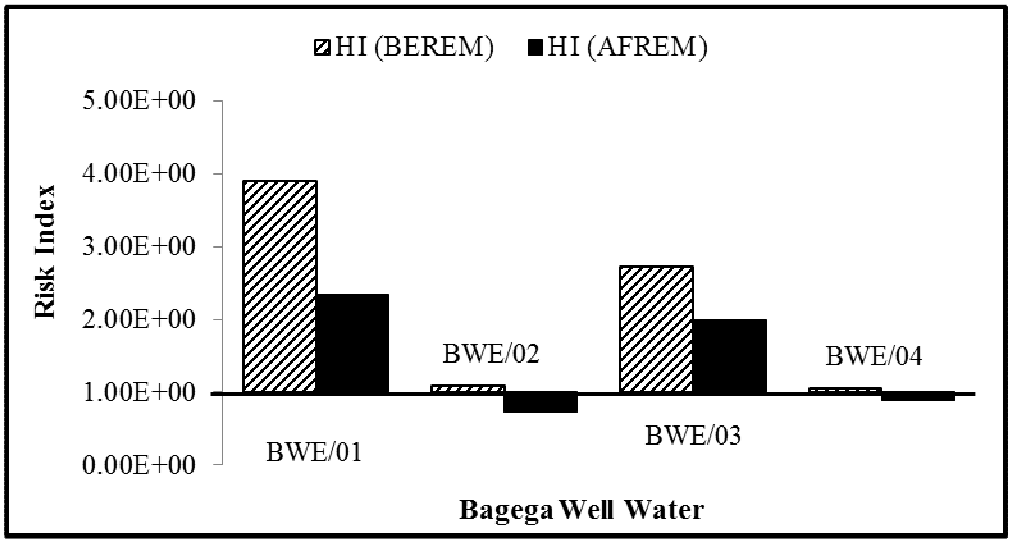


Fig. 7: Health Risk Before and After Remediation in BWE

Remedial Option Effectiveness in Water Sample at BBH

Table 10 shows that the mean value of lead concentration of 202.46 µg/l before remediation was decreased to 159.67 µg/l after remediation in the sampled BBH, which confirms that there is 21.1 % of lead reduction after remediation. Meanwhile, for every concentration of lead before remediation, there will be 0.78 µg/l of lead concentration after remediation. The variation of lead concentration as measured by the coefficient of variation (CoV) was more varied with lead concentration before remediation than after remediation. The values of standard deviation and the range also confirmed that there is increased variability of lead concentration before remediation than after remediation.

Table 10: Descriptive output for Lead Concentration in Sample at BBH

Item	BEF_{REM}	AFT_{REM}	% Change	Ratio
Mean	202.46	159.67	21.1	0.78
Std. Deviation	39.41	32.05	18.6	0.01
Range	55.73	45.32	18.7	0.01
CoV (%)	20.1	19.5		

BEF_{REM} - Before remediation; AFT_{REM} - After remediation; CoV - Coefficient of Variation

Meanwhile, Figure 8 justifies that the two boreholes water still posed health risk to people after remediation as their values were above the 1.00E+00 USEPA health risk index standard like that of before remediation. Therefore, the remediation carried out at BBH/01 and 02 were not effective. This might be the reason for sealing off the two boreholes.

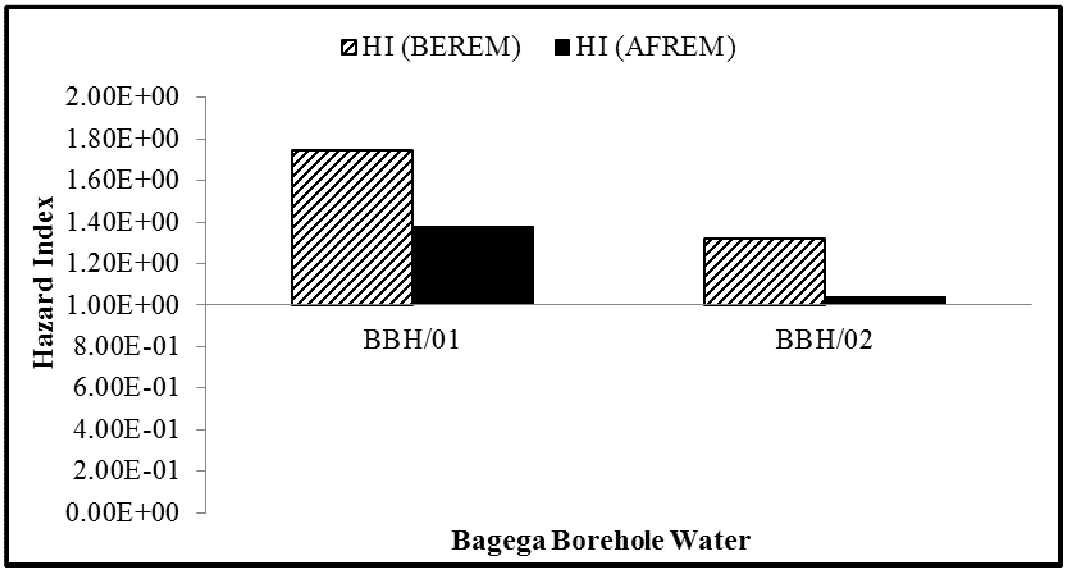


Fig. 8: Health Risk Before and After Remediation in BBH

Remedial Option Effectiveness in Water Sample at BPO

Table 11 shows that the mean value of lead concentration of 4913.04 µg/l before remediation was decreased to 1432.54 µg/l after remediation in the sampled BPO, which proves that there is 70.8 % of lead reduction after remediation. Meanwhile, for every concentration of lead before remediation, there will be 0.25 µg/l of lead concentration after remediation. The variation of lead concentration as measured by the coefficient of variation (CoV) was more varied with lead concentration before remediation than after remediation. The values of standard deviation and the range also confirmed that there is increased variability of lead concentration before remediation than after remediation.

Table 11: Descriptive output for Lead Concentration in Sample at BPO

Item	BEF_{REM}	AFT_{REM}	% Change	Ratio
Mean	4913.04	1432.54	70.8	0.25
Std. Deviation	1894.95	1414.68	25.3	0.21
Range	5907.70	3687.05	37.6	0.45
CoV (%)	98.8	38.6		

BEF_{REM} - Before remediation; AFT_{REM} - After remediation; CoV - Coefficient of Variation

Out of the seven sampled pond water, three (BPO/01, 04 and 06) posed no health risk to users after remediation while the remaining four samples still posed health risk to their users after remediation as shown in Figure 9. This implies that remediation carried out at BPO were not effective at BPO/02, 03, 05 and 07 which may be attributed to the reason of making a fenced wall round these ponds.

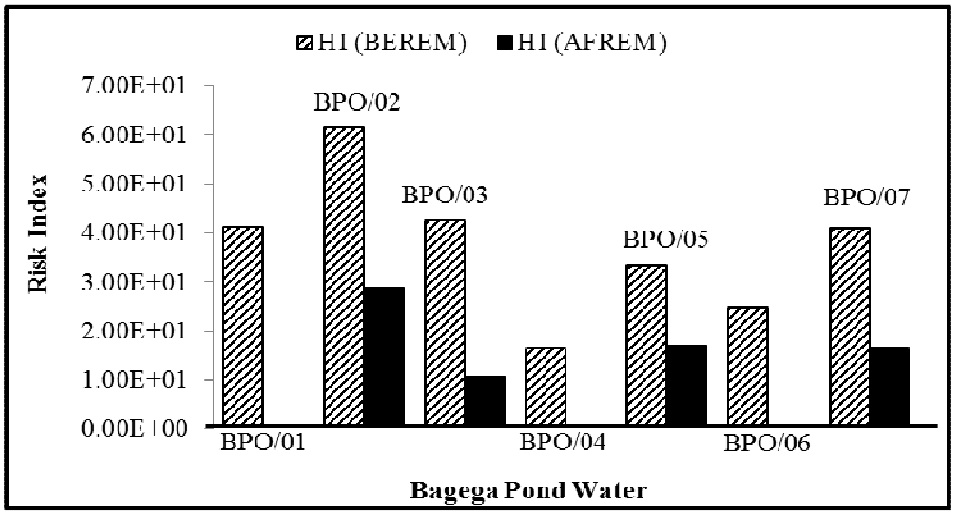


Fig. 9: Lead Pollution Before and After Remediation in SPO

Health Risk (HI) before and after Remediation in Water Sample

The paired sample t-test statistic was used to test whether there is a significant difference in the health risk posed by lead concentration before and after remediation in each water sample. Table 12 presents the respective t-value (t), the degrees of freedom (df), and the statistical significance (2-tailed p-value) of the paired t-test in each of water samples(BWE, BBH and BPO). The p-values in BWE and BBH are greater than 0.05 (P> .05) while the p-value in BPO is less than 0.05 (P< .05). This justified that there is no statistically significant difference in the health risk posed by lead concentration before and after remediation in each of BWE and BBH while there is a statistically significant difference in the health risk posed by lead concentration before and after remediation in BPO. On average, the severity of health risk posed by lead concentration were ranked in descending order of BPO>BWE>BBH as presented by the mean difference.

Table 12: Paired Sample t-test for HI before and after Remediation in Water Sample

	Paired Differences							
Site ID	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	df	Sig. (2-tailed; p-value)
BWE (BEF_{REM}) – BWE (AFT_{REM})	0.693	0.609	0.304	-0.276	1.661	2.275	3	0.107
BHH (BEF_{REM}) – BBH (AFT_{REM})	0.325	0.064	0.045	-0.247	0.896	7.222	1	0.088
BPO (BEF_{REM}) – BPO (AFT_{REM})	26.509	9.102	3.440	18.091	34.927	7.705	6	0.000

Significant at 5 %; BEF_{REM} – before remediation; AFT_{REM} – after remediation

Conclusion and Recommendation

The results of remedial option's effectiveness in soil sample revealed that there was 92.9 % reduction in lead value at BRC, 96.1 % at BRG, 92.2 % at BVC, 81.0% at BPA and 51.7 % at BFA while water exposure point shows 31.8 % at BW, 21.1 % at BBH and 70.8 % at BPO after remediation. The health risk analyses of soil samples recorded that BRC, BRG and BVC posed no health risk to the people while BPA/01, 06 and 10; BFA/01, 03 and 04 posed health risk to the people after remediation. Also, the results of water samples showed that was 31.8 % reduction in lead value at BWE, 21.1 % at BBH and 70.8 % at BPO. Meanwhile, the health risk analyses of water samples showed that BWE/01 and 03; BBH/01 and 02 posed health to the people while BPO/01, 04 and 06 posed no health risk to the people after remediation. The study, therefore recommended remediation of the sites that posed health risk to the people after remediation in order to prevent reccurrence of lead poisoning in the study area.

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