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The Impact of Gold Ore Mining on Total Lead (Pb) Concentration in Some Mining and Residential Communities in Zamfara State, Nigeria

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Abstract
Illegitimate artisanal gold mining quite often results in elevated lead (Pb) concentrations in mining and residential areas close to ore mining sites, which exposes the communities to varying degrees of health and environmental challenges.Here,mining and residential soils from Abare, Dareta and Bagega, Anka local government,Zamfara state's exposed communities, were examined for total Pb concentration.Three replicates of soil from four different soil fields in mining and residential areas were carefully selected for sampling from the surface layer 0 to 21 cm.All thesoil samples were digested and analysed using flame atomic absorption spectrophotometry (Varian model-AA240FS). The total Pb concentration in the mining areas ranges from 466.01-729.13 mg/kg (Abare), 151.34-168.21 mg/kg (Bagega) and 108.89-258.88 mg/kg (Dareta), while those from the residential areas ranges from 326.28-391.38mg/kg (Abare), 67.74-79.44 mg/kg (Bagega) and 17.58-43.40mg/kg (Dareta).This study revealed that the Pb concentration in all mining areas exceeded the standard ofthe department of petroleum resources of Nigeria's 85 mg/kg threshold (DPR).According to the study, the only residential communities with Pb concentrations above the DPR threshold are those in Abare.Based on the computed degree of contamination indices in those areas using the single pollution index (SPI) and Nemerow composite pollution index (NCPI), the study revealed the residential sites are within the safety limit, whereas the mining sites are slightly contaminated. Nevertheless, more studiesareneeded to determine the Pb speciation in those areas.

Keywords: Environment, Gold Mining, Lead contamination, pollution, Soil

INTRODUCTION
Lead (Pb) is among the environmental toxicants that find their way into the environment through natural or anthropogenic sources (Šimůnek*et al.*, 2006; Abdulkareem*et al.*,2015). These

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activities' prominent examples include agricultural,industrial processes, municipal waste disposal, mining (Ostergren *et al.*,1999), and other mine tailings (Šimůnek*et al.*,2006). Exposure to high Pb concentration is linked to numerous health and environmental issues such as renal, neurological, developmental effects (Haque*et al.*,2021), soil pollution and phytotoxicity (Gimmler*et al.*,2002; Abdulkareem*et al.*, 2015), among others. Environmental pollution from mining activities and artisanal gold mining has consistently imposed negative consequences onthe environment, human health, and other economic development worldwide (Adamu *et al.*,2014; Sulaiman*et al.*,2019).

In 2010 incidences of Pb poisoning werereported in some parts of Zamfara state, Nigeria, due to unauthorized gold mining and its crude processing by the residents near the mines (UNEP/OCHA, 2010; Nuhu *et al.*,2014;Tirima*et al.*,2018; Anka *et al.*,2020). Also, several reports confirmed that in addition to the unauthorized mining in those communities, processing of the gold ore is carried out in and around the houses of villages near mining areas (MSF, 2012; Plumlee*et al.*,2013), which resulted in health issues, food contamination, water and the entire ecosystem in general. Due to these obvious health challenges and related environmental crises, joint studies were conducted by state, federal, and other agencies to determine the level of Pb concentration in most mining and residential areas of the communities in the state (UNEP/OCHA, 2010; Von Lindern*et al.*, 2011; MSF, 2012; Plumlee *et al.*,2013).According to the findings of these studies, Pb concentrations in mining and some residential areas exceed the established 85 mg/kg DPR and 400 mg/kg US EPA thresholds (UNEP/OCHA, 2010; MSF, 2012). As a result, immediate measures were recommended to minimize the consequences of Pb pollution, including the prohibition of unlicensed mining in those areas, remission of crude ore processing in residential areas, and the immediate remediation of affected villages (Nuhu *et al.*,2014; Sulaiman*et al.*,2019).

Despite numerous control and remediation measures imposed in those areas, reports indicated mining activities, grinding, concentrating ores, tailings disposal, and mill wastewater deposition in some of these areas persists(Salisu *et al.*, 2016; Adewumi,2020). As a result, there is a need to evaluate the Pb concentration and degree of contamination in mining and residential areas, particularly during post-remediation exercises. Thus, this study was carried out to determine the Pb concentration and degree of contaminationin the mining and residential areas near the mining sites of Anka Local Government Area, Zamfara State.This study will provide baseline data on Pb concentrations, status, and degree of contamination in these areas.In addition, the output will facilitate the design of effective and reliable remediation strategies for these contaminated communities.

MATERIALS AND METHODS

Study sitesdescription

The Anka local government of Zamfara state is one of the most prominent localities bedeviled by the problemsrelated to Pb poisoning due to intense and consistent unauthorized gold ore mining. The local government has an estimated population of 142,280 and total land under cultivation of approximately 2,746km^2 (Johnbull*et al.*, 2019), with a location coordinate of latitudes 11° 40′ 0″ and 12° 20′ 0″ North and longitudes 5° 50′ 0″ and 6° 20′ 0″ East. The study was conducted in selected mining and residential areas of three Local Government Area include; Abare, Bagega and Dareta (Fig. 1).These areas were recognised as having the most risk from lead poisoning due to gold ore processing and noticeable mining activities (UNEP/OCHA, 2010). Abarehas an estimated population of 5000 people and was confirmed as a Pb contaminated area(UNEP/OCHA (2010). Its inhabitantsare primarily farmers, while many youths earn their living by engaging in illegal gold ore mining. On the other hand, Bagega is another Pb contaminated area, with an estimated 8500 people (Tirima*et al.*,2018).Most people in this area rely on farming while others, especially youth, earntheir living by trading and unauthorized gold ore mining. The last study area is Dareta, which is mainly considered as a remediated area based on June-July 2010 remediation exercises(UNEP/OCHA, 2010). This community has an estimated population of 2000 people(Udiba*et al.,* 2020). Residents of this area are predominantlyfarmers, while a significant proportion of its youth earn their living by trading and illegally mining gold ore. Generally, in all these study areas,gold ore processes involve crushing, washing, drying, aggregating mercury (Hg), and then melting the aggregates to remove gold (Adewumi, 2020). Fascinatingly, most of these processes are performed at or near residential areas. Also, most people store their processed materials in their residences(UNEP/OCHA, 2010; Nuhu *et al.*,2014;Tirima*et al.*,2018; Anka *et al.*,2020).

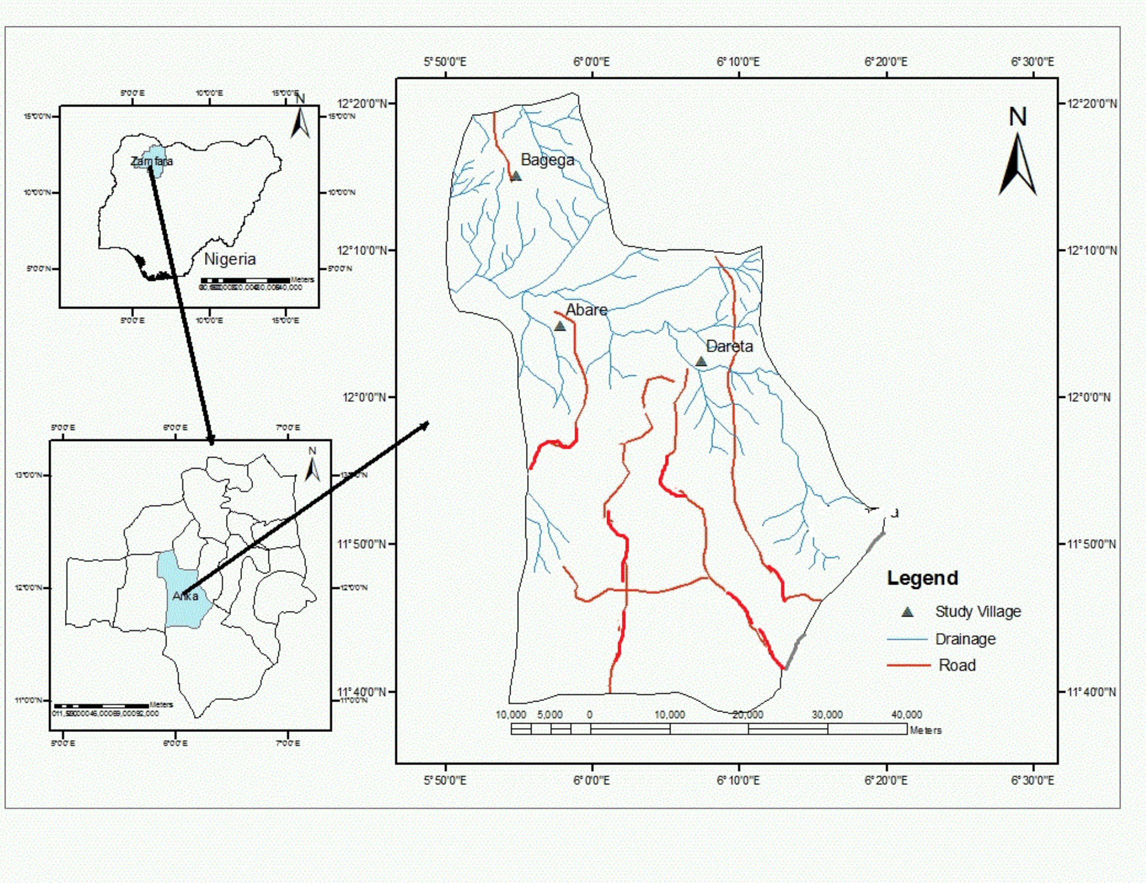

Figure 1: Location of the study sites from Anka local government, Zamfara state, Nigeria

Soil Sample collection and preparation

Soil samples were collected from the mining field and residential areas close to the active mining sites at a 0-20 cm soil depthin March 2019. Four different soil fields from mining and residential areas were selected for sampling ineach study area (Fig. 1). Three replicates of the samples were collected from each site, givingtwelve (12) samples from each study area(table 1). The soil samples collected were placed inside a polythene bag, taken to a laboratory, air-dried, and sieved through a 2 mm sieve to determine the total Pb concentrations (Chaudhry *et al.*,2012; Abdulkareem*et al.*,2015).

Table 1. The location coordinates of Abare, Bagega and Dareta sampling points

	Site	Sampling point	Sample type	Location coordinates	
				Lat. (N)	Long. (E)
1	Abare	A	Soil	12, 07685	5, 95623
2		B	Soil	12, 07708	5, 95607
3		C	Soil	12, 07691	5, 94623
4		D	Soil	12, 07760	5, 95633
5	Bagega	A	Soil	11, 86522	6, 00008
6		B	Soil	11, 86621	6, 00127
7		C	Soil	11, 86703	6, 00187
8		D	Soil	11, 86291	6, 00129
9	Dareta	A	Soil	12, 03035	5, 95375
10		B	Soil	12, 01997	5, 95924
11		C	Soil	12, 03035	5, 95375
12		D	Soil	12, 03143	5, 95511

Determination of Soiltotal Pb concentration

The air-dried soil samples were digested according to Nwajel (2000); Cao *et al.* (2010) with a slight modification. Approximately 0.3 g of dried soil samples were treated with 3 mL HNO_3 in digestion tubes and left overnight. Subsequently, 1 mL of $HClO_4$ and 3 mL HF were added to the mixture. The mixture was heated to 80°C for 3 hours and allowed to be fully digested and then filtered. The filtered solution was made up to 100 mLin a standard plastic bottle with distilled water and analyzed for total Pb concentration using flame atomic absorption spectrophotometry (Varian model-AA240FS) in the Ahmadu Bello University, Zaria, Nigeria, multi-user laboratory.

Data analysis

Single pollution index (SPI)

The single pollution index (SPI) was determined as a ratio of Pb concentration in the soil to that of regulatory standard using equation **(i)**(Hu *et al.,* 2017).

$$\text{SPI}= \frac{\boldsymbol{Conc.\ (inthesoil)}}{\boldsymbol{pollutionthreshold}} \quad \ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Nemerow composite pollution index (NCPI)

Nemerow composite pollution index (NCPI) is suitable for classifying the soils in terms of heavy metalpollution. It was computed based on equation **(ii)** (Hu *et al.,* 2017).

$$\textbf{NCPI} = \frac{\sqrt{(\boldsymbol{Pmax})^2+(\boldsymbol{Pi})^2}}{\boldsymbol{2}} \ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

The grade of the pollution based on this index is presented in table 2.

Table 2. Classes of the single pollution index (SPI) and Nemerow composite pollution index (NCPI)

Class	SPI	Grade	NCPI	Grade
1	≤ 1.0	Safety	≤ 0.7	Safety
2	1.0 <SPI ≤ 2.0	Slight pollution	0.7 <NCPI ≤ 1.0	Alert
3	2.0 <SPI ≤ 3.0	Mild pollution	1.0 < NCPI ≤ 2.0	Slight pollution
4	3.0 <SPI ≤ 5.0	Moderate pollution	2.0 < NCPI ≤ 3.0	Moderate pollution
5	SPI > 5.0	Severe pollution	NCPI>3.0	Severe pollution

Pb Conc. (mg/kg)

		Mining areas			**Residential areas**	
	Abare	Bagega	Dareta	Abare	Bagega	Dareta
Site A	$729.13^{a} \pm 0.032$	$168.21^{a} \pm 0.091$	$254.88^{a} \pm 0.674$	$391.38^{a} \pm 0.120$	$68.4^{c} \pm 0.103$	$18.24^{c} \pm 0.157$
Site B	$469.06^{c} \pm 0.065$	$162.34^{b} \pm 0.098$	$227.05^{b} \pm 0.430$	$326.28^{c} \pm 0.220$	$69.18^{b} \pm 4.83$	$43.40^{a} \pm 0.061$
Site C	$490.00^{b} \pm 0.003$	$151.34^{c} \pm 0.189$	$112.20^{c} \pm 0.021$	$366.62^{b} \pm 0.550$	$79.44^{a} \pm 1.231$	$23.40^{b} \pm 0.103$
Site D	$466.01^{d} \pm 0.093$	$168.20^{a} \pm 0.072$	$108.19^{d} \pm 0.013$	$391.40^{a} \pm 0.103$	$67.74^{d} \pm 0.060$	$17.58^{d} \pm 0.060$
P-value	<0.001	0.031	<0.001	0.021	<0.001	0.041
DRP, (2002)	85 (mg/kg)					
US- EPA (2004)	400 (mg/kg)					

Chen*et al.,*(2015): Hu *et al.,*(2017) classifications.

Statistical analysis

The data collected were analyzed using SPSS 25 software (US, Chicago, IBM Company) and Microsoft Excel (version 2016). Means between the study sites for each study area were analyzed using one-way ANOVA, and statistically significant differences were computed using TurkeyHSD at p <0.05.

Ethics approval

Approval was granted by the College of Health Sciences Research Ethical Committee, Bayero University, Kano, Nigeria.

RESULTS

The mean Pb concentration of the mining and residential soil across all the study sites is presented in table 3. The total Pb concentrations in the mining areas range from 466.01 to 729.3 mg/kg, 151.34 to 168.21 mg/kg and 108.19 to 254.88 mg/kg in Abare, Bagega and Dareta, respectively.

Table 3.Pb concentrations (mg/kg) in the mining and the residential areas across the three study sites

Values are means ± standard errors (n = 3). Means with the same superscript letter within each column are not significantly different at $P < 0.05$

The SPI values were computed using 400 mg/kg US EPA Pb allowable limits (Table 4). The SPI results from the mining sites ranges range from 1.17 -1.82 (Abare), 0.38-0.42 (Bagega) and 0.27- 0.648 (Dareta), while in the residential areas, it ranges from 0.92 -0.96 (Abare), 0.15-0.19 (Bagega) and 0.04- 0.11 (Dareta).The NCPI values in the mining areas are 1.13, 0.32 and 0.24 in Abare, Bagega and Dareta, respectively, whereas in the residential areas, its 0.52, 0.36 and 0.27 in Abare, Bagega and Dareta, respectively.

Table 4. Degree of Pb contamination in the mining and the residential areas across the three study sites

	SPI					
	Mining area			**Residential area**		
	Abare	Bagega	Dareta	Abare	Bagega	Dareta
Site A	1.82	0.42	0.64	0.96	0.17	0.05
Site B	1.17	0.41	0.57	0.82	0.15	0.11
Site C	1.23	0.38	0.28	0.92	0.19	0.06
Site D	1.17	0.42	0.27	0.96	0.17	0.04
NCPI	1.13	0.22	0.24	0.52	0.36	0.27

SPI (Single pollution index), **NCPI** (**Nemerow composite pollution index**) **SPI** and **NCPI**<1= Safe, >1= Pollution critical limit thus, unsafe.

The Pb concentrations in the mining sites fromAbare are all above the 400 mg/kg US EPA permissible limits, while all the sites in Abare, Bagega and Dareta are above the 85 mg/kg DPR permissible limits.

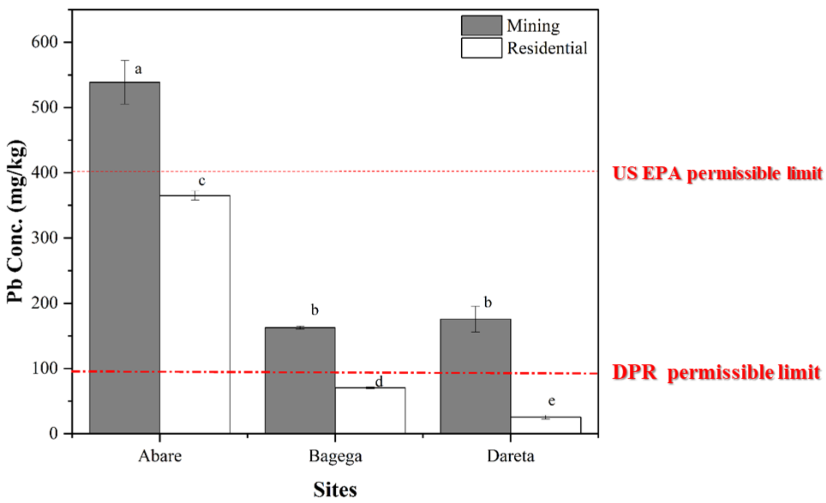

Figure 2: Comparison of total Pb Conc. (mg/kg) between the two locations among the three studies areas of Anka local government, Zamfara State, Nigeria

DISCUSSION

Nearly all the study sites in the three study areas have their total Pb concentrations above the 400 mg/kg US EPA (2004) permissible limit and 85 mg/kg in the Nigerian soils set by the Department of Petroleum Resources of Nigeria(DPR, 2002).This finding is consistent with the results of UNEP/OCHA (2010),Lo *et al*.(2012) and Udiba*et al.*(2012),where Pb concentrations in the areas around the active mines were found above the current US EPA and DPRpermissible limit. Likewise, recent findings by Anka*et al.*(2020) justify the result of this study, where Pb value of 385 to 688 mg/kg was found in some villages close to the active mining sites of these study areas.The elevated Pb concentrations in these areas can be attributed to the artisanal (local) mining operations and gold ore processing activities that continue to take place in these areas.

The total Pb concentrations in the residential areas range from 326.28 to 391.4 mg/kg, 67.74 to 68.4 mg/kg and 17.58 to 43.40 mg/kg in Abare, Bagega and Dareta, respectively. These results indicated all the study areas have their Pb concentrations below the 400 mg/kg US EPA permissible limit. Whereas Abare study sites exceed the 85 mg/kg DPRpermissible limits, all the sites in Bagega and Dareta are within the DPRlocal threshold limits for soil.This finding is similar to Abdu and Yusuf (2013), who discovered variation in Pb concentrations in village compounds away from active mining sites. Based ontheir findings, the Pb concentrations decrease with an increase in distance away from the primary ore excavation sites.Similarly, a study by Sulaiman*et al.* (2019) identified low Pb concentrations in some residential areas of Bagega and Dareta, respectively.

The low Pb concentrations in these areas may be attributed to the remediation measures implemented in these areas following the horrible incidence of Pb poisoning in 2010 andto the fact that the majority of mining processing is conducted away from residential areas.In a study conducted by Udiba*et al*. (2020),it was found that the Pb concentrations in most residential soil ofDaretaare within the local and international standards. This finding is, therefore, consistent with the result of our study. The high Pb concentrations in Abare's residential areas can be attributed to the rudimentary artisanal processing of ores in those areas.A similar findingis observed in a study by Tirima*et al.* (2016), where the practices of the ore mining process wererevealed, which includes transportation of gold ore to residential area compounds for threshing, washing, crushing, and storing of the processed material. As a result of these practices, Pb contamination was widespread in many compounds and villages.Tirima*et al.* (2016) discovered that the same households used in ore processing are also used in post-harvest food processing, implying a higher risk of Pb particle contamination and dust deposition in food.

The excessive accumulation of Pb insoiltypically occurs through extraction and exploitation by human activity (Fewtrell*et al.*,2003), facilitated transport or wind dust deposition onto the soil and plant surface in some situations(Miranda *et al.*,2005). As a result, contamination ofagricultural land may occur, which subsequently affects the cultivated food crops and vegetables due to elevated Pb concentrations in the soil or dust Pb particles deposition.Tirima*et al.*(2016) emphasized the link between indigenous agricultural labour practices and artisanal mineral exploitation and processing in these areas, which serves as a risk co-factor that amplifies the risks of secondary Pb poisoning exposure pathways. Overall, Pb contamination of soil or inhalations through dust particles may cause significant health concerns and potential health risks to food consumers in those areas and beyond.

The comparison of the total Pb concentration between mining and residential sites is depicted in Figure 2. The Pb concentrations in the mining sites fromAbare are all aboved the 400 mg/kg

US EPA permissible limits, while all the sites in Abare, Bagega and Dareta are above the 85 mg/kg DPR permissible limits. These findings are similar to those obtained by (UNEP/OCHA, 2010; Galadima and Garba, 2012; MSF, 2012; Mohammed and Abdu, 2014).These elevated concentrations of Pb in these areas can be linked to the artisanal gold mining activities actively taking place in the vicinity of those areas. Therefore, these high Pb concentrations in the mining area may contaminate soil and crops and vegetables cultivated in the area.

On the other hand, the Pb concentrations in all the study sites from the residential areas are below the 400 mg/kg US EPA permissible limits. In contrast, only sites from Abare are above the DPR 85 mg/kg permissible limits. A finding from Sulaiman*et al.*(2019)andAnka*et al.*(2020) observed elevated Pb concentrations in most residential areas of Abare, which is similar to this study's findings. These elevated Pb concentrations can be attributed to those areas' persistent crude gold processing method. Conversely, the low Pb concentration in Dareta and Bagega could be attributed to the massive awareness in those communities, resulting in decreased storage and processing activities in the residential areas. Additionally, it can be recalled that Dareta and Bagega were remediated on different occasions(Udiba*et al.,*2012);thus, the artisanal gold mining activities in those areas are minimal compared to those in Abare. As a result, the problems of Pb cross-contamination in Dareta and Bagega may be lesserthan those in Abare, where artisanal mining is still prevalent and locals are still practicing crude gold processing.

The SPI and NCPI results from Abare in mining areas indicated slight pollution status ($1.0 < SPI \le 2.0$) and ($1.0 < NCPI \le 2.0$) based on Chen*et al.*(2015) and Hu *et al.*(2017) classifications. However, all the sites in the residential area indicated a safety status of ≤ 1.0 SPI and≤ 0.7 NCPI,according toChen*et al.* (2015) and Hu *et al.*(2017) classifications. These findings are consistent with Adewumi's (2020) report, where a high degree of pollution in some mining sites around Anka was found. These high SPI and PLI values may be directly linked to the high intensity of artisanal mining in Abare, as opposed to Bagega and Dareta, where a large section of their mines have been remediated on numerous occasions (UNEP/OCHA, 2011: Tirima *et al.,*2018: Anka*et al.,*2020; Udiba*et al.,*2020).

CONCLUSION

This study aimed to study the Pb concentrations from mining and residential areas associated with artisanal gold mining in Ankalocal government, Zamfara state. The study demonstrated that artisanal gold mining resulted in elevated Pb concentrations above DPR and US-EPA threshold in mining sites in some communities of Anka. In contrast, gold mining has little impact on the residential areas of Anka communities. Furthermore, the SPI and NCPI pollution indices show that all the studied areas can be considered safe for agricultural activities, except for the Abare mining areas. Hence, more attention should be paid to studying Pb bioavailability and its relationships with soil physicochemical characteristics to manage and control Pb pollution in those areas effectively.Overall, the information will support developing a more effective remediation strategy in these affected areas.

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